NEPAL RENEWABLE ENERGY PROGRAMME

ASSESSMENT OF EXISTING TRANSMISSION AND DISTRIBUTION SYSTEM TO INTEGRATE STORAGE SYSTEMS IN THE NATIONAL GRID

January 2023

NEPAL
RENEWABLE
ENERGY
PROGRAMME

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ABBREVIATIONS AND ACRONYMS

AEPC	Alternative Energy Promotion Centre
BESS	Battery Energy Storage System
CUF	Capacity Utilization Factor
DC	Distribution Centre
DCSD	Distribution and Consumer Services Directorate
DRE	Distributed Renewable Energy
EA	Executing Agency
EPC	Engineering, Procurement and Construction
ERC	Electricity Regulatory Commission
FY	Financial Year
GoN	Government of Nepal
GWh	Giga Watthour
HEP	Hydro Electric Plant
Hz	Hertz
HV	High Voltage
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INPS	Integrated Nepal Power System
INR	Indian Rupees
NPR	Nepali Rupees
IREDA	Indian Renewable Development Authority
IRR	Internal Rate of Return
kV	Kilo Volt
kW	Kilo Watt
LCOE	Levelized Cost of Energy
LDC	Load Dispatch Center
LRMP	Loss Reduction Master Plan
LV	Low Voltage
MHP	Micro Hydro Plant
MOEW	Ministry of Energy, Water Resources and Irrigation
MOF	Ministry of Finance
MSEDC	Maharashtra State Electricity Distribution Company Limited
MV	Medium Voltage
MVA	Mega Volt Ampere
MW	Mega Watt

NEA	Nepal Electricity Authority
NREP	Nepal Renewable Energy Programme
NPV	Net Present Value
O&M	Operation and Maintenance
PBP	Pay Back Period
PSS/E	Power System Simulation/ Exemplary
RE	Renewable Energy
ROE	Return on Equity
RoR	Run of River
RTC	Real Time Clock
SCADA	Supervisory Control and Data Acquisition
S/S	Substation
TA	Technical Assistance
ToR	Terms of Reference
T/PMD	Transmission/Project Management Directorate
UK	United Kingdom
USD	United States Dollar
VRE	Variable Renewable Energy
WECS	Water and Energy Commission Secretariat

EXECUTIVE SUMMARY

The INPS (Integrated Nepal Power System) is tentatively weak in west of Butwal

Electricity transmission in west of Butwal takes place at 132 kV. Number of 132 kV substations exist in the area that includes Butwal, Mainihawa, Motipur, Arghakhanchi, Chanauta, Lamahi, Ghorahi, Kusum, Hapure, Nepalganj, Bhurigaun, Lamki, Pahalmanpur, Attariya, Syaule and Mahendranagar where the voltage is stepped down to sub- transmission/primary distribution voltage for distribution. Number of 33 kV and 11 kV lines emanate from these substations to supply electricity in the local areas. In many cases, these lines extend to long distances resulting in frequent outages, voltage drops and energy losses. With the expansion of the high voltage substation, supply situation has improved in many places, still large voltage drops exists at distribution level mainly attributed to long sub transmission/distribution lines supplying large loads.

Due to location of most of the hydro power plants on east of Butwal and transmission line bottle necks to transmit power from east to west, there has been difficulty in meeting the electricity demand of west of Butwal. Power has to be imported from India even in period during which sufficient power is available in the system.

There are paradoxes between the energy access and quality of power especially towards the west of Butwal.

The grid electricity access as of March 2022 has been reached 94% of total population (MOF, 2022). Energy consumption in Nepal grew at an average annual growth rate of around 11% during the last decade. After decades of load shedding, regular supply was resumed in 2017. With resumption of regular supply, the energy consumption has grown significantly. However, INPS is in nascent stage in western Nepal. Currently, the region has highest transmission voltage level of 132 kV only. This too is limited in Terai area and up to Chameliya HEP in Sudurpashchim Province. Even the generation plants are few in the region. All three provinces have a number of projects under construction at 33 kV level that will be completed in next couple of years under Distribution System Upgrade and Expansion Project implemented by NEA. Despite knowing Nepal would be a power surplus nation, the government failed to materialize concrete plans to export and promote consumption of power. The government is yet to build transmission lines, sub-stations, and install transformers in several parts of Nepal to promote internal consumption.

In the western region, occasionally during summer, system voltage was recorded lower than the permissible limit in some substations. Capacitor banks installed in various substations helped to some extent in maintaining voltage but it is not sufficient enough. The voltage could not be maintained at the desired level despite the continuous effort of Load Dispatch Centre which is the NEA's center for grid operation.

The expansion and up-gradation of transmission lines, sub-stations have been sluggish especially towards western part of Nepal

Though, NEA's initiative to upgrade and expand transmission infrastructure throughout the country by launching the 'Electricity Grid Modernization Project' is a step towards the right direction however these have been slow in pace. In 2020 alone, Nepal lost 95.61 GWh energy that could have been produced by 18 private hydropower plants, due to the lack of adequate transmission lines. Despite knowing Nepal would be a power surplus nation, the government failed to materialize concrete plans to export power. The government is yet to build transmission lines, sub-stations, and install transformers in several parts of Nepal.

Though there has been different financial support from multilateral agencies, donor agencies provided approximately 123 million USD as long-term loans and grants through direct payment to consultants and contractors in accordance with the GoN budgetary program in FY 2021/22. The investment for the overhaul of the transmission and distribution network has increased rapidly however more funding needs to come in for GoN to provide reliable electricity to all. Also, in many instances projects delays have hampered the overall growth of the region as most of the projects have been dropped or not being executed due to the lack of funding.

Inadequate capacity of HV transmission lines has shaped situation of power dependency from India

Many of the transmission system in INPS operate on a "n-0" basis, i.e., there is no contingency transmission provision. There is no redundancy in the network allowing a single fault to result in the loss of generation, loss of load or even full system collapse. Also, many links in the INPS grid system are heavily loaded resulting in poor voltages as low as 0.8 p.u. Overall transmission losses on in 2021/22 was 4.49% while the corresponding figure for west of Butwal was 3.62%. The transmission line Hetauda-Bharatpur 132 kV, Damauli -Bharatpur 132kV, Bharatpur – Kawasoti - Bardghat132 kV, Lekhnath – Syanga - Kaligandaki A, Marsyangdi - Bharatpur 132 kV, Duhabi - Anarmani 132 kV were being operated almost in full capacity continuously which might have originated the power cut in some areas.

In recent years, difficulty in the smooth power supply to the western part of the country (west from Butwal) has been realized due to the unavailability of sufficient generation in the western part of the country to cater the growing demand. Due to the transmission line's inadequate capacity, surplus generation of the eastern part of the country cannot be transmitted to the west thus western part of the country have been partly supplied from the imported power from the Tanakpur (India).

Subpar Sub-transmission and Distribution System has resulted in significant loss of revenues for NEA

The quality of Nepalese power system, however, hasn't been par to the technology and standards of other countries. Besides, frequent tripping of power lines and unreliable power supply along with a poorly regulated voltage in many locations raise some question about the reliability of Nepalese power systems. According to the standards, Nepalese domestic voltage level must be 230 V with an error of ±5%. However, due to poor planning and system design voltage can go down to as much as 17 - 20% or lower which is unacceptable for many electrical equipment. One of the reasons of such unregulated voltage is the unprecedented and unscientific length of distribution feeders. In urban areas, feeder length is generally governed by the current carrying capacity of the feeder whereas in rural areas the same is governed by the voltage drop. As a rule of thumb, the length of 11 kV feeder could be around 11 km to limit the voltage drop. However, the length of above feeder was found to be greater than 30 km which means the end user of the feeder has a poorly regulated voltage supply. This is one of the many issues responsible for the poor voltage regulation in many places of Nepal. Because of poorly maintained transformers, substations and transmission line, significant energy is lost yearly resulting in loss of revenue amounting to millions of rupees.

Analysis shows most of the substation's capacity are just sufficient to cater the present peak demand

Most of the substations towards west of Butwal have the capacity just sufficient to cater to the current peak demand. Mainihawa, Motipur, Sandhikharka and Ghorahi (Jhigni) substations are exceptions as they are relatively new substations. Thus, newer substations, or some measures such as installation of DREs are essential to cater the loads in these regions. Based on the current year and historical data, energy demand forecast was carried out for selected load centres in the region. Two cases each were considered for each province. Energy demand at Chanauta is forecasted as 230.24 GWh in 2030. Energy demand at Nepalgunj is forecasted as 245 GWh in 2030. Energy forecast is carried out in Karnali Province for two sample load centres viz. Jumla and Surkhet. The former presents the case of relatively recently electrified area whereas the latter presents the case where the electricity is supplied for more than three decades. Energy demand at Jumla is forecasted as 3.99 GWh in 2030. Energy demand at Surkhet is forecasted as 115.72 GWh in 2030. Jumla distribution centre lies in the hilly region and serves Jumla district where the INPS is recently approaching. Surkhet distribution center feeds the Birendranagar, capital city of Karnali Province. Energy demand at Dhangadi is forecasted as 223.4 GWh in 2030. Energy demand at Belauri is forecasted as 56.32 GWh in 2030. With some transformers loaded at full capacity and most of sites where forecasting has been carried out, the substation loading is more than 75% there by requiring up-gradation of the substations to cater to the energy demands.

Load flow analysis shows voltages in the permissible limits only for few substations
Load flow analysis indicates voltages at the 132 kV substations are towards the lower side but are within the permissible limit set forth by the grid code i.e., ±10%. At the higher voltage levels, the voltage is typically managed using reactive power compensation approach. However, in actual at some of the substations like Kohalpur and Hapure, the voltage level reaches below the permissible limits in few cases. For 33 kV system, the lower limit of the voltage is 29.7 kV but the simulation has showed the voltage dropping to beyond 20 kV. Such extreme conditions are seen for the substation which are far from 132 kV grid substations and are connected by extremely long 33 kV lines or are heavily loaded without reactive power compensation. The voltage situations of 33 kV system in Butwal, Bhairahawa, Kapilvastu and Sandhikharka area has improved with the commissioning of new 132 kV substations. Voltage drop still exists in Taulihawa, Bhairahawa and Palpa 33 kV substations. The actual loading of the 132 kV transmission line west of Butwal is within the permissible limit. In case of 33kV lines it is found that two out of 17 major line sections are overloaded in Karnali Province. The 11.49 km Kohalpur Grid - Nepalgunj Medical College have the maximum loading of 132.80%. Similarly, the section from Nepalgunj Medical College and Bheri Diversion Tapping with sectional length of 10.28km have 125.62% loading (LRMP, 2021/22). The situation will not improve before commissioning of Kohalpur-Surkhet 132 kV transmission line and Surkhet 132 kV substation under construction. In Sudurpaschim Province, Attariya – Dhangadhi 33 kV line section is loaded at 109.38% of the maximum loading capacity while loading of remaining line sections are below maximum loading capacity. To overcome the situation, it is planned to construct another 33 kV line between Attariya and Dhangadhi.

DRE and BESS can help manage the grid more efficiently
As the power system of Nepal is evolving, there will be significant rise in loads as forecasted by different agencies. Current distribution network may not be able to cater the ever-increasing demand. There are two possible solutions to this problem. The first would be the expansion of the existing transmission and distribution network which includes building new

substation and transmission line while the second option would be setting up distributed sources of energies like solar, battery storage and small hydro where applicable. The distributed energy resources will supply the power directly to loads thereby reducing the burden on the feeder and improving the voltage profile.

Impact analysis of solar PV power plant on frequency deviation and voltage indicated stable behavior of the system and the voltage and frequency deviations were within the prescribed limit. However, when the solar power plant is far from the hydro power plant, the frequency of oscillations are sustained for longer time. This is the case for the locations west of Butwal where few hydro power plants are located at far off distances. Adaptation of DRE with BESS would help improve the situation in which if there is outage of the solar power plant, battery storage system will take over the load and the supply will remain intact.

A battery energy storage system supports the solar PV plant pacifying its stochastic nature and even supplying active power during the evening peaks and could even support a part of network islanding the weak grid. Modelling and analysis of 3 selected sites namely, Chanuta, Nepalgunj and Surkhet at 33kV voltages of selected substations at 1 pm on a typical day, showed that the injection of Solar PV plant serves in improving the voltage profile.

BESS has a tremendous market potential in Nepal

There are 71 substations especially for HV and MV voltage transmissions. Based on the analysis the average load for these substations is 25-80 MVA. Considering average load of 25 MVA per substation it presents a total market potential of 1 billion USD. However, the addressable market potential taking account only 50% of the potential is met, is around 530 million USD with the current market prices. This entails huge opportunities for developers and investors.

Financial Analysis shows that there is a need of higher storage tariffs throughout the year with certain amount of subsidy to entice developers to install BESS based projects

Using bottom up pricing method and cost of 300 US$/kWh for 4 MWh batteries shows subsidy of 50% with a 12.40 tariffs for storage will provide returns alluring to the developers. Based on the estimation it shows an attractive ROE of 19% with a payback of 9.46 years. Also based on the RTC peak shaving tariffs in India and including the addition of variability in costs different scenarios for tariffs were analysed.

1 INTRODUCTION

The expansion of hydropower—mostly run-of-river (ROR) plants which accounts for around 84% of the total installed capacity of Nepal—poses new challenges to maintain the balance of supply and demand and system adequacy due to the daily and seasonal fluctuations in supply. Energy storage has the potential to help meet these challenges by managing fluctuations in electricity supply and maximizing the use of Nepal's domestic hydropower as well as helping integrate DRE in the grid. These initiatives and policies indicate that GoN and relevant stakeholders have realized the need to modernize and upgrade the power system.

The INPS (Integrated Nepal Power System) is relatively weak in west of Butwal. There are number of 132 kV substations in the area that includes Butwal, Mainihawa, Motipur, Arghakhanchi, Chanauta, Lamahi, Ghorahi, Kusum, Hapure, Nepalganj, Bhurigaun, Lamki, Pahalmanpur, Attariya, Syaule and Lalpur. Number of 33 kV and 11 kV lines emanate from these substations to supply electricity in the local areas. In many cases, these lines extend to long distances resulting in frequent outages, voltage drops and energy losses. This study intends to look into the areas where the grid is weak and what transmission level voltages are prevalent there. Further to it, intends to find out if using DRE system will help support the grid in weak islanding conditions. The Nepal Renewable Energy Programme (NREP) which is implemented by the Alternative Energy Promotion Centre (AEPC), with financial support from UK Aid through the British Embassy-Kathmandu is conducting the present study.

1.1 Objectives of the Study

The main objectives of this assignment are:

a) To assess the existing, under construction and planned transmission and distribution system west of Butwal;

b) To review the power quality, transmission and distribution losses, identify the problems in the transmission and distribution system and provide recommendations to improve power grid reliability and quality and minimize the potential challenges;

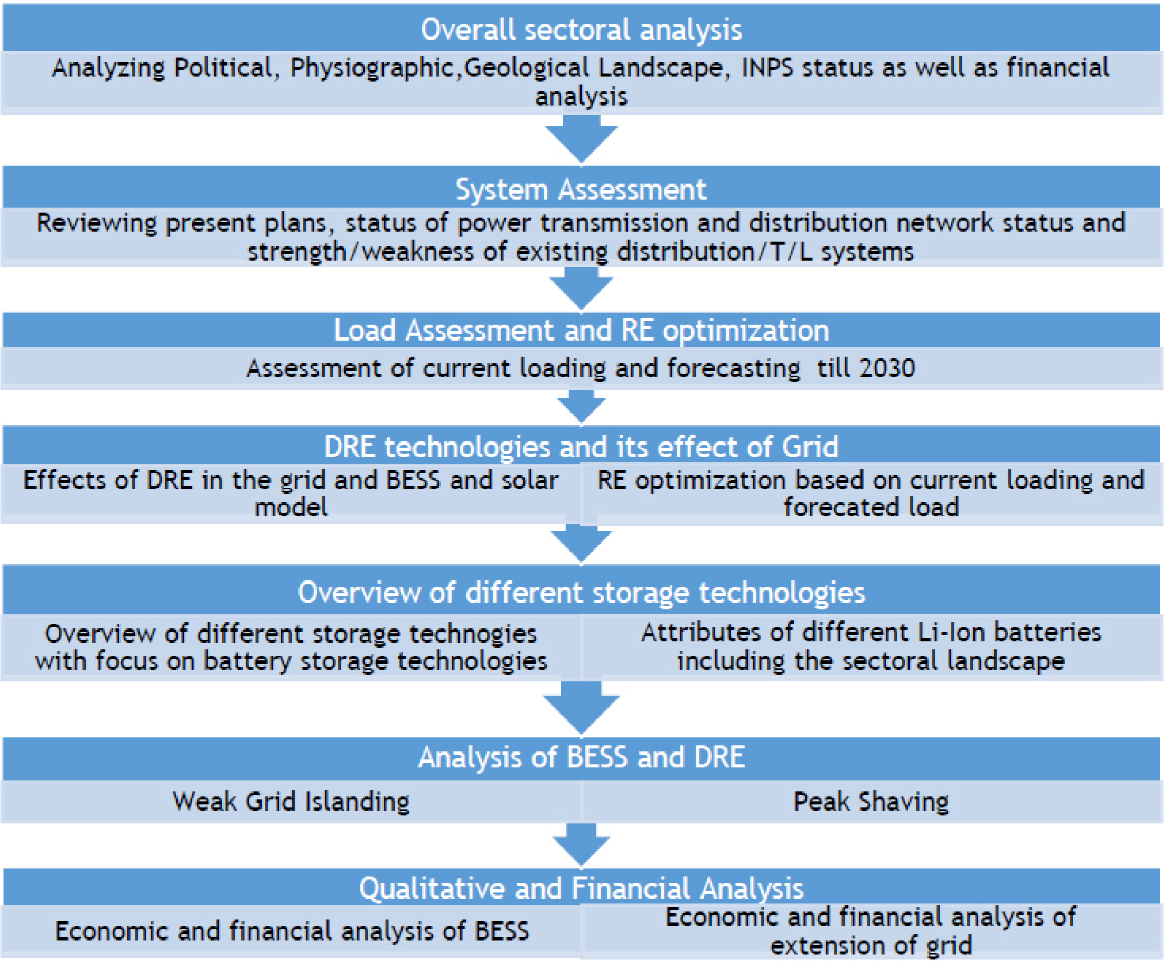
c) To identify the location and size of renewable energy for integration in to the grid;

d) To estimate optimum share of renewable energy for integration into the grid; and

e) To carry out economic and financial analysis of renewable energy integration into the grid.

1.2 Methodology

Based on the objective mentioned above the methodology carried out for the entire scoping including technical and financial assessment taken in to carry out this study is:



1.3 Limitations of the Report

The analysis in this study has been based on the data on existing, under construction and planned transmission and distribution system. The proposed project area covers three Lumbini, Karnali and Sudurpaschim Provinces. It is not possible to include the detailed analysis of renewables covering whole area for integration into the national grid. Hence, only few problematic areas are considered for the detailed analysis.

The minor details are subject to change during detailed feasibility studies and project implementation; and financing parameters can be changed based on lenders criteria, projections based on preference of developers and banks, the criteria for adopting the variations, and also some inherent variations due to change in US Dollar prices. The market rates, technology innovations and working methodology can also bring some changes in the financing projections. The indicators may vary on the span of project implementation and disbursements criterions.

Although, there are reasonable contingencies allocated for the possible deviation in various estimates, rates and budgeted costs and financing terms, the outcome and indicators listed in this report should be perceived comparatively as a present financing scenario of such size of solar photovoltaic and BESS project of this capacity to take any further strategic decisions on project financing.

1.4 Organization of the Report

This report lays details of the study to assess the existing electricity transmission and distribution system and supply quality to identify location for distributed renewable energy (DRE) for integration into the Integrated Nepal Power System (INPS) in Western Nepal[1] (West of Butwal). The main objective of the report is to provide information on existing status of transmission and distribution system west of Butwal and explore possibility of integrating renewables to the grid. This chapter (Chapter 1) has laid down the background, objectives and scope of the study.

The sectoral landscape of the project area is discussed in Chapter 2. Chapter 3 describes the current status of Integrated Nepal Power System (INPS). Distributed Renewable Energies (DREs) are discussed in Chapter 4 with respect to the grid. Analysis of Battery Energy Storage System (BESS) and DREs integration in INPS West is analyzed in Chapter 5. The Qualitative and Financial Analysis of the assignment is portrayed in Chapter 6 whereas the Chapter 7 sketches the conclusions of the study. Finally, References and appendices are provided at the end of report.

2 SECTOR LANDSCAPE

The primary intent of energy sector in any region is to enhance the development of that region. Enhancing DREs in western Nepal is no difference. In order to gain benefit from the projects, it is first essential to understand the landscape of the region. This chapter describes the various sectors of the project area. Foremost, the geographical location is discussed followed by the electrical infrastructure in the region.

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[1] Western Nepal, West of Butwal and INPS-West refers to the comprehensive project area of Lumbini, Karnali and Sudurpashchim Provinces of Nepal

2.1 Political, Physiographic and Geological Landscape

Nepal is politically divided into seven provinces. The project area, mapped in Figure 1, constitutes of three westernmost provinces, viz. Lumbini, Karnali and Sudurpashchim. These three provinces share boundary together. Further, they share boundary with China to the north, India to west and south and Gandaki Province to the east. These parts have vast lands ranging from high rise mountains in north to plain land in Terai region in south.

[2]

Physiologically Nepal is divided typically into three physiographic divisions viz., Himalayan, Hilly and Terai. However, literatures depict seven sub-divisions usually. Figure 2 illustrates the physiographic sub-divisions of Nepal.

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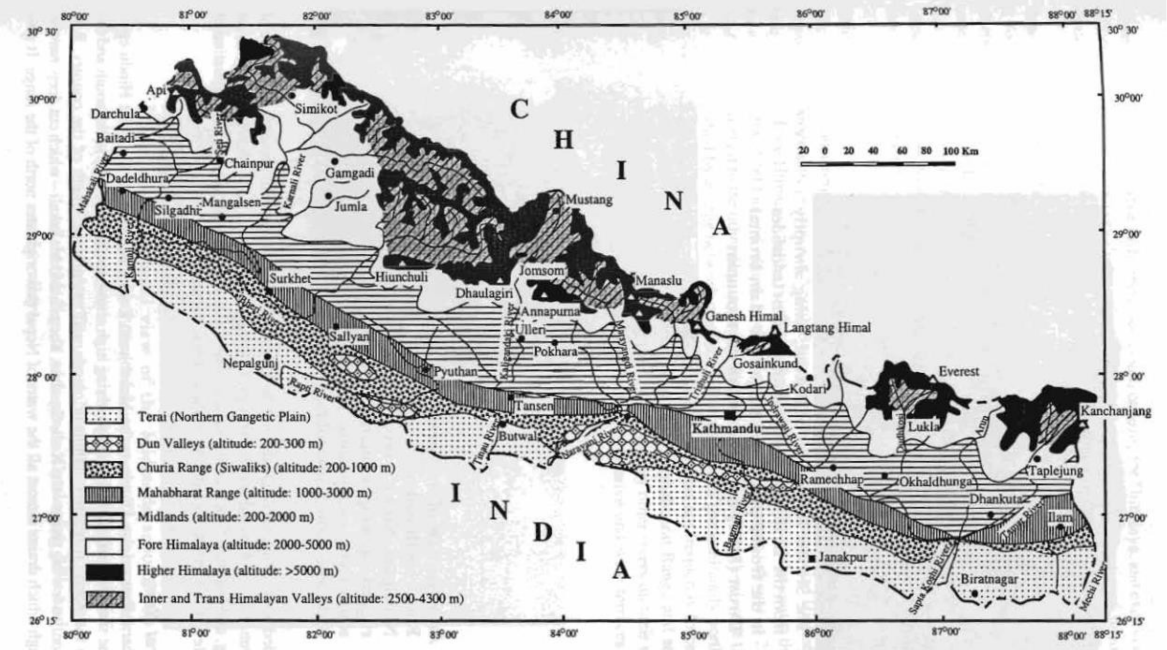
[2] Source: SRTM, Open Street Map, Open Data Nepal



[3]

The southern belt constitutes of plain lands and has higher population density compared to northern regions. In terms of electricity supply, the ragged hills in the central and northern regions of project area homes potential for hydropower plants of varying sizes. Currently, many MHPs and few HEPs cater electrical loads in those regions either in grid-connected or isolated mode.

Electricity is a utility as it requires incessant connection of wires from source to the load. These wires are supported by physical towers or poles depending upon the voltage level of the transmission system. Thus, understanding the geology of the region is essential. To be specific, hydropower plants that have underground powerhouse are affected more by the region geology. For transmission and distribution of electricity, geomorphic knowledge is essential. The geomorphic map of Nepal is presented in Figure 3. The northern regions such as Midlands, Fore Himalaya, pose a greater challenge to constructing power lines.

Further, excessive rainfalls in any area could also hamper the operation of the transmission system and could even induce tower failure. Thus, power system designers also consider the precipitation rates (Figure 4) while planning the transmission infrastructure.

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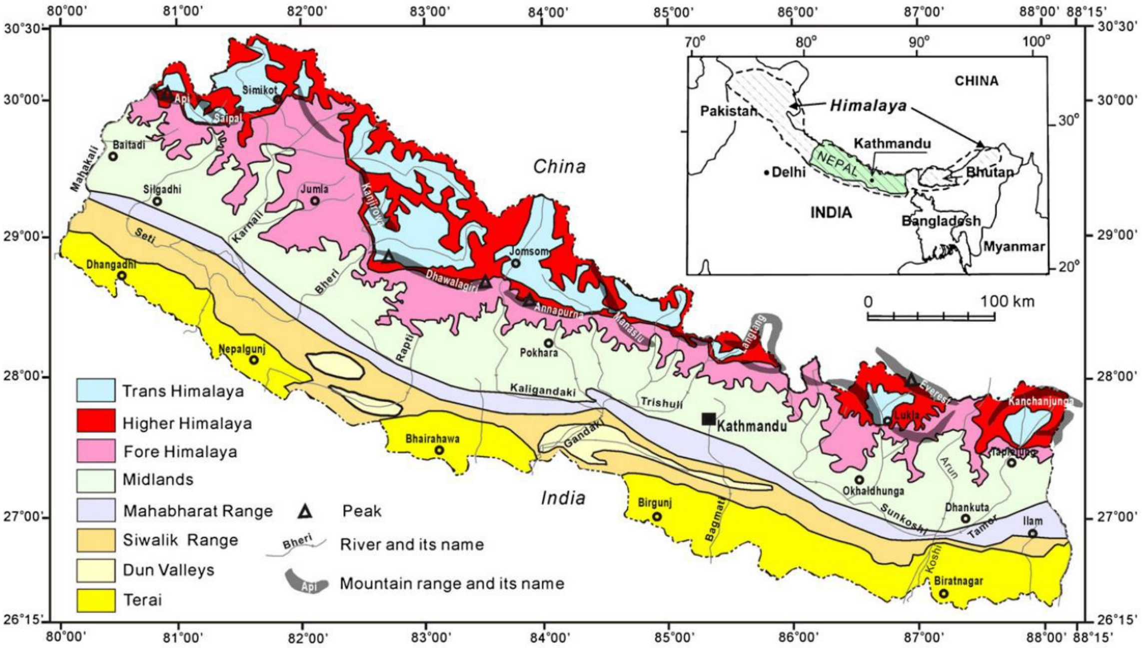
[3] Source: Upreti B. N., An overview of the stratigraphy and tectonics of the Nepal Himalaya, Journal of Asian Earth Sciences, 1999

Lumbini Province lies in the Hilly region and plain land of the Terai. It is bordered by India in the south and Gandaki Province, Karnali Province and Sudurpashchim Province in the east, west and north respectively. Six districts lie in the Terai region and the remaining six in the hilly region out of a total of twelve districts within its territory. The province primarily has Terai, Siwalik range and Mahabharat range with a couple of Dun Valleys. It observes rainfall of around 2000 mm annually.



[4]

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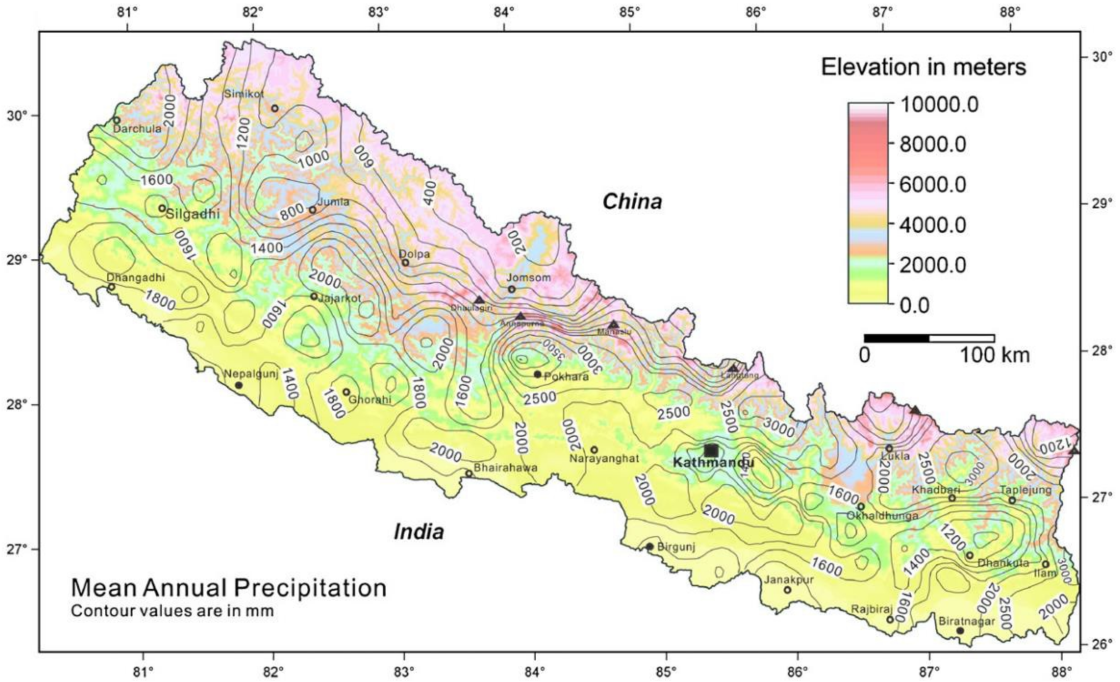
[4] Source: Ranjan Kumar Dahal and Shuichi Hasegawa, Representative rainfall thresholds for landslides in the Nepal Himalaya, Geomorphology, 2008



[5]

Karnali Province is situated in the mid-western part of Nepal. This is the biggest province in terms of area. The bordering provinces are Sudurpashchim Province in the west, Lumbini Province in the south and east, a part of Gandaki Province in the east and China in the north.

Geomorphological regions of this province include Midlands as well as Fore Himalayas in addition to the Terai, Siwalik range and Mahabharat range. The province observes lesser rainfall averaging around 1,400 mm per annum with lower rainfall in the northern regions.

Sudurpashchim Province is located in the western-most part of Nepal. There are three geographical features in this province: the Himalayan in the north, the Hilly in the middle and the Terai in the south. The river Karnali flows in the east and river Mahakali draws the border in the west. It borders India in the west as well as south and China in the north. The province almost reflects the geomorphological characteristics of Karnali province. However, it observes higher rainfall compared to Karnali province.

Political, physiological, geomorphic and precipitation characteristics of the region all impact in energy generation and electricity distribution in the region. Electricity transmission and

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[5] Source: Ranjan Kumar Dahal and Shuichi Hasegawa, Representative rainfall thresholds for landslides in the Nepal Himalaya, Geomorphology, 2008

distribution system in the project area is still in inchoate phase. The following section juxtaposes the electrical infrastructure of the country with the infrastructure in Western Nepal.

2.2 Energy Landscape in Nepal

The grid electricity access has been reached to 94% of total population as of March 2022 (MOF, 2022). Energy consumption in Nepal grew at an average annual growth rate of around 11% during the last decade. After decades of load shedding, regular supply was resumed in 2017. With resumption of regular supply, the energy consumption has grown significantly. This trend will continue further in future with improvement in supply situation.

As of 2022, total electricity consumption in Nepal is 8,824 GWh of which household consumption is around 42%, commerce/trade is around 7%, industrial consumption is around 39% and other sources constitute 11% (NEA, 2022). Out of the total consumption, about 14% is imported from India. The system peak demand grew at the rate of around 6% during the past decade and reached 1,748 MW in 2022. The total installed capacity of grid is 2,190 MW out of which 2,082 MW is from hydropower, 54 MW from thermal plant and 55 MW is from renewable energy. Off-grid RE mainly contributes around 32 MW.

Nepalese power sector is still in the shaping period. NEA, the vertically integrated public utility, enjoyed the monopoly in the power sector till 1992. Through enactment of Electricity Act, 1992; power, generation, transmission and distribution were opened to private sector. Since then, a number of hydro power projects are developed or are at different stages of development by the private sector. Even if GoN established Rastriya Prasaran Grid Company Ltd. (RPGCL) in 2015 to promote development of transmission systems in Nepal, NEA is still the large generator of electricity and is the largest transmission and distribution grid owner. Also, Power Trading Company has been established to facilitate within and outside country power trade. In addition, after enactment of Electricity Regulatory Commission Act, 2017, GoN formed Electricity Regulatory Commission (ERC) in 2019. New draft Electricity Act for Development and Management of Electricity sector is pending in the parliament since 2005 for promulgation.

2.2.1 Status of Power Transmission and Distribution Network

Power system is a convolution of generation, transmission and distribution system. In Nepal electricity is generated at 50 Hz frequency and at a nominal voltage of 11 kV or 13.8 kV etc. to be stepped up through transformers to 66 kV or 132 kV or 220 kV or 400 kV for feeding to the grid i.e., a high voltage transmission network that transmits the power to grid substation transformers to be stepped down at 66 kV, 33 kV and 11 kV for delivery to the consumers of various categories.

The transmission system in Nepal (Figure 5) is dominated by an east-west 132 kV line running from Anarmani S/S in the east to Lalpur S/S in the west. Except for the sections Hetauda S/S - Bharatpur S/S – Bardaghat S/S and Anarmani S/S – Duhabi S/S, the entire east-west line is constructed with double circuit towers using ACSR Bear conductors. The section of line from Hetuda to Duhabi is complete double circuit ACSR Bear conductor. The 132 kV section Hetauda S/S - Bharatpur S/S – Bardaghat S/S is single circuit lines with ACSR Panther conductors. As of the year 2022, Nepal power grid comprises approximately 514.46 circuit km 66 kV lines, 3,459.54 circuit km 132 kV lines and 602.60 circuit km 400/220 kV lines. The 400/220 kV and 66 kV lines are connected with the 132 kV network through 400/220/132 kV and 132/66 kV tie-bus transformers respectively. There are 71 grid substations with total capacity of 7,148.60 MVA that receive power from high voltage transmission lines and deliver to the consumers through tens of thousands of kilometers 33 kV, 11 kV and 0.4 kV distribution lines.

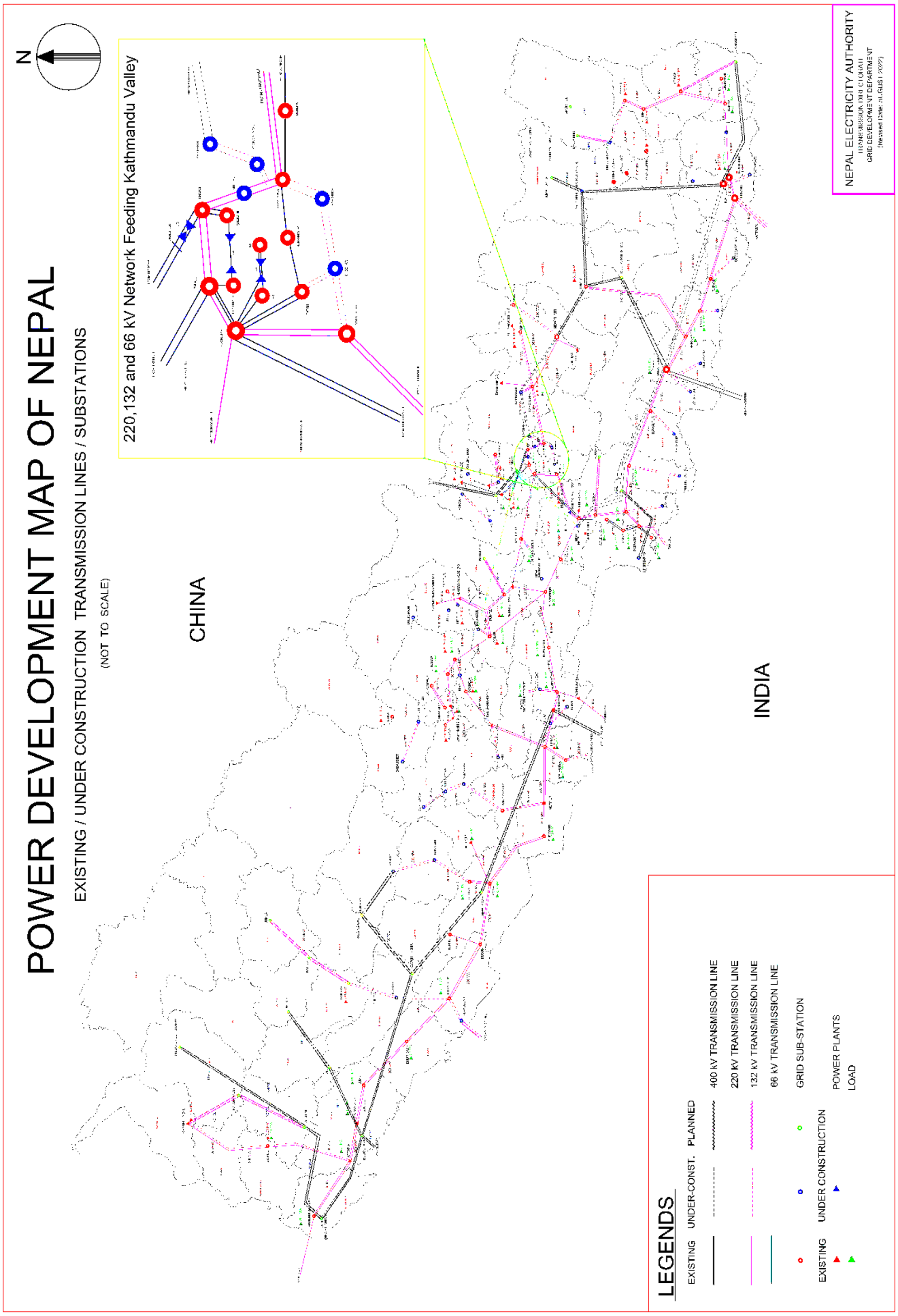


Figure 5: Power Development Map of Nepal (NEA, 22)

2.3 INPS in Western Nepal

INPS is in nascent stage in western Nepal. Figure 6 displays the grid reach in western Nepal. Currently, the region has highest transmission voltage level of 132 kV only. This too is limited in Terai area and up to Chameliya HEP in Sudurpashchim Province. Even the generation plants are few in the region. All three provinces have a number of projects under construction at 33 kV level that will be completed in next couple of years under Distribution System Upgrade and Expansion Project implemented by NEA. These substations though shall face voltage issues due to long 33 kV lines extending 100s of kilometres. Theoretically, grid interconnection of Mini Hydro Plants and Solar PV plants in these areas will be beneficial for quality of power supply in the project area.

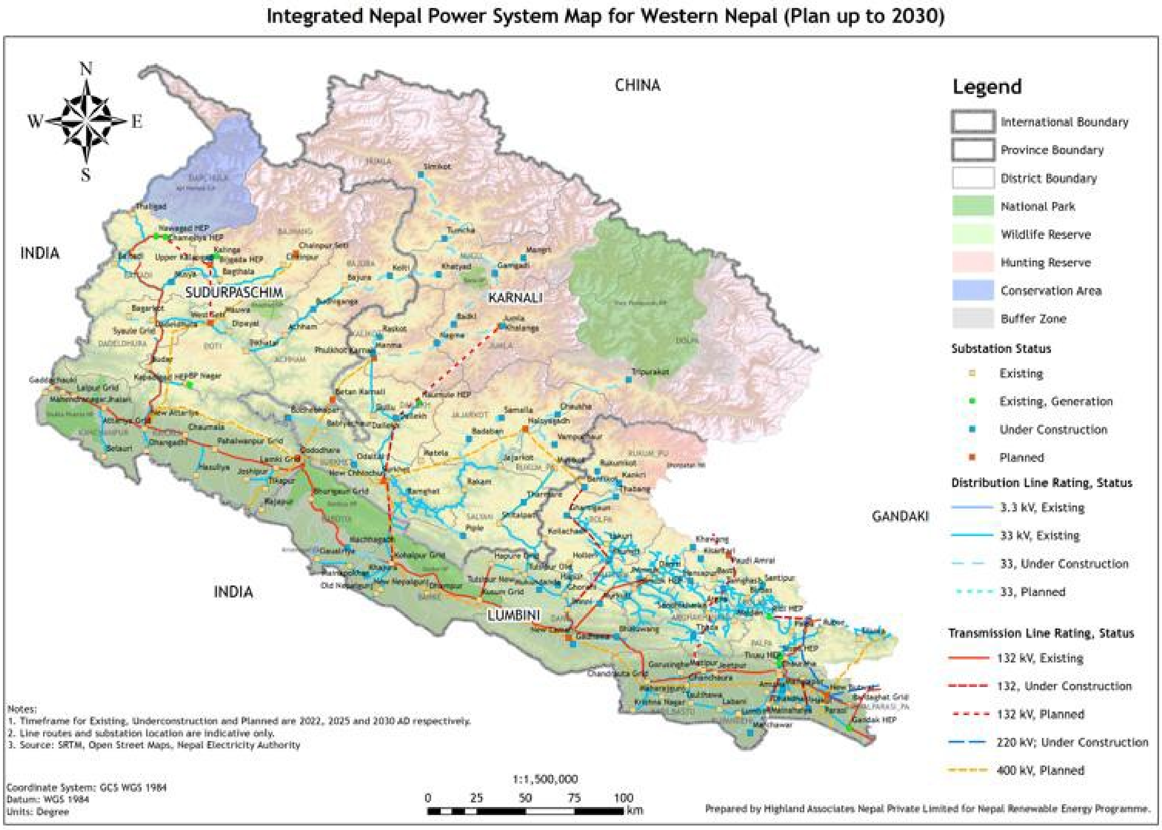
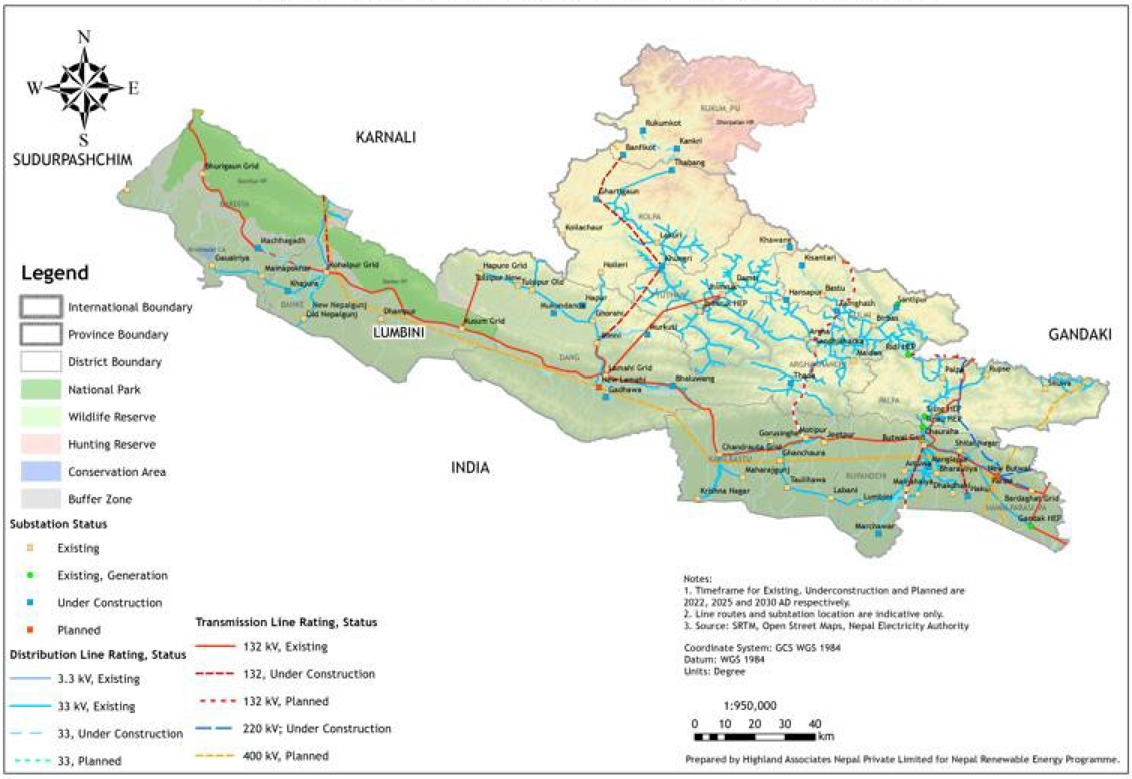


Figure 6: INPS Grid of Western Nepal, with Plans up to 2030

Figure 6 presents the electrical network of INPS in western Nepal. The existing lines are considered for the case 2022 of load flow. Lines and substations that are currently under construction are assumed to be completed by 2025 and thus are included in the case 2025. Any transmission level lines that are in planning phase are assumed to be ready by 2030 and thus implemented in developing the case 2030. The planned 33/11 kV substations, which are few in number, are not considered as they are highly likely to be cancelled should a HEP or HV substation be constructed in the vicinity. Electrical network in each province is described briefly in subsequent subsection.

2.3.1 Lumbini Province

Integrated Nepal Power System Map for Lumbini Province(Plan up to 2030)



Power is fed in the province through INPS as portrayed in Figure 7. Grid supply is available in all the districts. There are no major hydropower plants in the province. 12 MW Jhimruk hydropower plant is the largest plant in the region. However, there are small hydro power and solar plants in the province. There are thirteen 132/33 kV substations at Bardghat, Gandak, Sunawal, Butwal, Mainahiya, Motipur, Sandhikharka, Chanauta, Lamahi, Ghorahi, Kusum, Hapure, Kohalpur and Bhurigaun. Sub-transmission line in the province is at 33 kV and electricity distribution is at 11/0.4/0.23 kV from 132 kV and 33/11 kV substations. Numbers of industrial consumers are supplied at 33 kV. Lumbini province is sound from electrical infrastructure point of view among the three provinces in consideration. Figure 8 depicts the Single line diagram of electrical network of Lumbini Province.

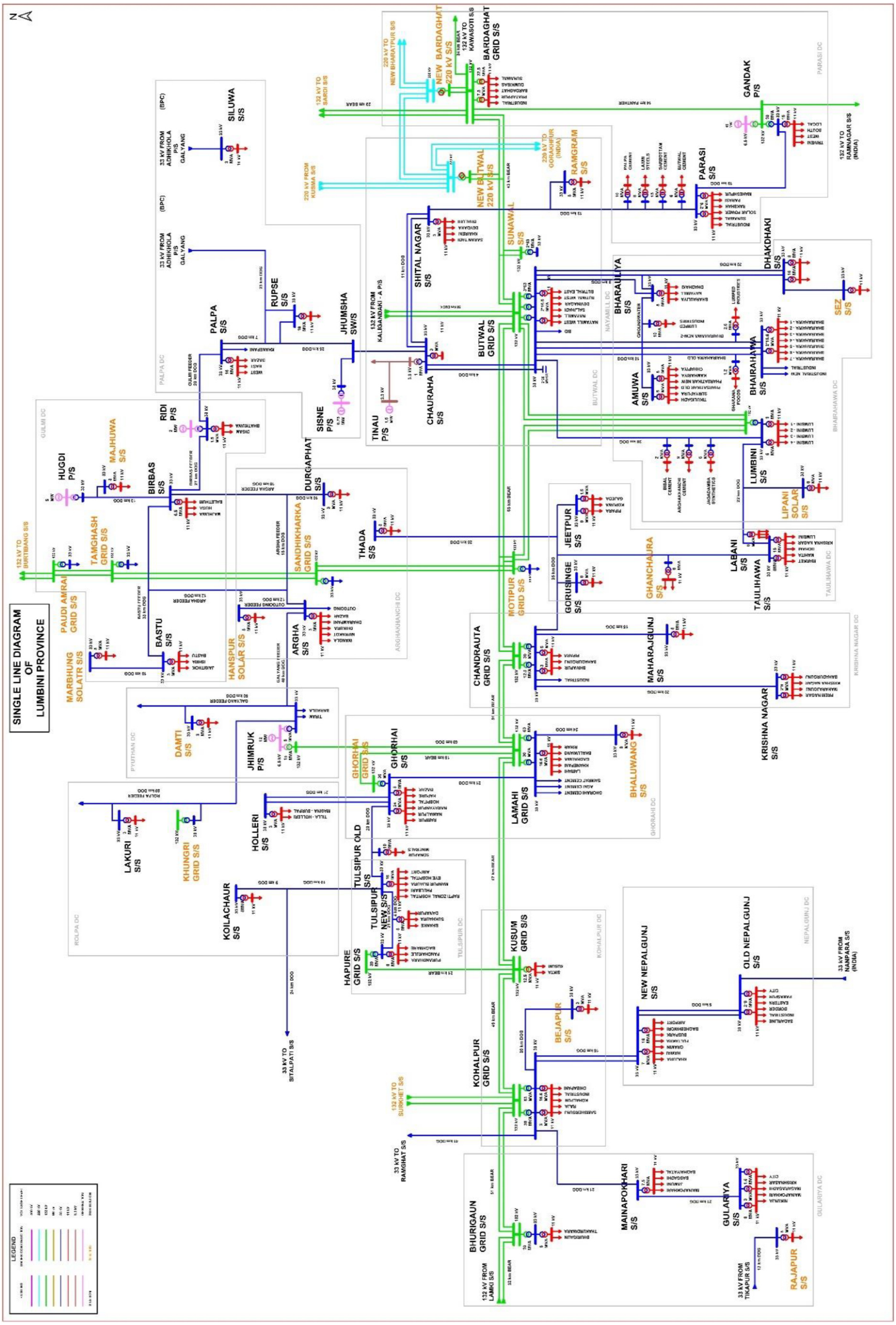
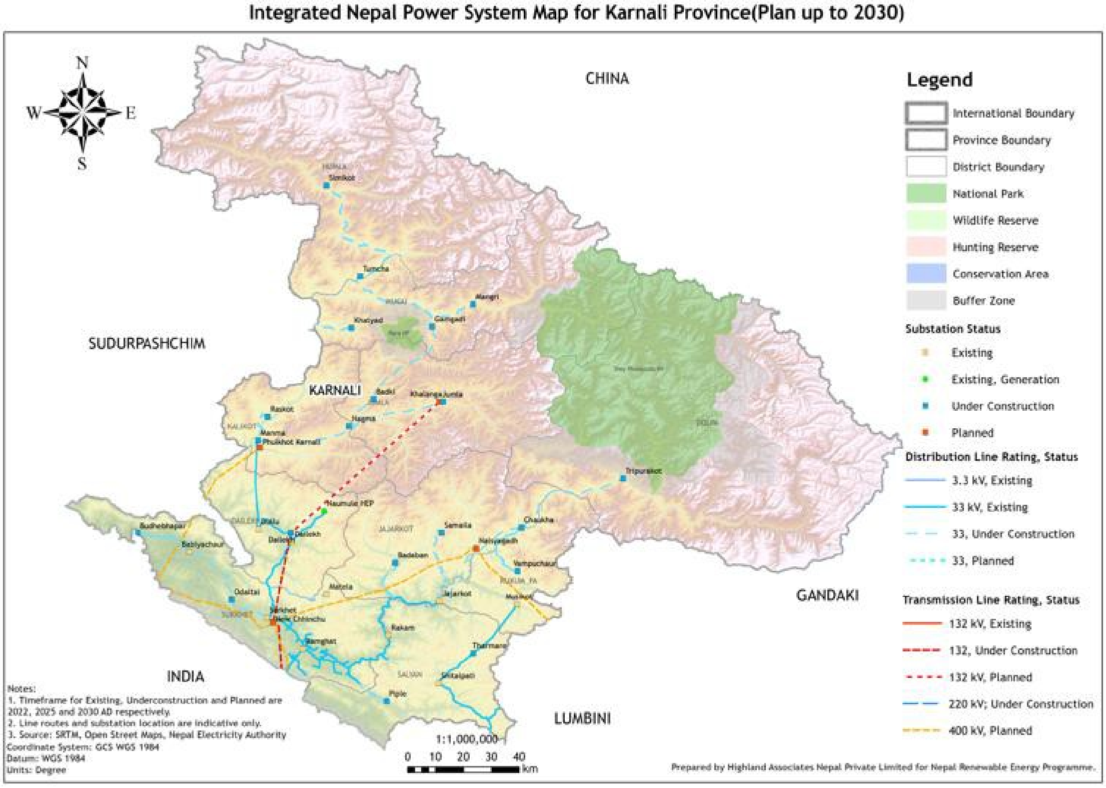


Figure 8: Single Line Diagram of Lumbini Province (DCSD, NEA, 2022)

2.3.2 Karnali Province


Integrated Nepal Power System Map for Karnali Province(Plan up to 2030)

Notes:
1. Timeframe for Existing, Underconstruction and Planned are 2022, 2025 and 2030 AD respectively.
2. Line routes and substation location are indicative only.
3. Source: SRTM, Open Street Maps, Nepal Electricity Authority
Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree

Prepared by Highland Associates Nepal Private Limited for Nepal Renewable Energy Programme.

Figure 9: Map of Karnali Province with planned INPS till 2030

Figure 9. There is no major hydropower plant in the province. However, there are few small hydropower plants in the province connected to the grid supply. Dwari Khola (3.75 MW) and Padam Khola (4.5 MW) are two small hydro power plants which are in operation and connected to Dailekh 33 kV substation. Construction of Upper Lohore (3.8 MW) is completed and waiting for completion of transmission line for operation. Parajol Khola (4 MW) is under construction which will take around two years for completion. Due to long sub-transmission lines at 33 kV passing through forest areas, there is frequent line tripping and voltage drop issue in the province. Distribution in the province is at 11/0.4/0.23 kV. Figure 10 presents the Single line diagram of electrical network of Karnali province.

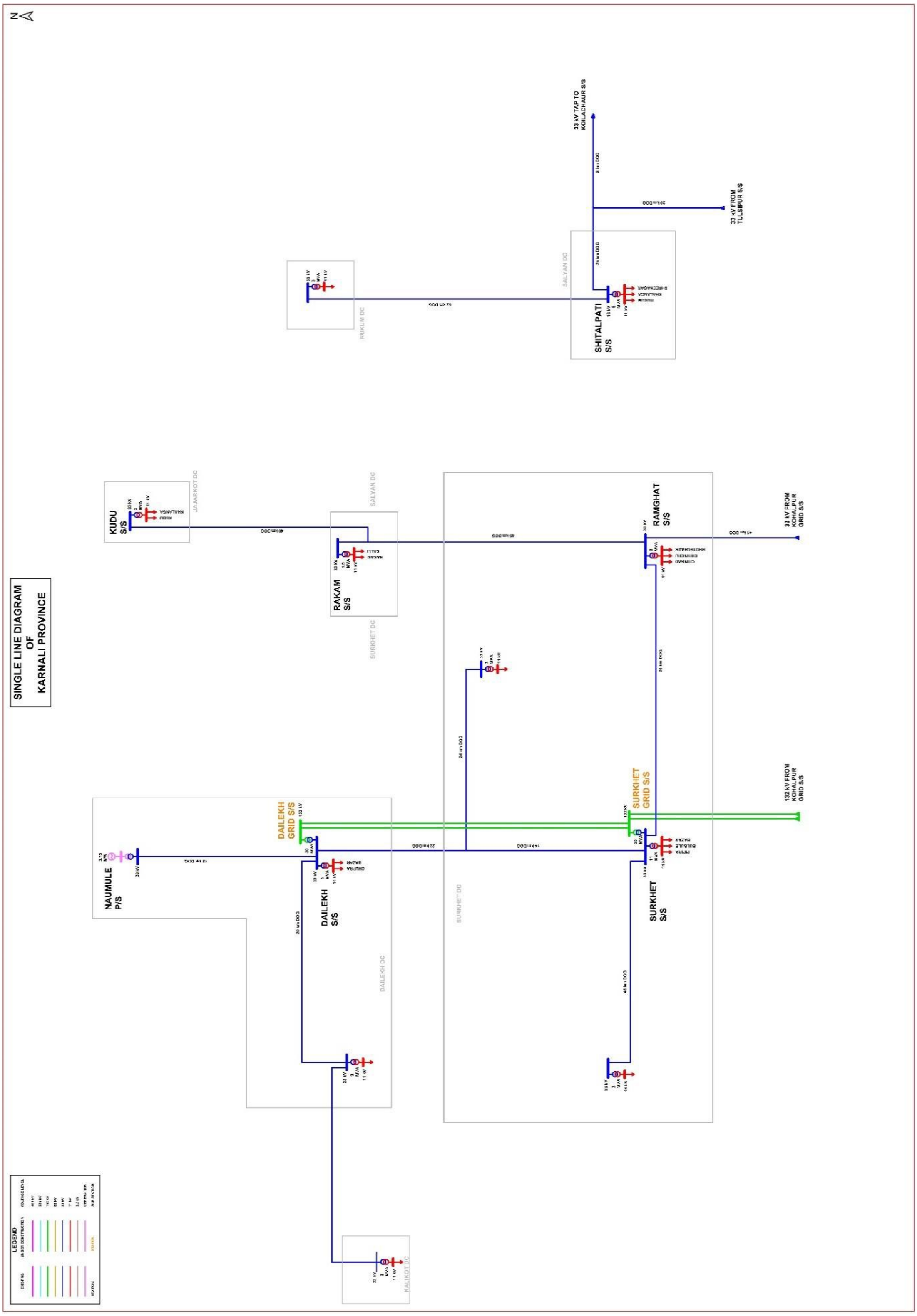


Figure 10: Single Line Diagram of Karnali Province (DCSD, NEA, 2022)

2.3.3 Sudurpashchim Province

Sudurpashchim Province is connected to INPS and its electrical network is displayed in Figure 11. Chameliya (30 MW,) is the major hydropower plant in the province, which plays a vital role in maintaining voltage level in the region. Naugad Hydropower Ltd. (9.5 MW) is in operation. Average annual generation of Chameliya for the last four years is 157 GWh. The plant is a peaking rub-off-river plant with 6 hours storage capacity. The plant has peak generation during the month of September-October and minimum generation in February. Kalanga Gad (15.33 MW), Sani Gad (10.70 MW) and Upper Kalanga Gad (38.46 MW) are some other power plants that are at the final stage of completion and waiting for transmission line completion for evacuation. One MW hydropower plant is connected to grid at Chainpur. There are other small hydropower plants connected to the grid. The province is connected to Tanakpur hydropower plant (India) through 132 kV transmission line. Lumki, Pahalmanpur, Attariya, Lalpur and Syaule are the 132/33 kV substations in the province. The sub-transmission voltage in the province is at 33 kV and distribution is at 11/0.4/0.23 kV. Single line diagram of the province's electrical network, which is used for the simulation purpose, is shown in Figure 12.

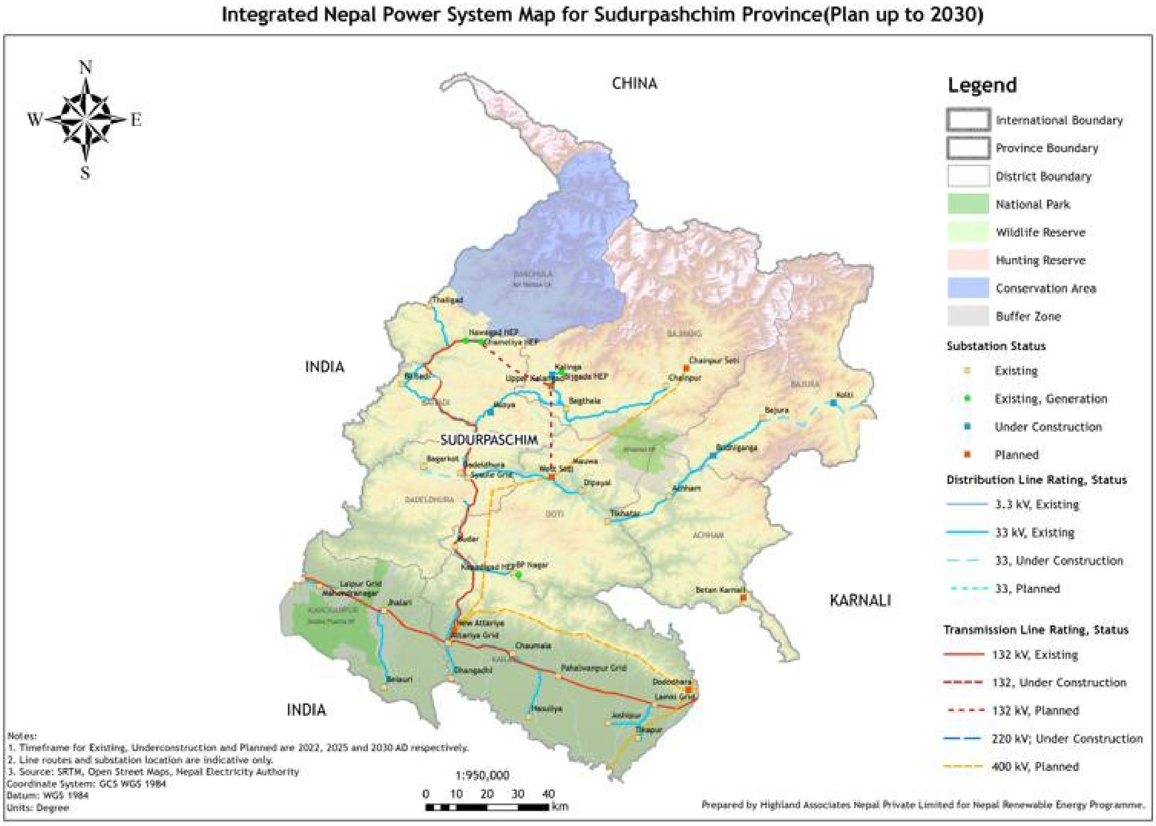


Figure 11: Map of Sudurpashchim province with planned INPS till 2030

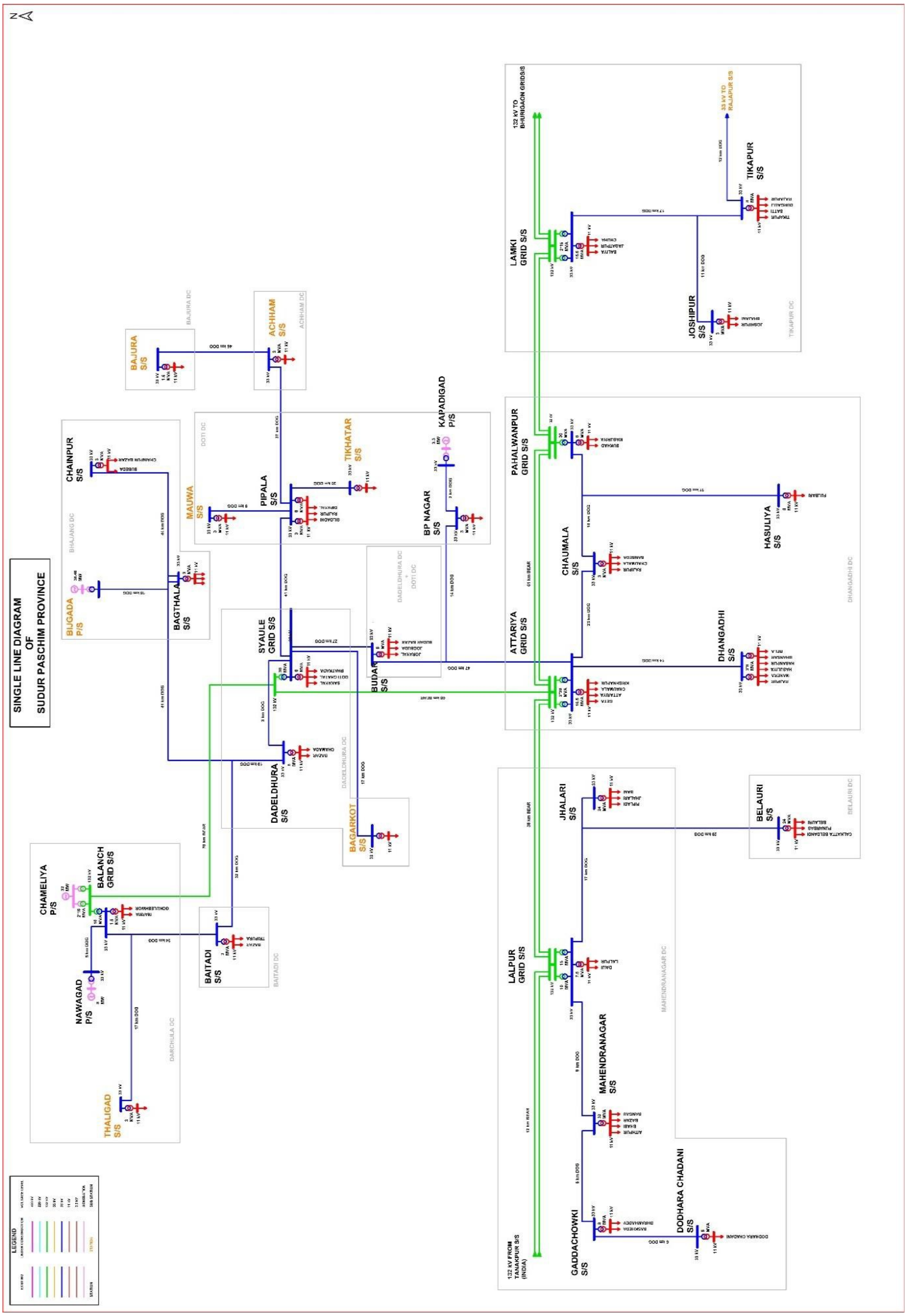


Figure 12: Single Line Diagram of Sudurpashchim Province (DCSD, NEA, 2022)

2.4 Financial Landscape

In 2020 alone, Nepal lost 95.61 GWh energy that could have been produced by 18 private hydropower plant's due to the lack of adequate transmission lines[6]. Despite knowing Nepal would be a power surplus nation, the government failed to materialize concrete plans to export power. The government is yet to build transmission lines, sub-stations, and install transformers in several parts of Nepal. This is another reason behind sluggish growth in power consumption and thereby, electricity wastage. However, the NEA's initiative to upgrade and expand transmission infrastructure throughout the country by launching the 'Electricity Grid Modernization Project' is a step towards the right direction.

NEA has been extensively been working on short term, medium-term and long-term development plans of transmission system network of 66 kV and above voltage levels to evacuate the power generated as per the GoN strategy (15,000 MW in 10 years). On these regards many projects like Solu Corridor 132 kV transmission line with an outlay of 44 million USD and jointly funded by GoN and EXIM Bank of India, Nawalpur 132 kV substation with an outlay of around 5 million USD, Motipur-Sandhikharka 132 kV transmission line with 11.2 million USD, expansion of Lamahi Ghorahi 132 kV substation with an outlay of 300k USD, Butwal Lumbini 132kV substation expansion with an outlay of 5.1 million USD have been completed.

Further to these completed projects there are many projects in construction for the strengthening as well as expansion of transmission and distribution lines. Some projects like the Burtibang- Paudi Amrai- Tamghas Sandhikharka- Gorusinghe 132 kV transmission line is being built with an outlay of 39.5 million USD, Kushaha- Kataiya 132 kV second circuit transmission line for strengthening of Nepal-India power transmission line with a cost of 5.5 million USD, Sunwal 132 kV substation with a budget of 5.28 million USD.

Currently there are above 30 of such projects working on extension and enhancement of transmission lines and substations of 220 kV, 132kV and 400 kV with a total investment of around 800 million USD. Most of these projects are to be funded by GoN but also will involve loan and grant from different development partners and banks like KfW, Exim bank of India, ADB, World Bank and others. These projects also include the construction of a 33/11 kV su-station, a 33 kV transmission line, Trishuli 3B Hub Substation and a network of 11 kV and 0.4 kV distribution lines as well.

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[6] https://www.nepallivetoday.com/2022/01/24/once-a-power-starved-nation-how-nepal-is-now- wasting-its-precious-electricity/

The Asian Infrastructure Investment Bank (AIIB) and the European Investment Bank (EIB) have committed to provide NEA with a concessional loan in the amount of USD 112.3 million and 100 million Euros, respectively, for the electrification of Provinces 5, 6, and 7, for which a subsidiary loan agreement (SLA) with GoN has been signed. ADB has also committed an additional USD 156 million for the automation and modernization of the electricity grid, for which a subsidiary loan agreement (SLA) with the government is being negotiated. The total long-term support from the GoN, the primary source of project financing, increased to 1.5 billion USD in FY 2021/22, from 1.3 billion USD in FY 2020/21. NEA received a long-term loan of 48 million USD from GoN source to invest in various projects. Similarly, donor agencies provided approximately 123 million USD as long-term loans and grants through direct payment to consultants and contractors in accordance with the GON budgetary program in FY 2021/22. The investment for the overhaul of the transmission and distribution network has increased rapidly however more funding needs to come in for GoN to provide reliable electricity to all.

2.5 Overall Taxonomy

One objective of this analysis is to develop an organizational framework that can support informed regulatory, policy, and stakeholder discussions to enhance the value-added services, energy products as well as enhanced and adjacent services. This will help facilitate the grid strength and reduce the transmission and distribution losses and improve the reliability of the grid. In order to establish a basis and applying a research methodology a taxonomy for the full range of potential commercial products and services that electric utilities could offer were evaluated for overall enhancement of the grid. That comprehensive categorization scheme includes four broad classes of offerings other than the regular generation and transmission services. To make the taxonomy more tangible and applicable, new opportunities offered in the market today or that have been identified and can be reasonably anticipated to be pursued in the future for overall enhancement of the network grids in the country is categorized.

Table 1: Overall taxonomy of the network grid foreseeing the overall landscape of future

CATEGORY	DESCRIPTION OF INDUSTRY
Generation and Utilities	Hydroelectric Power Generation
	Fossil Fuel Electric Power Generation
	Other Electric Power Generation
	Electric Power Distribution

CATEGORY	DESCRIPTION OF INDUSTRY
Transmission and Distribution (T&D)	Electric Bulk Power Transmission and Control
	Electric Power Distribution
Grid Services	Peak Shaving Load Management
Energy Products	Battery Energy Storage Smart Grid
Enhanced Services	Power Quality Reliability Differentiated Generation
Adjacent Services	Field Sensor Networks Data & Communications Optimization Solutions Customer & Administrative Insurance & Warranty

A wide variety of commercial opportunities provide a value-added component or attribute beyond the utility's traditional service offering. For example, value-added services have historically focused on offerings that target the source of the electricity (e.g., renewable energy products) or the power quality of the delivered electricity (e.g., smaller variations in the voltage). In other cases, the additional value may come from the provision of standby generators and other forms of enhanced reliability services. The overall study captures most of the offerings which will help enhance the grid and act as support towards west of Butwal.

3. SYSTEM ASSESSMENT

In order to understand the impact of the DREs on the grid, it is essential to understand the existing grid status in detail. This chapter lays the descriptive information of the existing transmission and distribution system of Nepal with emphasis on the western Nepal. The High Voltage transmission system, operation modality, sub-transmission and distribution system are introduced in the first section of this chapter. The second section discusses the loading in the electrical network, role of DREs and essential modifications in the grid to host the DREs.

3.1 Assessment of Existing Transmission and Distribution Systems

3.1.1 HV Transmission System of INPS

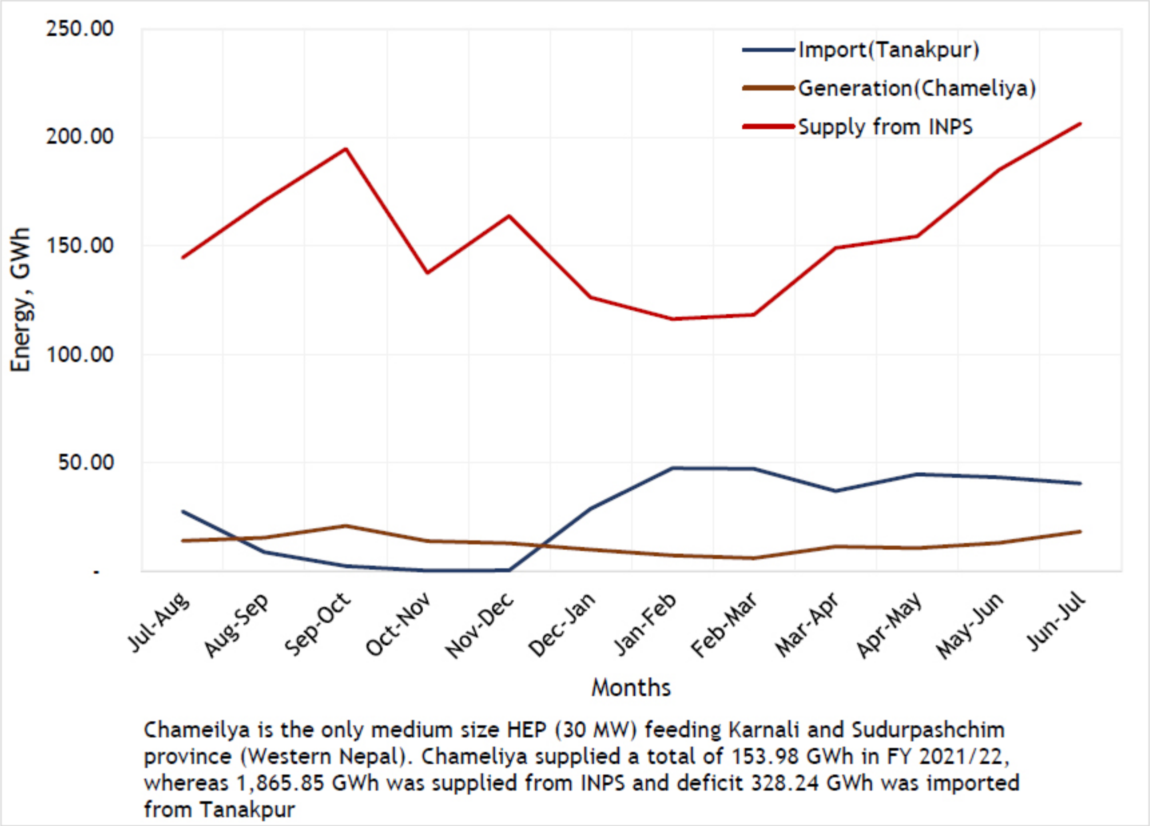
NEA's transmission system has been developed over the years based on the need to evacuate power from individual projects. Due to the inadequate funding, the planned expansion of NEA's transmission system was delayed. However, NEA and RPGCL are now developing number of transmission lines through government funding or funding from international financing agencies.

In the western region, west of Butwal, occasionally during summer, system voltage was recorded lower than the permissible limit in some substations. Capacitor banks installed in various substations helped to some extent in maintaining voltage but it is not sufficient enough. The voltage could not be maintained at the desired level despite the continuous effort of Load Dispatch Centre (LDC) which is the NEA's centre for grid operation.

Many of the transmission system in INPS operate on an “n-0” basis, i.e., there is no contingency transmission provision. There is no redundancy in the network allowing a single fault to result in the loss of generation, loss of load or, even full system collapse. Many links in the INPS grid system are heavily loaded resulting in poor voltages as low as 0.8 p.u. Overall transmission losses on in 2021/22 was 4.49% while the corresponding figure for west of Butwal was 3.62%. The lower level of losses west of Butwal could be attributed to lower level of demand. The total reactive compensation in the INPS system is below the system demand. NEA plans to include necessary capacitor compensation to support voltages on the system.

Due to the addition of more and more generations in the system, the existing aging transmission arrangements are inadequate to evacuate power to load centers. The transmission line Hetauda-Bharatpur 132 kV, Damauli - Bharatpur 132kV, Bharatpur – Kawasoti - Bardghat132 kV, Lekhnath – Syanga - Kaligandaki A, Marsyangdi - Bharatpur 132 kV, Duhabi - Anarmani 132 kV were being operated almost in full capacity continuously which might have originated the power cut in some areas.

In recent year, difficulty in the smooth power supply to the western part of the country (west from Butwal) has been realized due to the unavailability of sufficient generation in the western part of the country to cater the growing demand in the area. Due to the transmission line's inadequate capacity, surplus generation of the eastern part of the country cannot be transmitted to the west thus western part of the country have been partly supplied from imported power from Tanakpur (India). The amount of energy locally generated, imported from India and supplied from Nepal grid in areas west of Butwal is presented in Figure 13. Despite Nepal being a generation surplus country in the wet season, still imported power is playing a vital role in the supply of power in the western part.



Chameilya is the only medium size HEP (30 MW) feeding Karnali and Sudurpashchim province (Western Nepal). Chameliya supplied a total of 153.98 GWh in FY 2021/22, whereas 1,865.85 GWh was supplied from INPS and deficit 328.24 GWh was imported from Tanakpur

Figure 13: Energy Mix in HV transmission system in western Nepal

3.1.2 HV Transmission System operation of INPS

NEA has its load dispatching facilities with SCADA system communication link with number of power stations and grid substations. As recorded by LDC, the annual system collapses and energy not served during the year 2021/22 are as follows: Annual tripping time: 40 times, 543 minutes and energy not served is 6,005 MWh. Although system collapse is relatively frequent, its impact is diminished by the quick restart of hydro generation. The system can be restored usually within 20 minutes after a collapse. Similarly, the availability of real- time data and better communication systems have improved the overall reliability of power stations and transmission lines and has helped to minimize the time required for restoration of the power system following black-outs. The frequency of interruption has remarkably reduced which shows that the system maintenance has improved. NEA is performing routine inspection and maintenance as recommended by the manufacturer and schedule prepared by the Grid

Operation Department. Maintenance is carried out only in “off-line” mode. Unscheduled maintenance is carried out in the event of a break down due to a storm, lightning or equipment failure etc.

3.1.3 Sub-transmission and Distribution System of INPS

Power is transmitted at 132 kV or higher voltages, while distribution to domestic, industrial and other consumers is done in lower voltage levels viz. 33 kV and 11 kV. Domestic household consumers are supplied through the 11 kV feeder network that is stepped down to 400/230 V three/single phase supply through distribution transformers located in different locations. The bulky industrial consumers are provided with 33 kV feeders directly to meet the high demand of industrial loads.

The quality of Nepalese power system, however, hasn’t been par to the technology and standards of other countries. Besides, frequent tripping of power lines and unreliable power supply along with a poorly regulated voltage in many locations raise some question about the reliability of Nepalese power systems.

According to the standards Nepalese domestic voltage level must be 230 V with an error of ±5%. However, due to poor planning and system design voltage can go down to as much as 17 - 20% which is unacceptable for many electrical equipment. One of the reasons of such unregulated voltage is the unprecedented and unscientific length of distribution feeders.

In urban areas feeder length is generally governed by the current carrying capacity of the feeder whereas in rural areas the same is governed by the voltage drop. As a rule of thumb, the length of 11 kV feeder could be around 11 km to limit the voltage drop. However, the length of above feeder was found to be greater than 30 km which means the end user of the feeder has a poorly regulated voltage supply. This is one of the many issues responsible for the poor voltage regulation in many places of Nepal. Because of poorly maintained transformers, substations and transmission line, significant energy is lost yearly resulting in loss of revenue amounting to millions of rupees.

3.2 Electrical Loading in INPS West

The data on the present supply situation west of Butwal including the present loading of substations and lines, demand and supply situation were collected from NEA’s website and site visits of NEA’s local offices and substations.

3.2.1 Load and Energy Forecasting of INPS

As of 2021 mid-March, the ratio of conventional, commercial and renewable energy consumption to total energy consumption has been 68.6 percent, 28.2 percent and 3.2 percent, respectively (MOF, 2021). An accelerated recent increase of modern energy use is being observed, due to rapid urban growth. As for commercial energy sources, fossil fuels are imported, and will be imported for long time as Nepal has no known significant fossil energy resources. Hydropower is the biggest known commercial energy resource with a generally mentioned theoretical potential of 83,000 MW, and a very high economically exploitable potential of 42,000 MW.

Water and Energy Commission Secretariat (WECS), GoN carried out electricity load forecast as a part of the agency's overall responsibility of energy planning for the Government and thus, prepared a study report on load forecasting entitled, "The Electricity Demand Forecast Report (2015-2040)" in January 2017. The report presents the required installed capacity for meeting the load demand as shown in Figure 14.

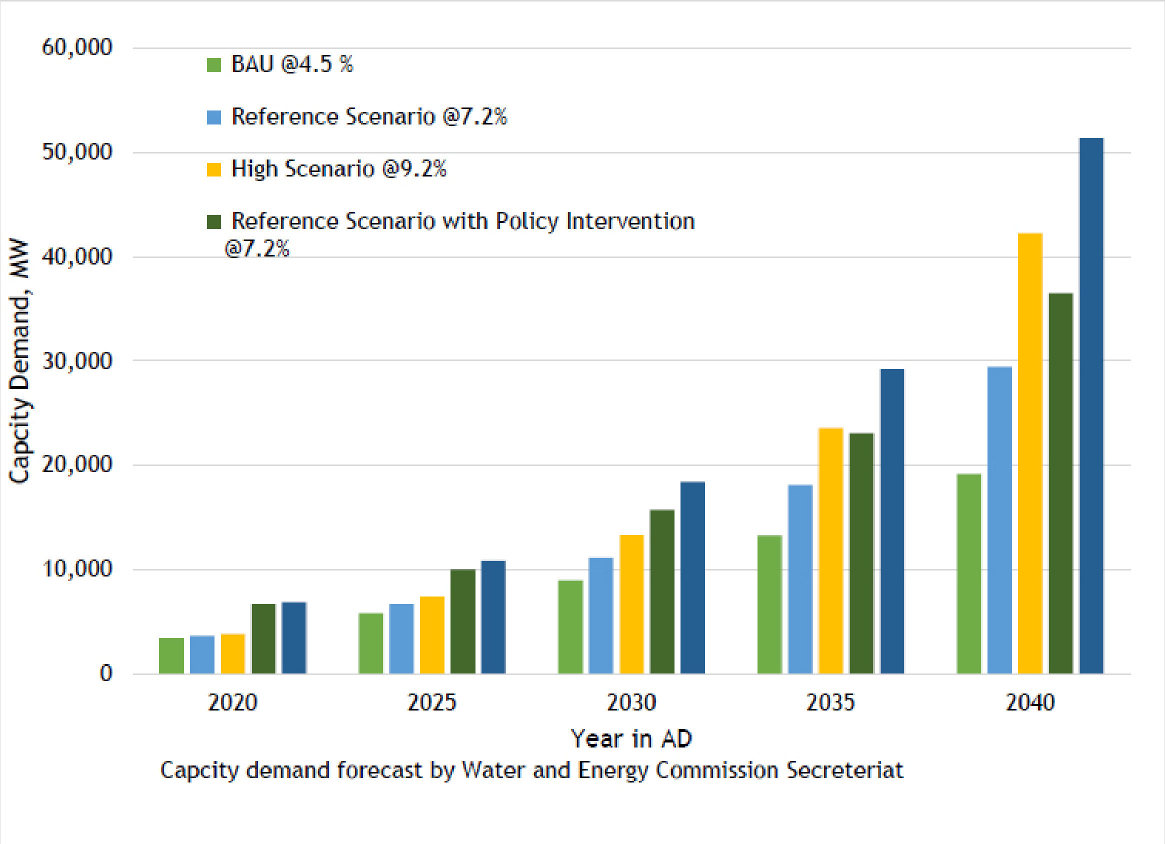


Figure 14: Required Capacity Demand Forecast by WECS (MW)

The installed capacity is based on capacity factor of 50%, regular and unexpected outage, 20%, transmission and distribution loss of 25% and additional power required to supply the peak demand 30%. The WECS report consists of three different scenarios: Growth Rate 4.5% (Business as Usual), 7.2% (Reference Scenario) and 9.2 % (High Scenario). In the latter two scenarios, policy intervention are considered. The energy forecast by WECS is presented in Figure 15 for reference.

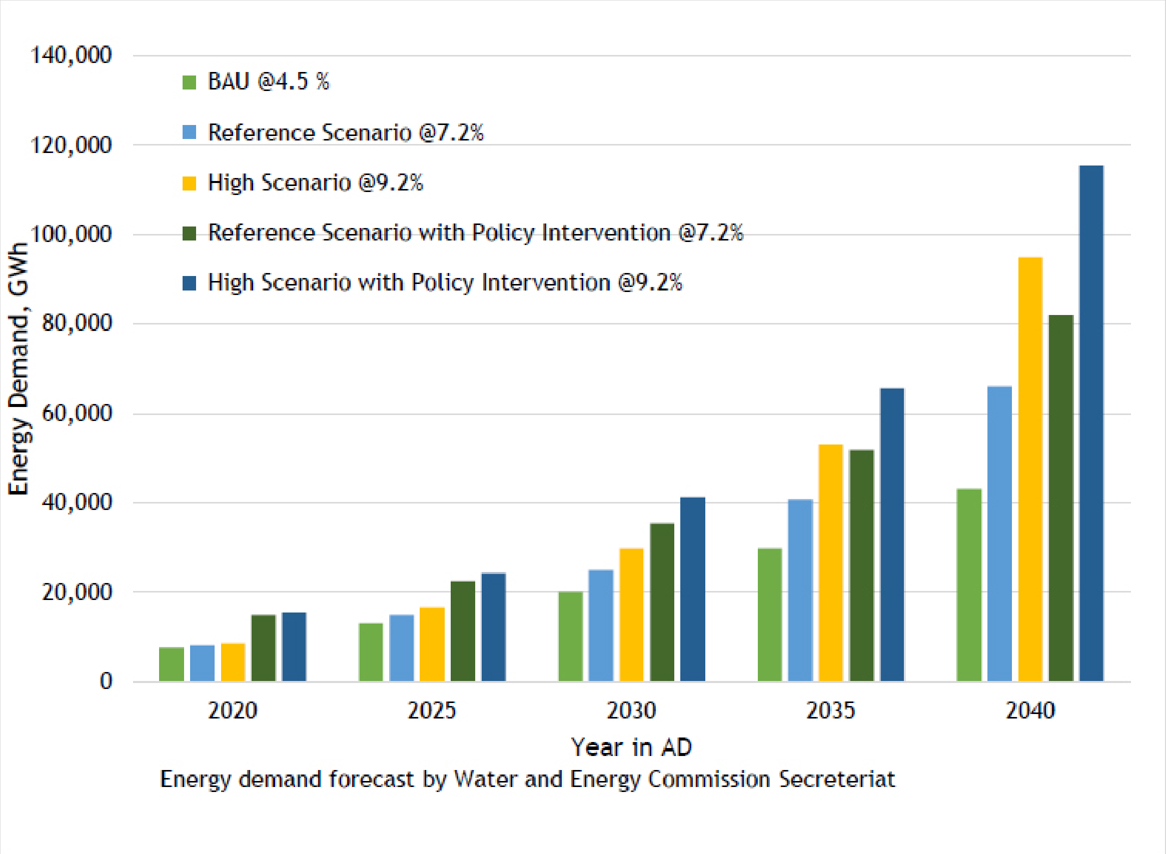


Figure 15: Energy Demand Forecast by WECS (GWh)

The loading in 132 kV substations in INPS West are analysed in this study. Peak demand and Energy demand for 2022 are shown in Figure 16 and Figure 17 respectively. The peak demand relates with the capacity requirement of the system whereas the energy demand shows how the system stands from usage perspective. The key observation here is that most of the substation's capacity are just sufficient to cater the present peak demand. Mainihawa, Motipur, Sandhikharka and Ghorahi (Jhigni) substations are exceptions as they are relatively new substations. Thus, newer substations, or some measures such as installation of DREs are essential to cater the loads in these regions. While considering newer power plants in the grid, estimating energy demand is essential as the primary revenue of the plants are obtained from energy sale.

So, based on the current year and historical data, energy demand forecast was carried out for selected substation/load centres in the region. Two cases each were considered for each province. The forecasting was carried out using moving average method. A confidence level of 95% was taken meaning that 95% of future points are expected to fall within this radius from the result forecasted with normal distribution. Using confidence interval can help grasp the accuracy of the predicted model. In instances when the r^2 value was on the lower side upper bound level was considered to make sure that the data fits well in the regression level. As r^2 gives the fitness of model hence r^2 values of greater than 0.95 were only considered. In instances when the r^2 fell below the level polynomial forecasting were used to increase the goodness of the fit. The details for these load centers are described in the following sub-sections.

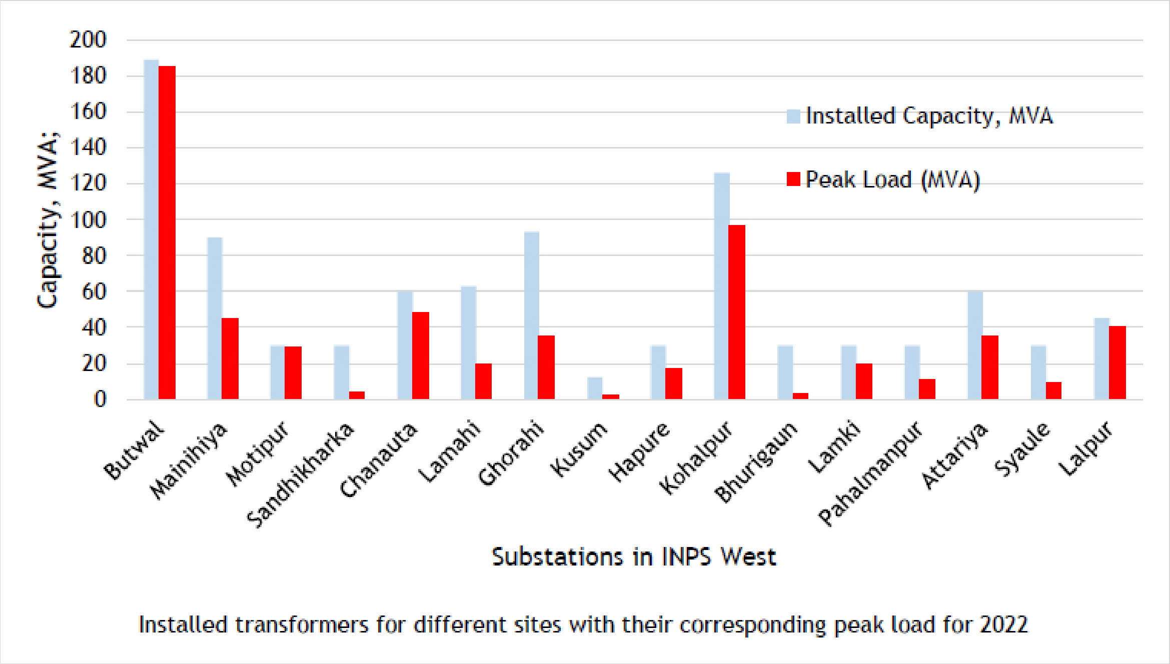
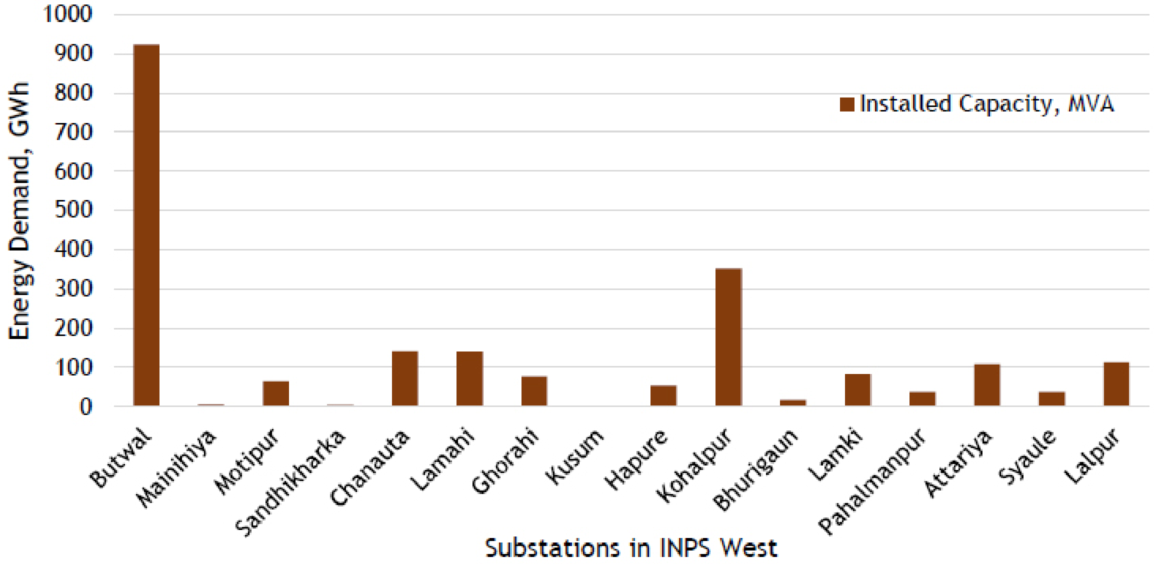


Figure 16: Peak demand of substations in INPS West in 2022



Total installed capacity and the corresponding energy demand from these substations for 2022.

Figure 17: Energy demand of substations in INPS West in 2022

3.2.1.1 Energy demand forecast for selected substations in Lumbini

The sample energy demand forecast in Lumbini substations are carried out for two load centres, viz. Chadrauta substation and Nepalgunj. The Chanauta grid substation lies in the Kapilvastu district of Lumbini Province (See Figure 6). It serves two 33/11 kV substations in the region viz. Maharajgunj, Krishna Nagar and Ghanchaura. Figure 18 portrays the forecasted load in reference to the historical load data from 2018 to 2021. It is observed that the r^2 value for the forecast is 0.99 which means that 99% of the data fit the forecast.

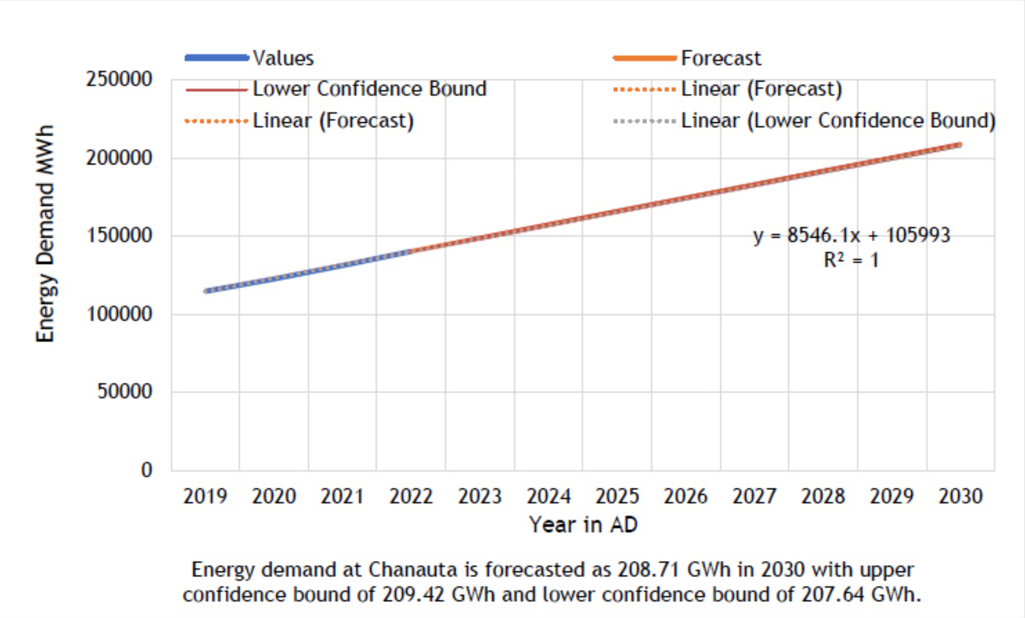


Figure 18: Forecasted energy for Chanauta till 2030

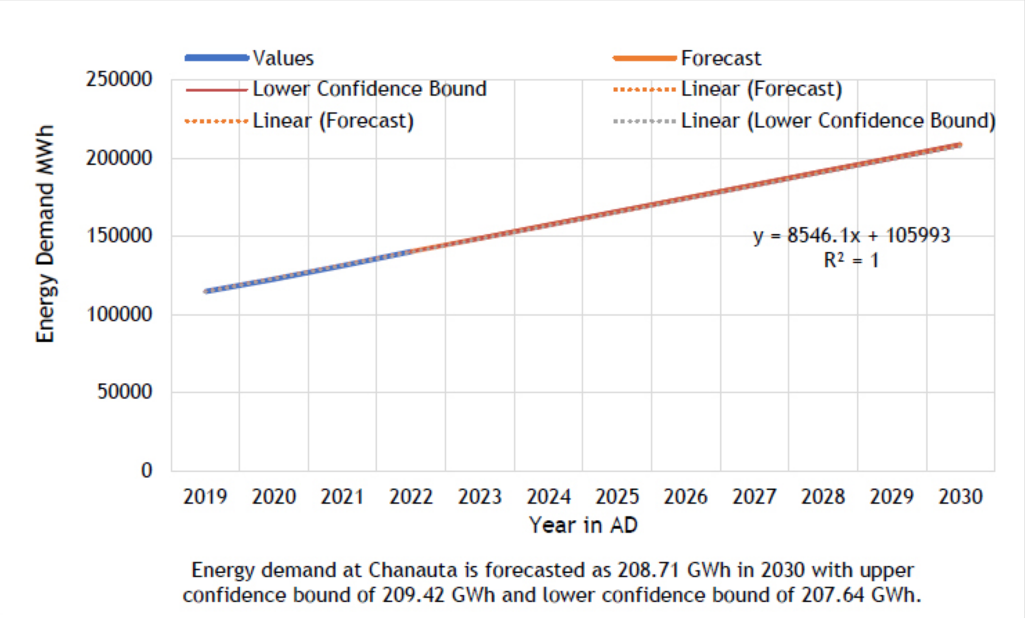


Figure 19: Forecasted energy for Nepalgunj till 2030

Nepalgunj Distribution Centre (DC) lies in Banke district of Lumbini Province (See Figure 6). From the forecast curve provided in Figure 19, it can be seen that the r^2 value for the forecast is 0.99 which means that 99% of the data fit the forecast.

3.2.1.2 Energy demand forecast for selected substations in Karnali

Energy forecast is carried out in Karnali province for two sample load centres viz. Jumla and Surkhet. The former presents the case of relatively recently electrified region whereas the latter presents the case where the electricity is supplied for more than three decades.

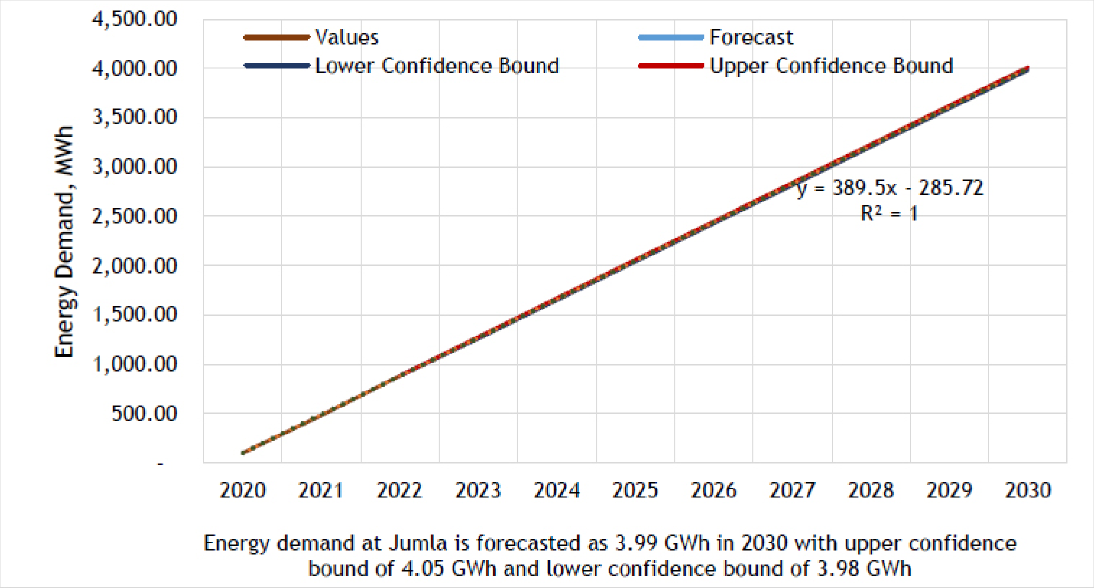


Figure 20: Forecasted energy for Jumla till 2030

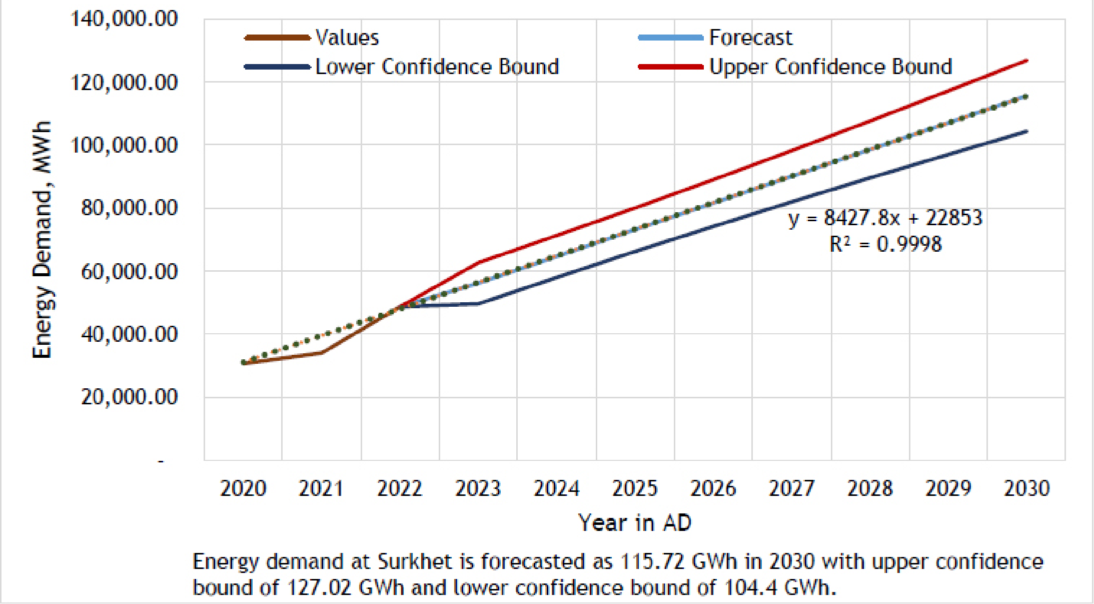
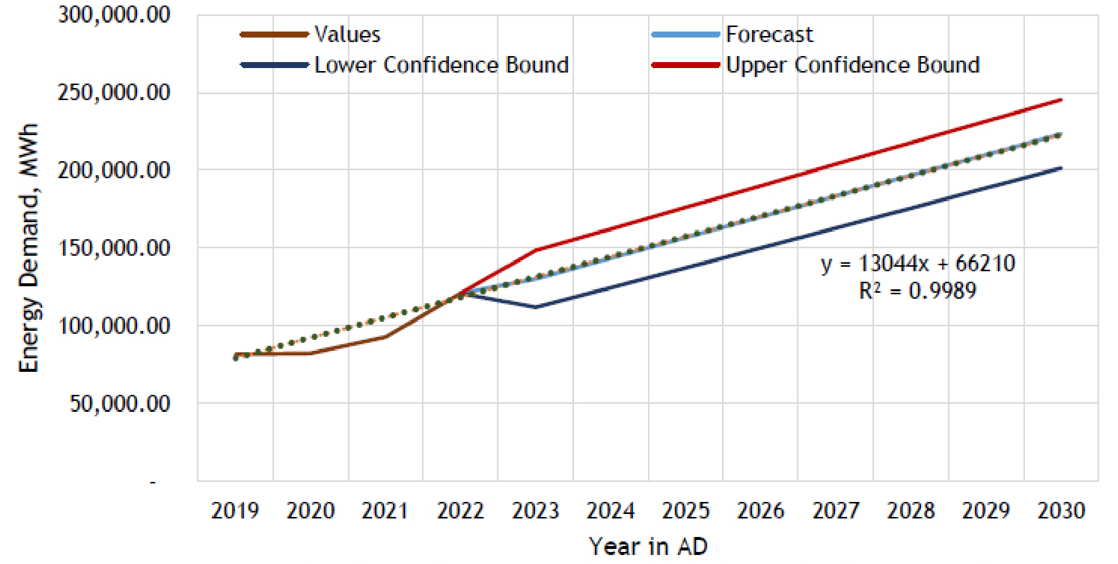


Figure 21: Forecasted energy for Surkhet till 2030

Jumla distribution centre lies in the hilly region and serves Jumla district where the INPS is recently approaching. Surkhet distribution center feeds the Birendranagar, capital city of Karnali province. Figure 20 and Figure 21 depict the forecast from Jumla DC and Surkhet DC respectively.

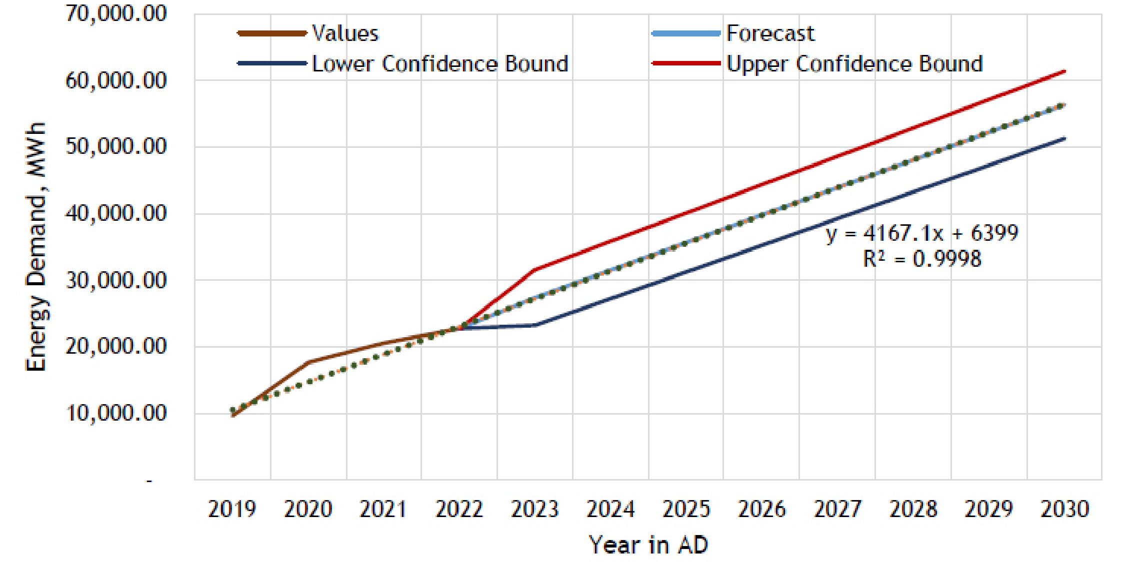
3.2.1.3 Energy demand forecast for selected substations in Sudurpashchim

In case of Sudurpashchim province, energy forecast is observed for load centres in Kanchanpur (Belauri) and Kailali (Dhangadi) district. The energy demand is estimated with the r^2 value of 0.9989 and 0.9998 for Dhangadi and Belauri distribution centres respectively.



Energy demand at Dhangadi is forecasted as 223.4 GWh in 2030 with upper confidence bound of 201.4 GWh and lower confidence bound of 245.4 GWh.

Figure 22: Forecasted Energy for Dhangadi till 2030



Energy demand at Belauri is forecasted as 56.32 GWh in 2030 with upper confidence bound of 61.35 GWh and lower confidence bound of 56.32 GWh.

Figure 23: Forecasted energy for Belauri DC till 2030

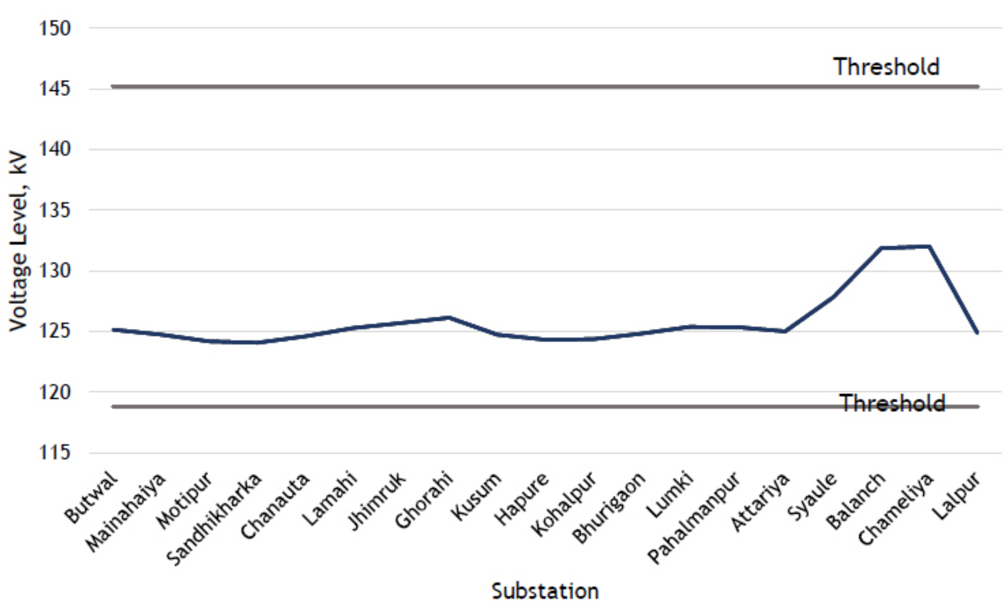
3.2.2 Load Flow Analysis of existing system

Load-flow study, is a numerical analysis of the flow of electric power in an interconnected system which focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyses the power systems in normal steady-state operation. Load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power-flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line.

A steady state load flow analysis has been performed to assess the present condition of the power network during peak load period. The loads of the substation have been derived from the peak loading of the transformers. The outcomes of the load flow simulations are discussed in the following sections.

3.2.3 Voltage Profile and Line Loading of Existing 132 kV Transmission Lines

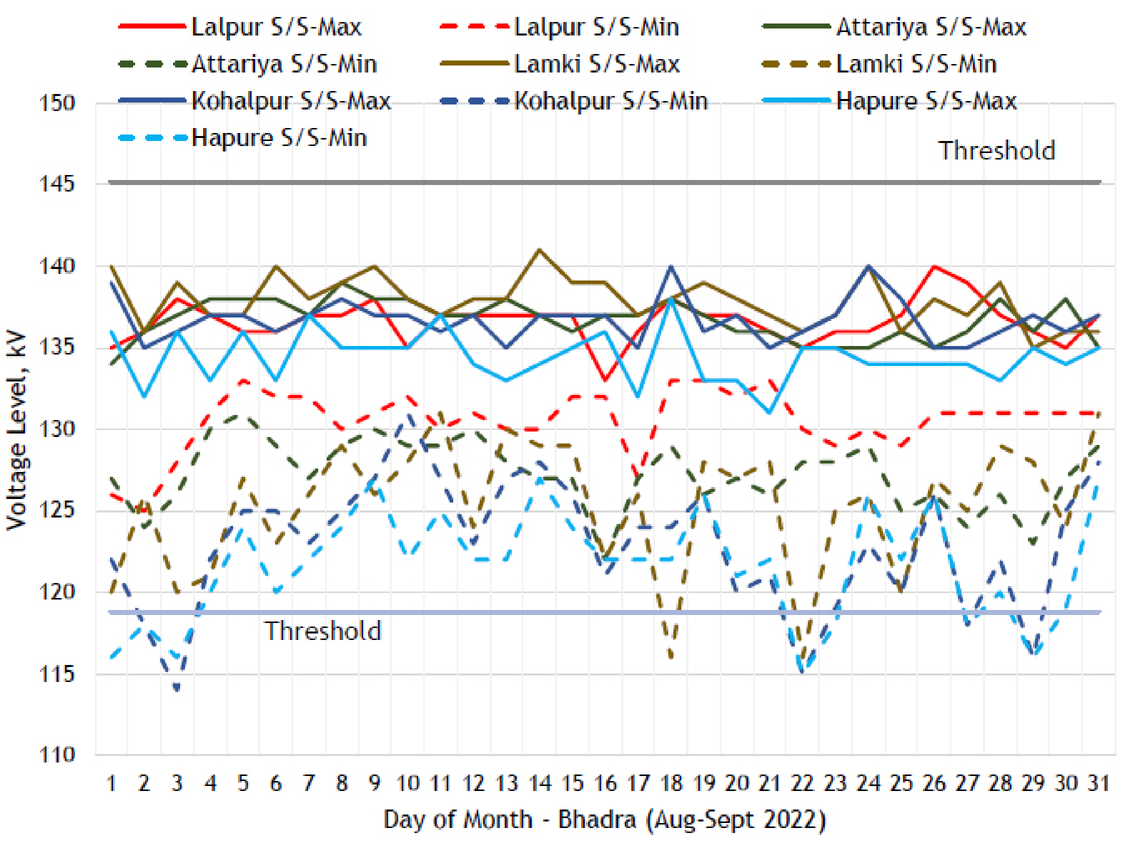
The voltage profile of the transmission line obtained from the simulation for INPS West for a typical operation case at different substations is presented in Figure 24. The voltages at the 132 kV substations are towards the lower side but are within the permissible limit set forth by the grid code i.e., ±10%. At the higher voltage levels, the voltage is typically managed using reactive power compensation approach.



Simulated voltage profile of 132 kV substations, west of Butwal lies within the threshold of ±10% of 132 kV.

Figure 24: Bus voltages of 132 kV substations in INPS west

The maximum and minimum voltage levels at different substations for the month of Aug.- Sep., 2022 as per actual loading is presented in Figure 25 which shows that the voltage level is found within the permissible limits except in few cases. Such cases are observed mainly at two substations e.g., Kohalpur and Hapure. Kohalpur substation is fed from both east and west side of the grid. Hapure is also the last substation fed from Kusum. The actual line loading of the 132 kV transmission line west of Butwal indicates that it is within the permissible limit.



Voltage profile of 132 kV substations, deviate from ±10% of 132 kV when loaded heavily.

Figure 25: Limit voltages in substations in INPS West for the month of Aug-Sept 2022

3.2.4 Line Loadings of the Existing 33 kV Sub-transmission Lines

Line loadings is the major performance indicators for the successful operation of the distribution system. An extensive study of the line loadings at 33 kV level was carried out by Loss Reduction Master Plan (LRMP) Study of NEA.

LRMP, 2021/22 specifies the loading conditions of 33 kV transmission lines in Lumbini Province. The study indicates that the majority of the line sections have loadings above 80% of the rated value. Some of the line sections have are overloaded, some have loadings between 90% and 100%, some have loadings between 80% and 90% and remaining lines have normal loadings. Chandrauta -Jeetpur-Taulihawa Tapping section and Yogikuti Grid – Palpa Cement Tapping are overloaded. However, with the commissioning of Mainihawa and Motipur 132 kV substations, the situation has been improved.

LRMP findings specify that in Karnali Province, two out of 17 major line sections are overloaded. The 11.49 km Kohalpur Grid - Nepalgunj Medical College have the maximum loading of 132.80%. Similarly, the section from Nepalgunj Medical College and Bheri Diversion Tapping with sectional length of 10.28km have 125.62% loading. The loadings of the rest of the lines fall in the normal range. The present load flow study also provides similar results. The situation will not improve before commissioning of Kohalpur-Surkhet 132 kV transmission line and Surkhet 132 kV Surkhet substation which is under construction presently.

Under Sudurpaschim Province, Attariya – Dhangadhi 33 kV line section is loaded at 81.34% of the maximum loading capacity while loading of remaining line sections are below maximum loading capacity (LRMP, 2022). In the present study, it is found that Attariya – Dhangadhi line section is overloaded to 109.38%. To overcome the situation, it is planned to construct another 33 kV line between Attariya and Dhangadhi. In the long run it is planned to extend 132 kV transmission line from Attariya to Dhangadhi to meet the growing load of Dhangadhi and nearby Kanchanpur areas.

3.2.5 Voltages in 33 kV Buses

Voltage level is one of the key indicators of the distribution system performances. Voltage level of different 33 kV substations beyond Butwal are discussed in this section. As per the Gird Code, the lowest permissible voltage during emergency condition is 90% of the rated value which is around 29.7 kV but the simulation has showed the voltage dropping to beyond 20 kV. Such extreme conditions are seen for the substation which are far from 132 kV grid substations and are connected by extremely long 33 kV lines or are heavily loaded without reactive power compensation.

The voltage situations of 33 kV substations in Butwal, Bhairahawa, Kapilvastu and Sandhikharka area as indicated in Figure 25 has improved with the commissioning of new 132 kV substations. Voltage drop still exists in Taulihawa, Bhairahawa and Palpa 33 kV substations due to long line and load at the tail end.

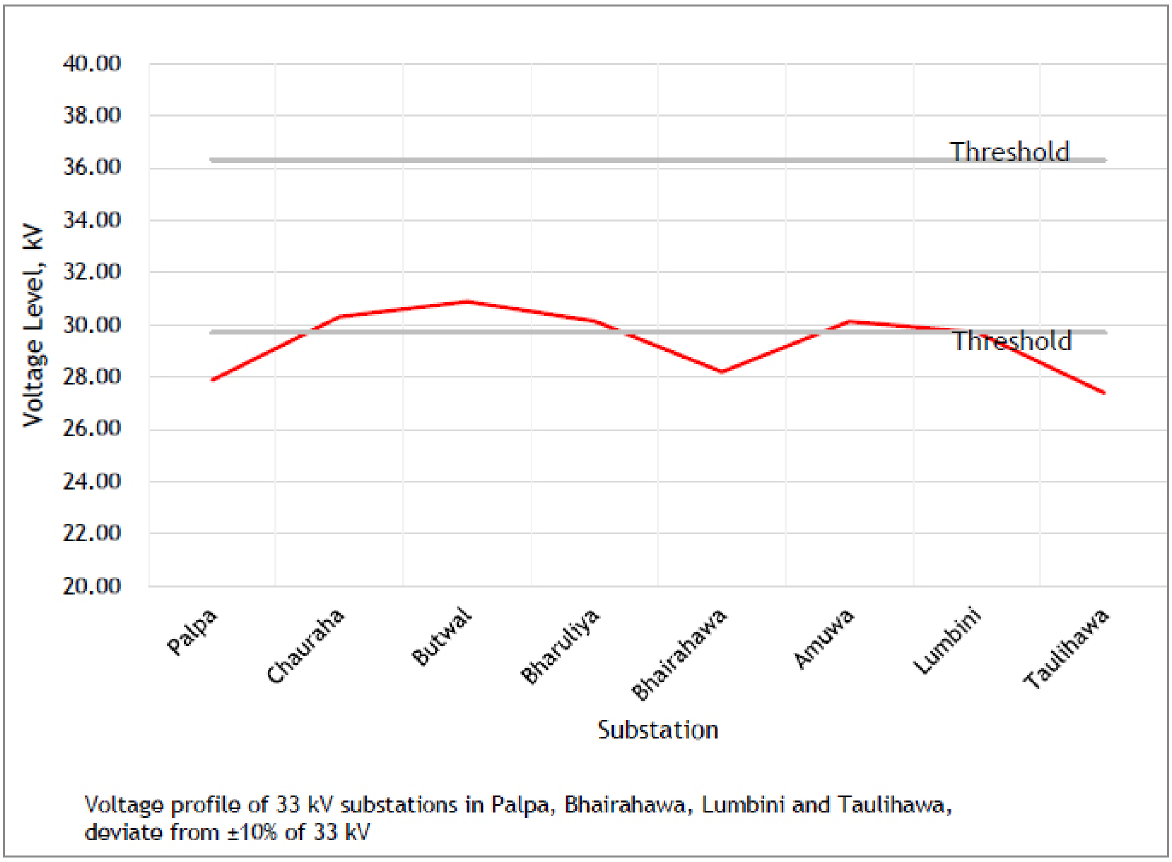
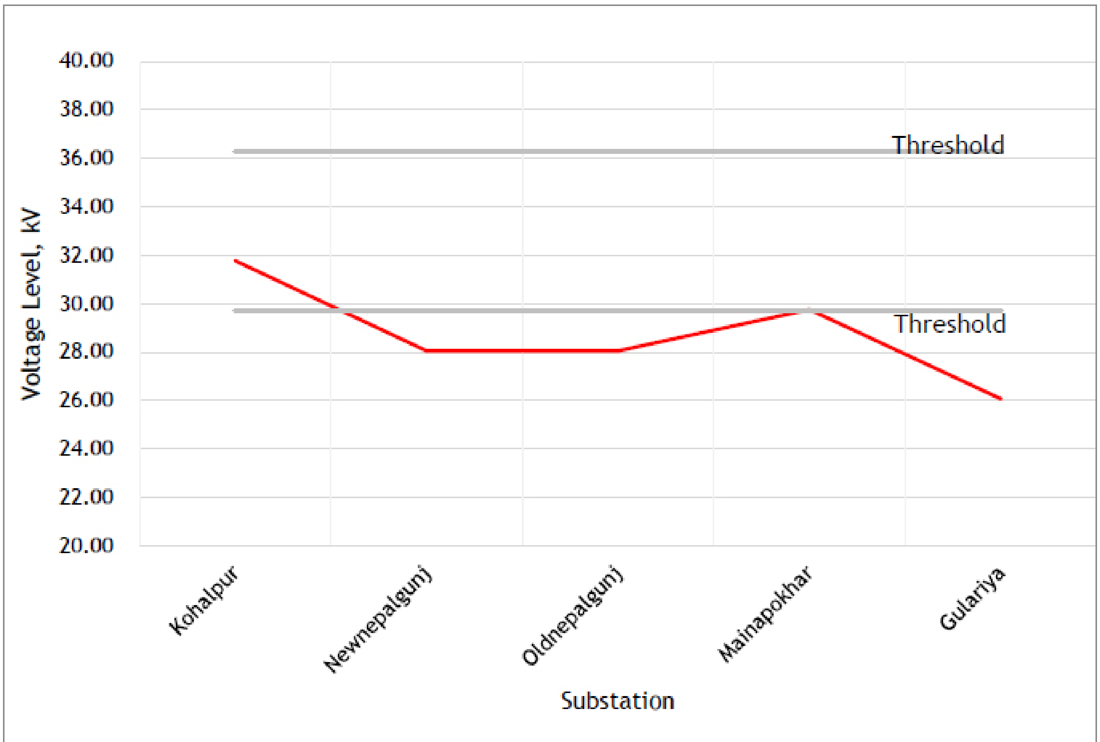
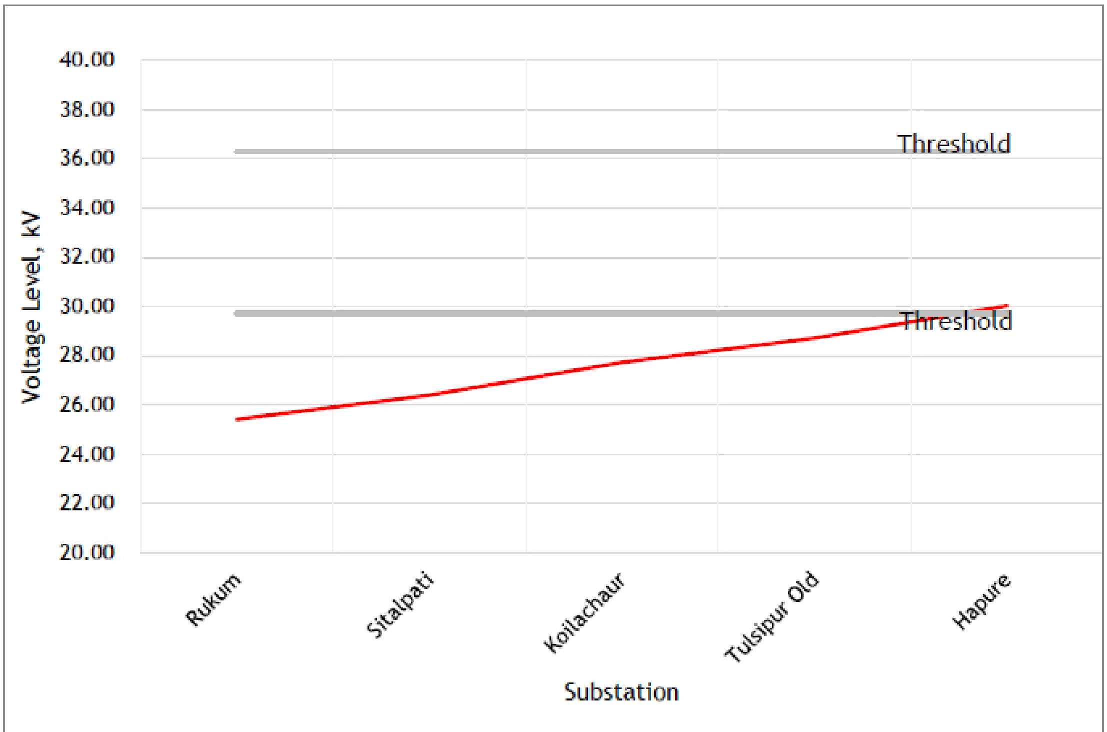


Figure 26: Voltages levels at different substations of Butwal-Bhairahawa-Taulihawa Section in Lumbini Province



Voltage profile of 33 kV substations of Newnepalgunj, Oldnepalgunj and Gulariya, deviate from ±10% of 33 kV

Figure 27: Voltage profile of 33 kV substations in western part of Lumbini Province



Voltage profile of 33 kV substations other than Hapure, deviate from ±10% of 33 kV

Figure 28: Voltage profile of 33 kV substations in northern side of Lumbini Province

All the 33 kV substations in Karnali Province are fed from Kohalpur grid substation via 33 kV line. e.g., Jajarkot, Rakam, Surkhet, Ramghat S/S have lower voltage as indicated in Figure 29. The voltage at substations beyond Surkhet are within the limit due to two small hydro power plants connected at Dailekh substation. Absence of power from small hydro plants will worsen the voltage profile. The actual voltage profile of Ramghat and Budbudi substation is provided in Figure 30 and Figure 31 respectively for reference.

The voltages recorded for Budbudi substation shows a very erratic pattern which can be considered normal for a distribution substation in Nepal. The voltage has started to drop as the load approaches morning peak and remains fluctuating within a small range till the evening peak. During the evening peak, the voltage should have dipped but it has spiked. Voltage variation could be attributed to loss of synchronization of small hydropower plants, switching on off loads on 33 kV line (line length is around 250 km).

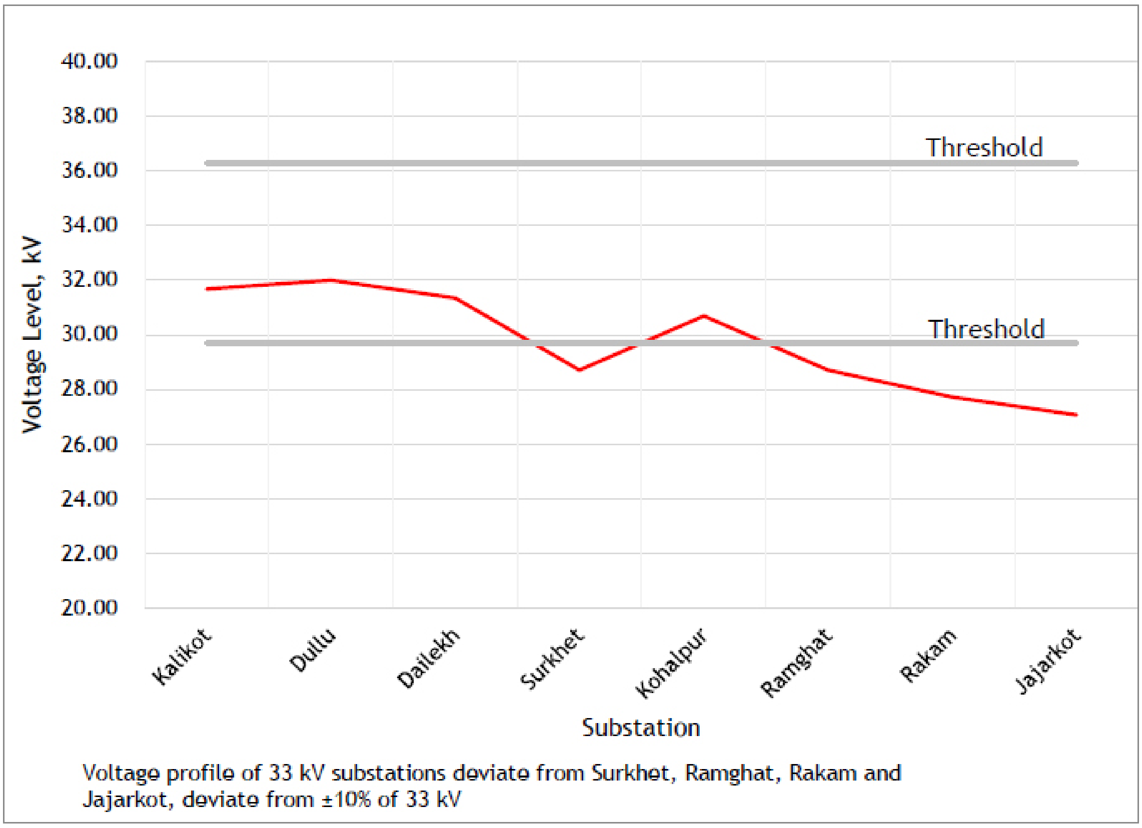
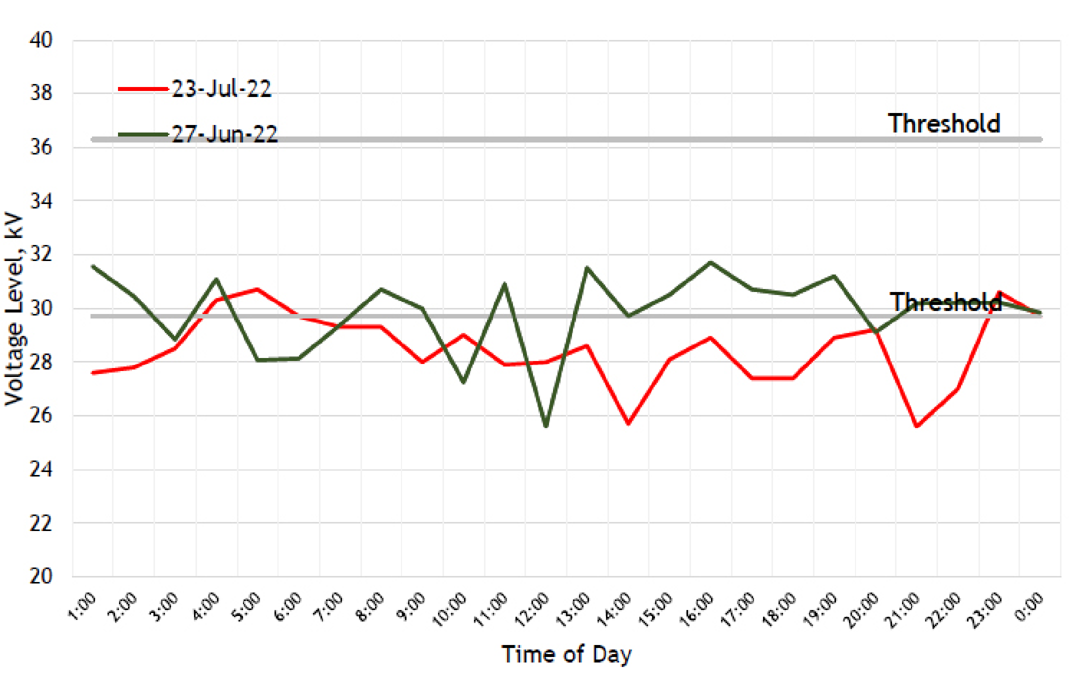
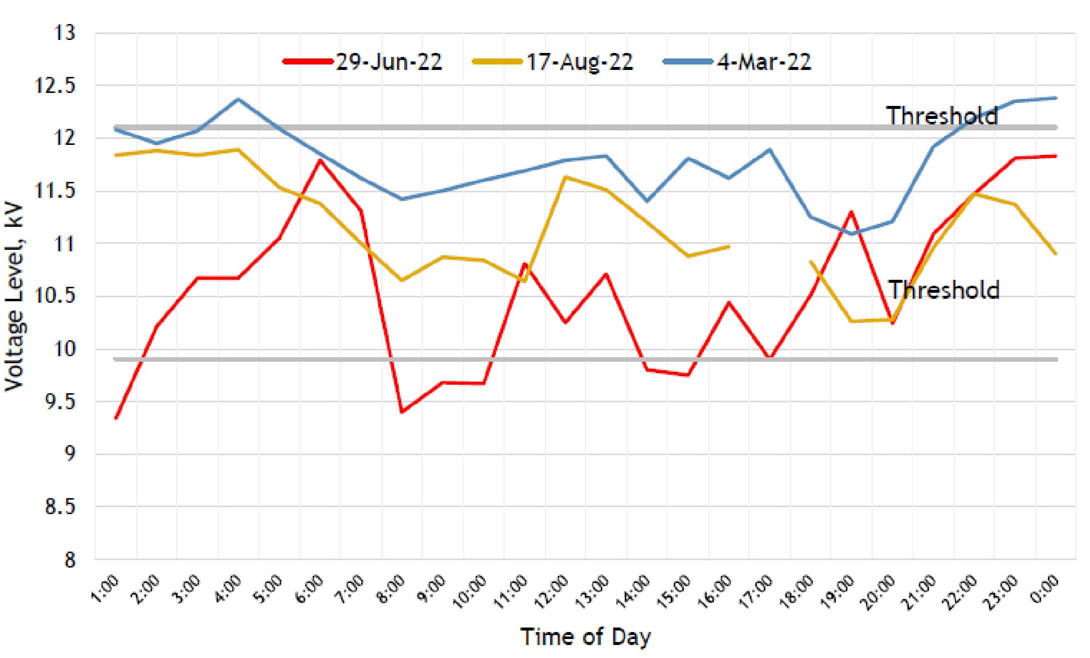


Figure 29: Voltage profile of 33 kV substations in Karnali Province



Voltage profile of Ramghat substation, deviate from ±10% of 33 kV due to long line fed from Kohalpur substation

Figure 30: Actual voltage profile of Ramghat Substation



Voltage profile of 33 kV Budbudi substation (Surkhet), deviate from ±10% of 11 kV

Figure 31: Actual voltage profile of Budbudi Substation (Surkhet) at 33kV

In Sudurpaschim Province, voltage drop problem exists at Rajapur, Dhangadhi, Jhalari and Belauri area as indicated in Figure 32, Figure 33, Figure 34 and Figure 35.This is attributed to large loads supplied at long distance.

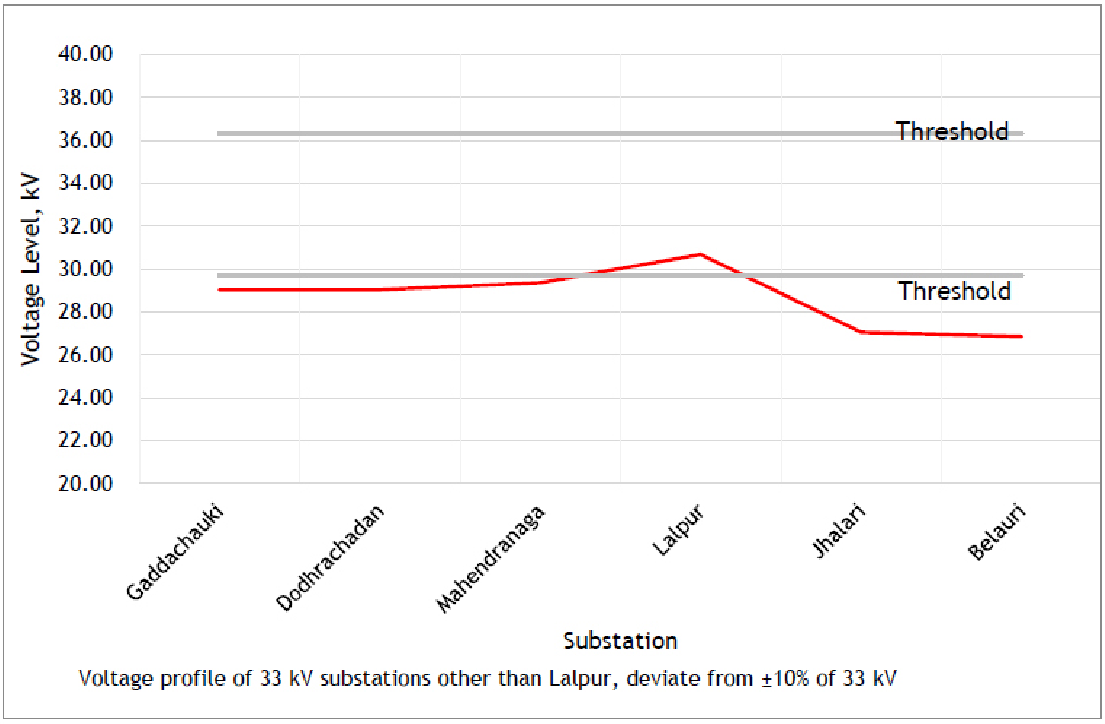


Figure 32: 33 kV voltage profile of substations fed from Lalpur 132 kV substation

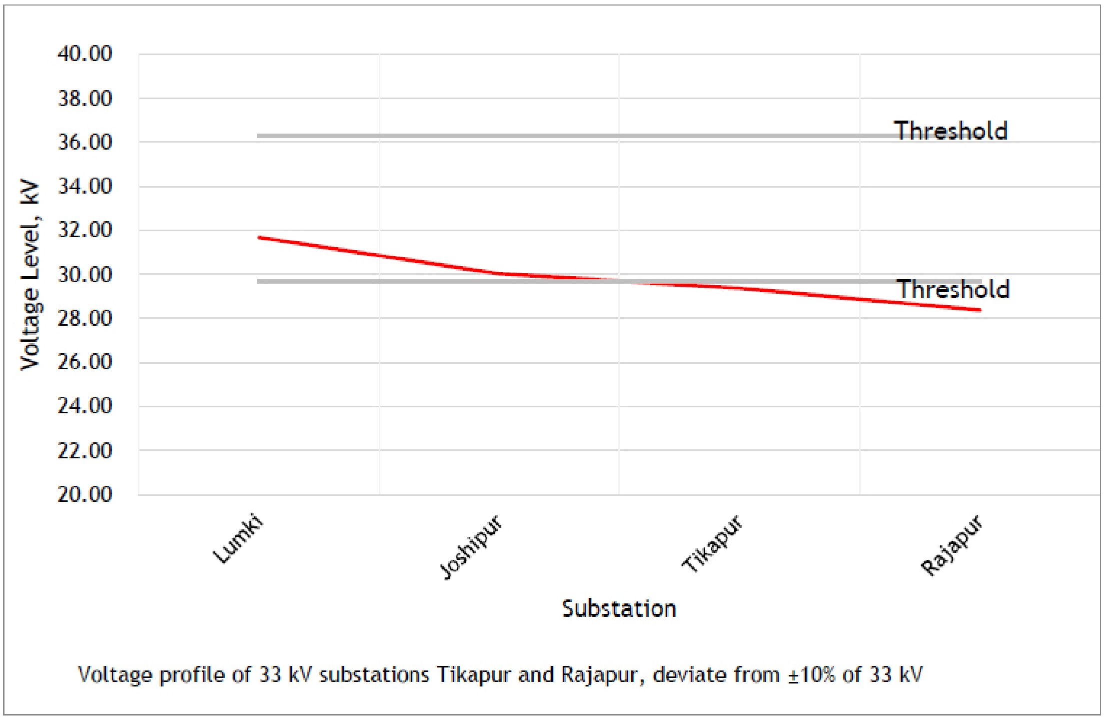


Figure 33: 33 kV voltage profile of substations fed from Lumki 132 kV substation

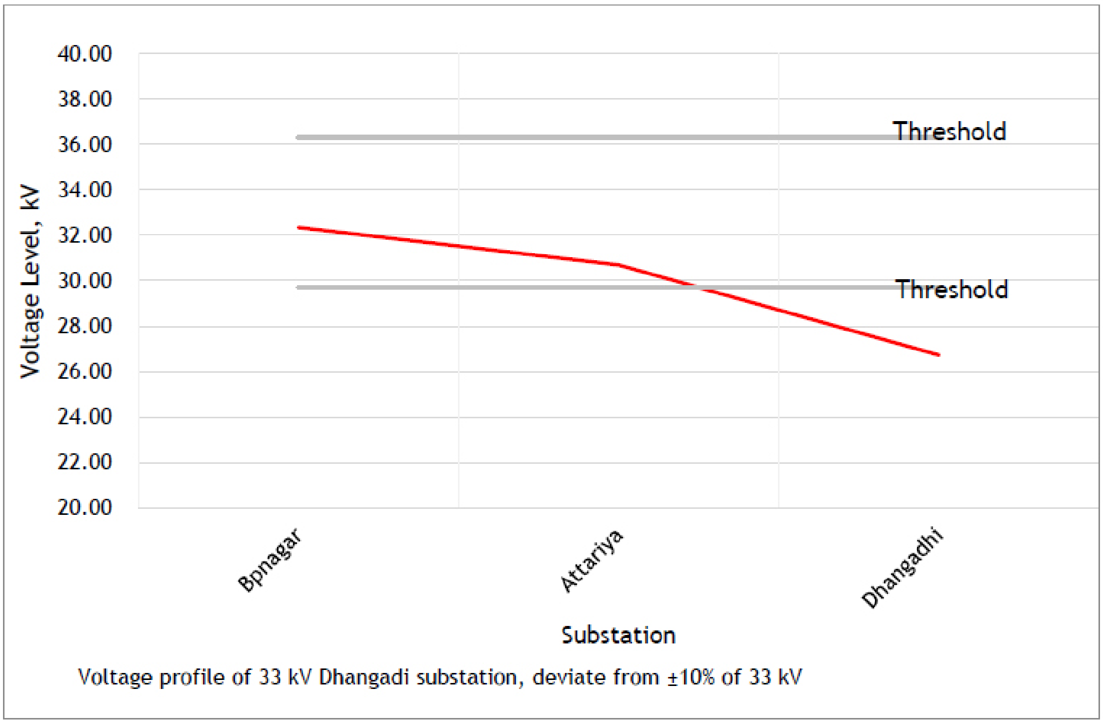


Figure 34: 33 kV voltage profile of substations fed from Attariya 132 kV substation

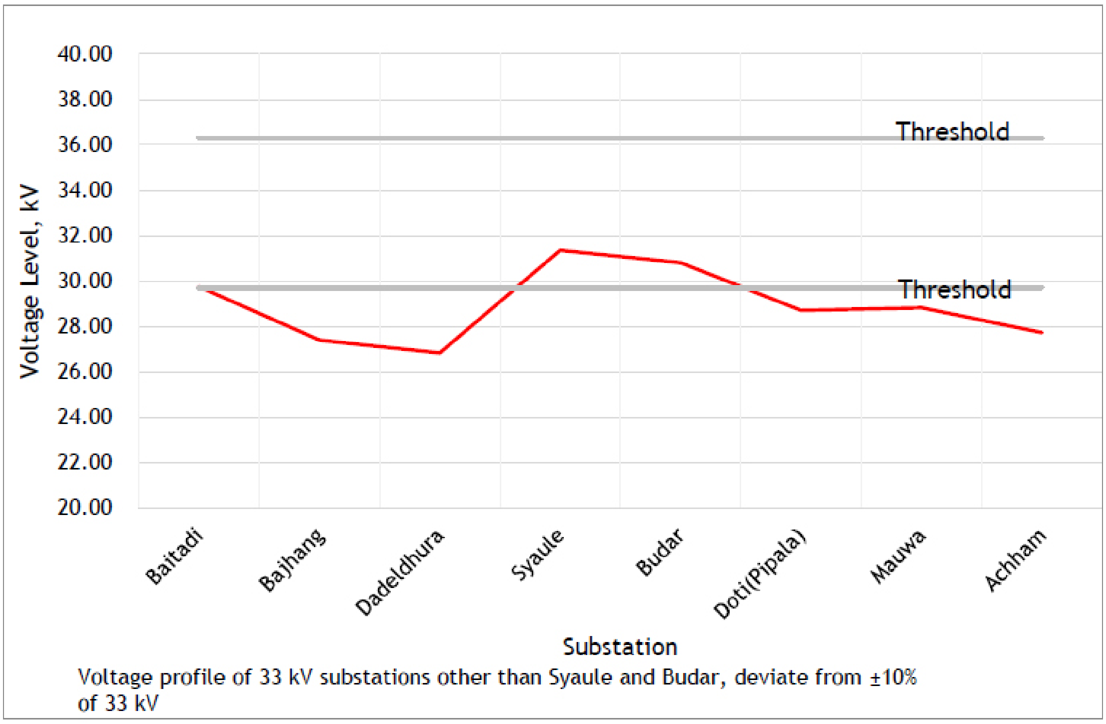


Figure 35: Voltage profile of 33 kV substations in northern region of Sudurpashchim Province

3.2.6 Assessment of the Losses at Transmission and Distribution System

Losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users. Total losses have two components: technical and non-technical.

Technical losses occur naturally and consist mainly of power dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems as depicted in Figure 36. Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and record-keeping.

NEA has recently prepared Loss Reduction Master Plan in which detailed analysis of distribution system losses is prepared and also the distribution system reinforcement plan is prepared for reduction of losses. Figure 37 presents component wise distribution losses of Lumbini, Karnali and Sudurpaschim Provinces.

Energy meters are installed in all the feeders in the NEA's substations which will record the amount of energy consumed or transmitted. Energy input to each substation and energy output from the substation along with self-consumption of the substation is all recorded from where the energy loss in the transmission line and substation could be calculated. In new high voltage substations, substation automation system (SAS) is used where the substation load details like voltage, current, energy, power factor, MW, MVARH etc. are recorded on hourly basis. Substation automation project is implemented in older substations also to make the data recording in substations automatic. As far as distribution line is considered, the energy consumption of each feeder and consumer is recorded. If the consumer could be categorized as per the feeder and transformer, distribution loss could also be calculated. However, energy meter has to be installed in each distribution transformer for this. Moreover, NEA is also preparing the GIS based record of distribution system. When GIS based distribution system data is linked with the consumer billing system data, calculation of feeder wise and distribution transformer loss calculation could be carried out.

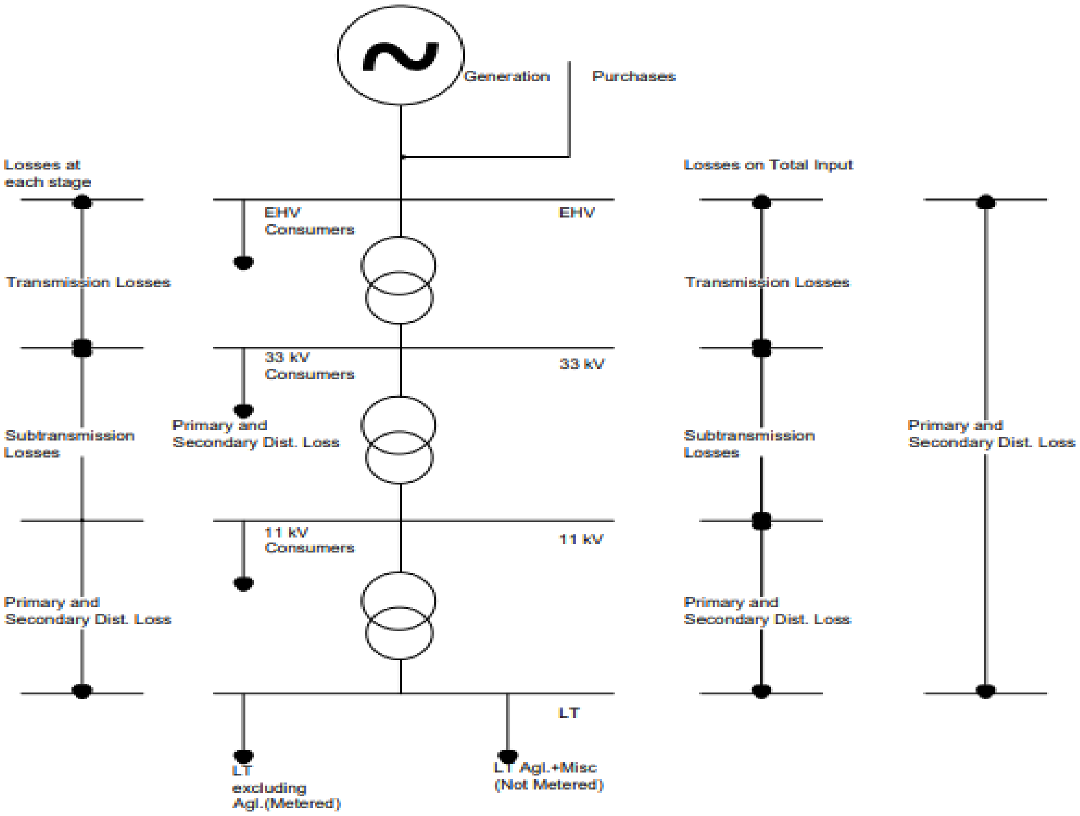
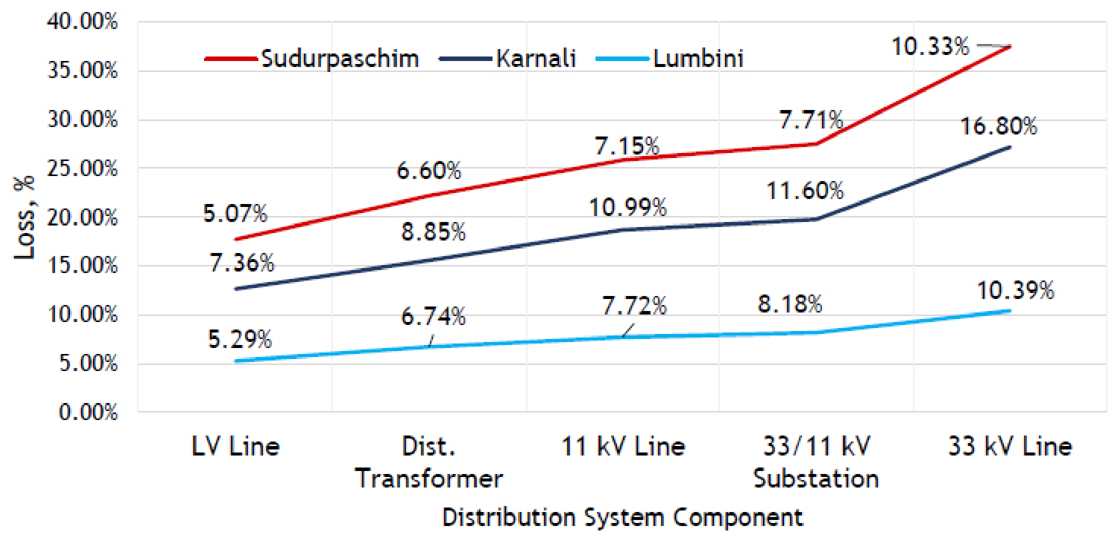


Figure 36: Losses in power system



Percentage losses are highest in Karnali province in distribution network at 19.15%, whereas those of Lumbini and Sudurpashchim provinces are 16.97% and 13.73% respectively. These values are on higher side of the national average of %.

Figure 37: Distribution System losses up to the component level, starting from LV line, in Lumbini, Karnali and Sudurpashchim Provinces (Source: LRMP)

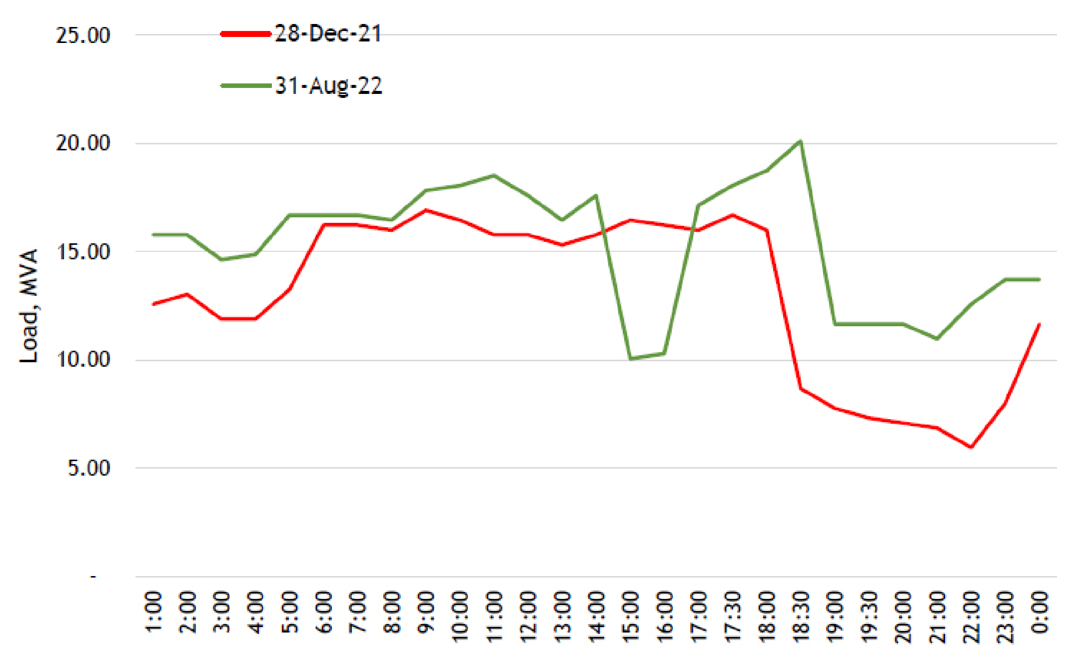
3.2.7 Load Profile in INPS West

The daily load curve of INPS shows evening peak which is prominent and morning peak at reduced level (NEA 2022). The sharp peak in the evening is attributed to load due to lighting and appliance load. The morning peak is attributed mainly to lighting and cooking. The load is normal at day time and it is very low during night. Due to sharp increase in load at evening time, the utility has to manage large capacity for short time in the evening while the plant will be idle for most of the time. In the absence of adequate storage type of power plant, the utility is facing difficulty in managing the peak load. Since storage, projects are costly with long gestation period, combination of solar and PROR projects help alleviate this sort of problem.

During evening time, the generation from the solar ceases to zero. Thus, the solar power plant can have significant contribution to generation during off peak time and has no direct contribution during the peak time. The indirect contribution from solar would be in assisting in operation of peaking run off river based hydro power plant. During the day time, peaking plant can store water to be used during the peak period.

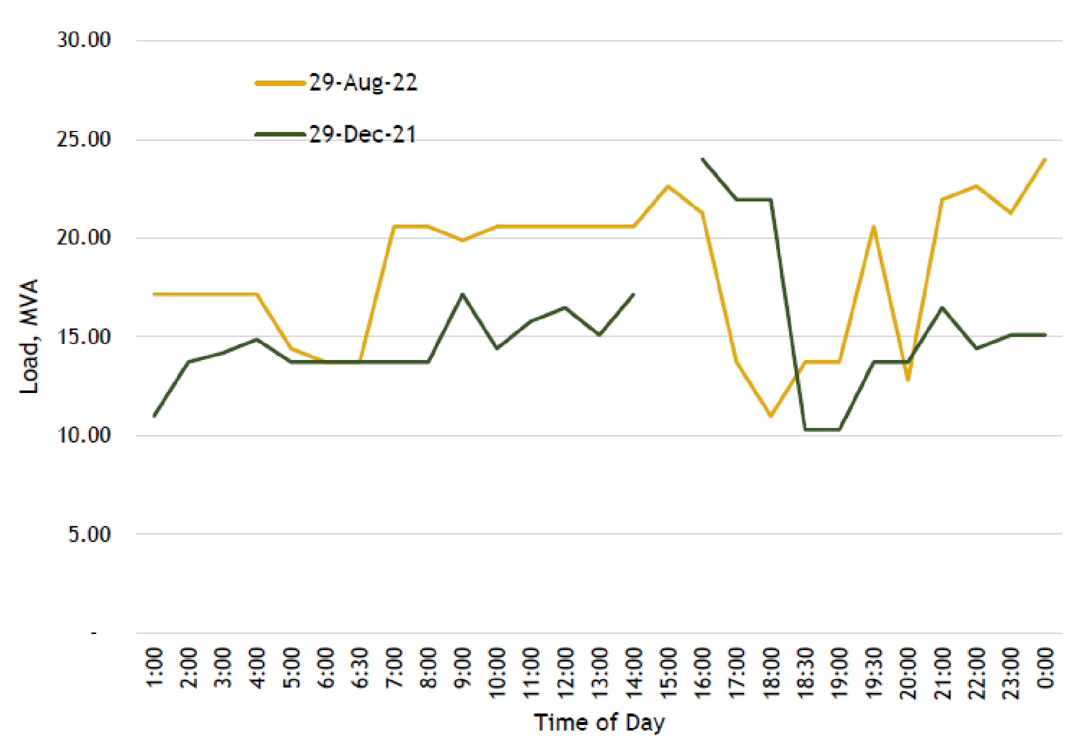
The effect of integrating solar power plants on voltage and frequency stability have been investigated into the hydro dominated power system of Nepal (Ravi et al). The study has shown stable nature of voltage and frequency for solar power plant near to hydro power station while those away from the hydro station and near to load centre can exhibit oscillatory nature when disconnected from the system. Load Profile of major 132 kV Substations in INPS West are shown in Figure 38 to Figure 44. From the substation load profiles, it could be observed that:

- System peak in Terai occurs during summer season while the reverse is true in hill areas;
- Load pattern is different in summer and winter;
- Winter load is significantly lower than the summer load in Terai region;
- Solar PV plants could be installed at Chanauta, Lamahi and Kohalpur substations with large industrial load.



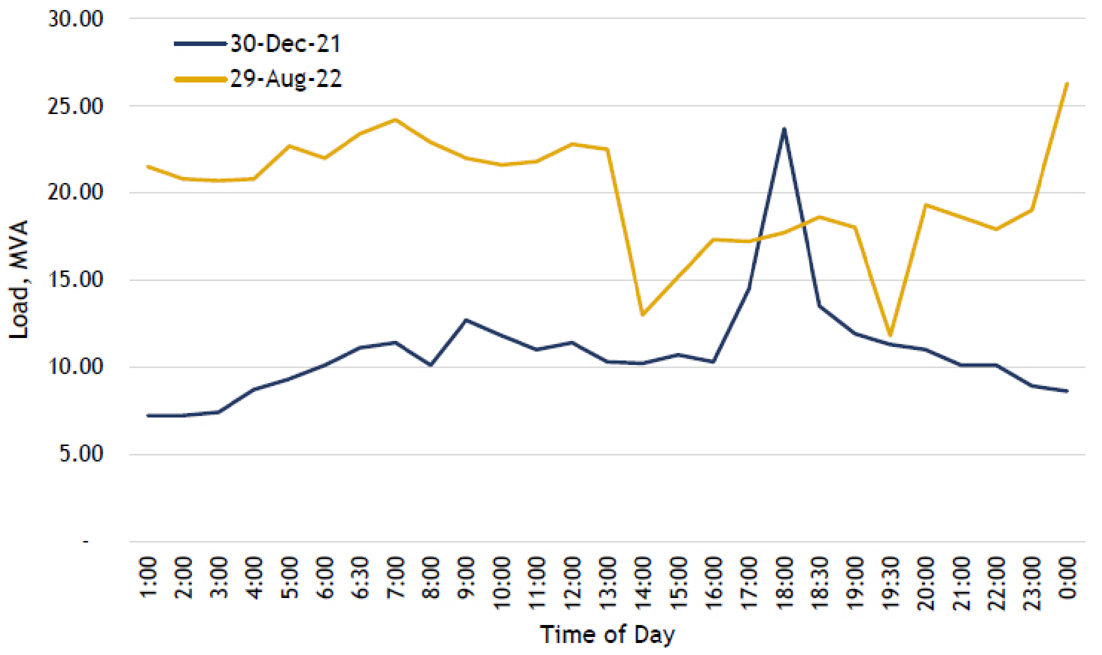
The load curve of Chanauta substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 38: Load Profile of Chanauta 132 kV Substation



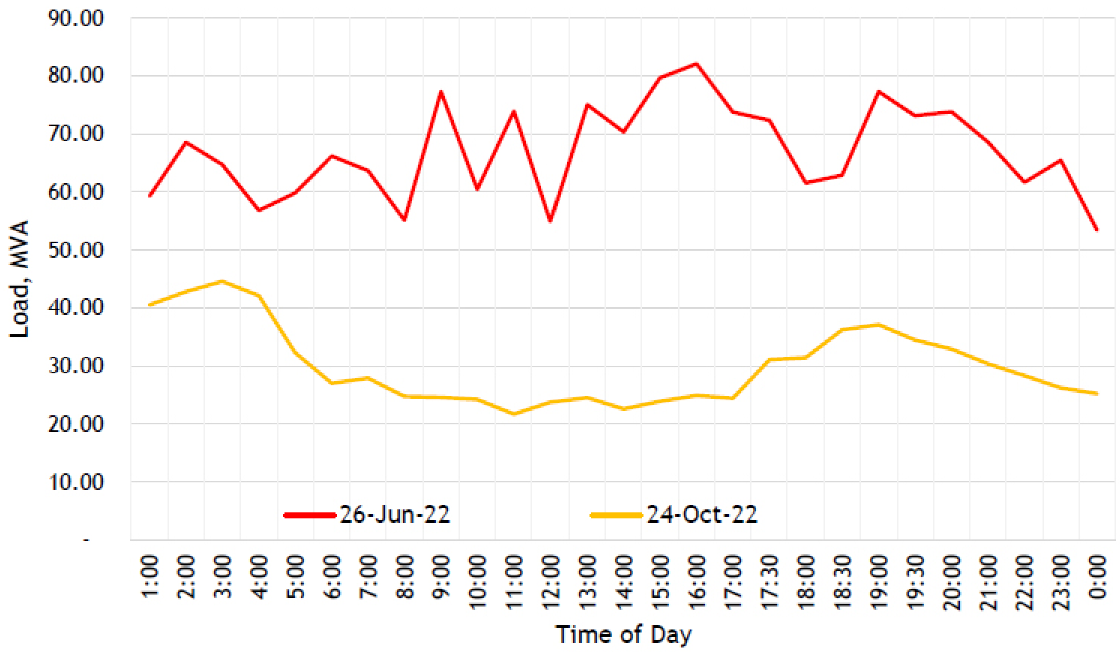
The load curve of Lamahi substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 39: Load Profile of Lamahi 132 kV Substation



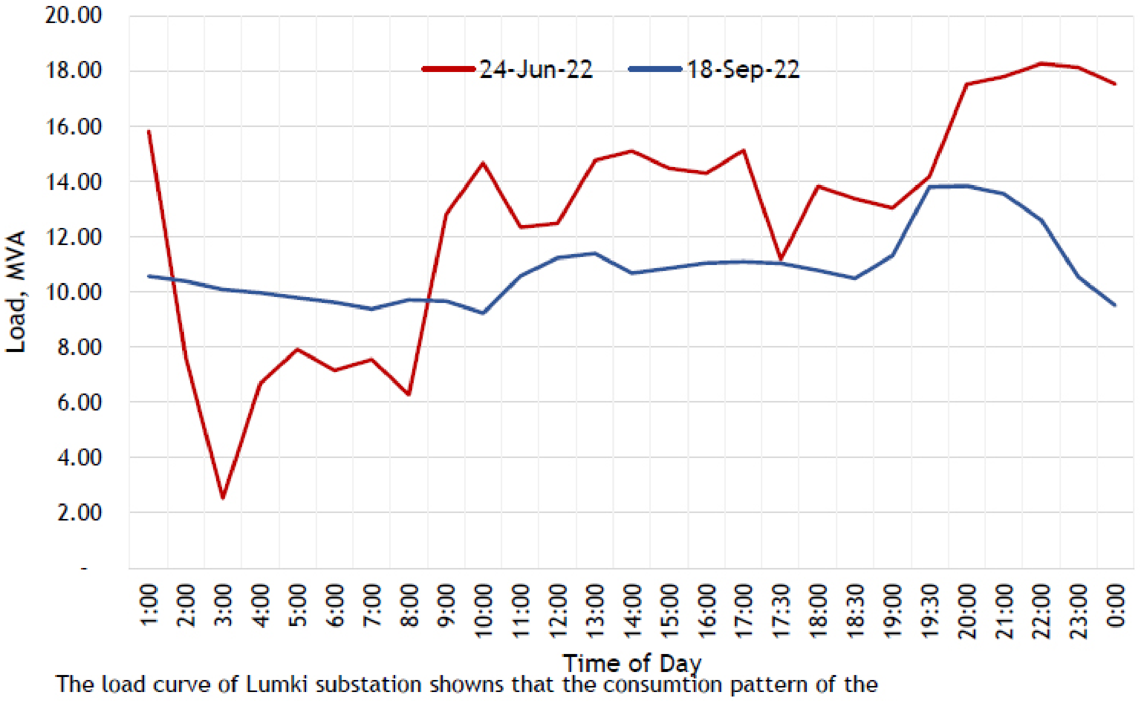
The load curve of Ghoraho substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 40: Load Profile of Ghorahi 132 kV Substation



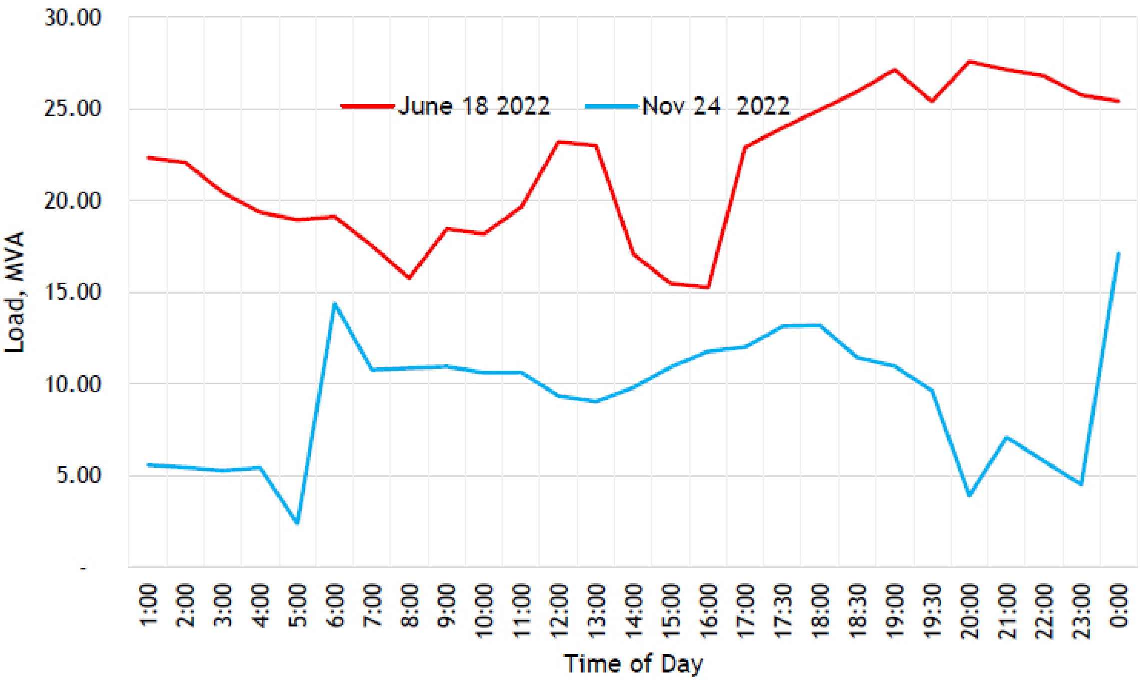
The load curve of Kohalpur substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 41: Load Profile of Kohalpur 132kV Substation



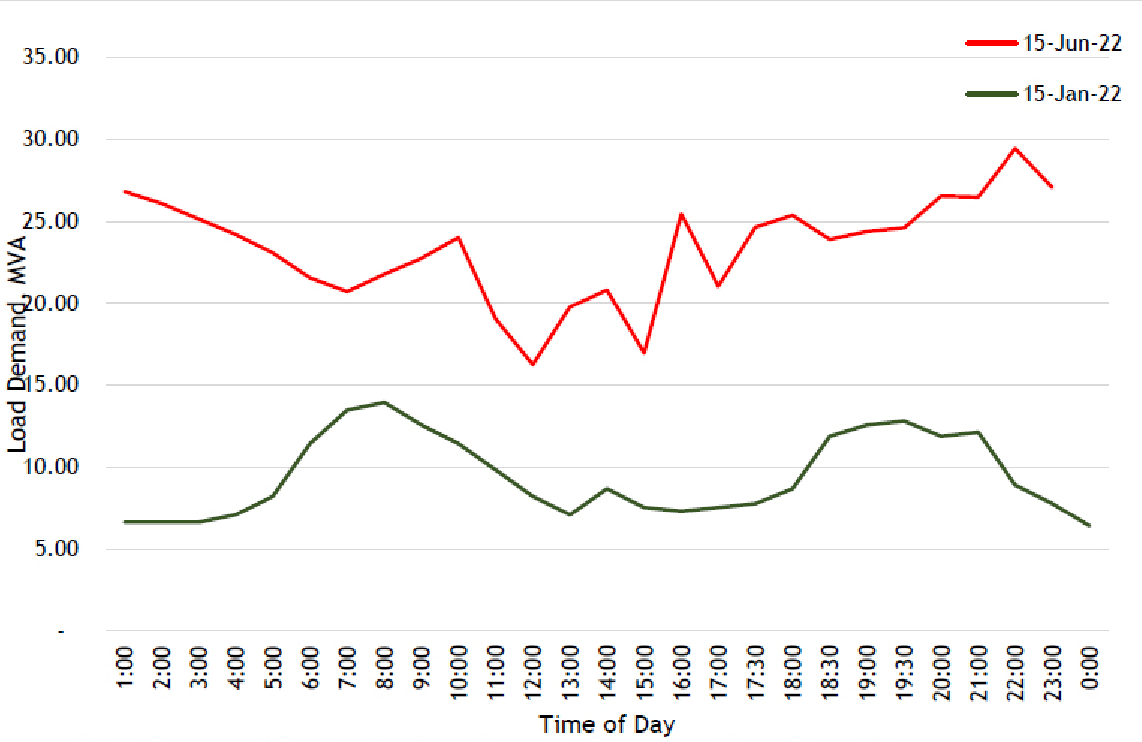
The load curve of Lumki substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 42: Load Profile of Lumki 132 kV Substation



The load curve of Lalpur substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

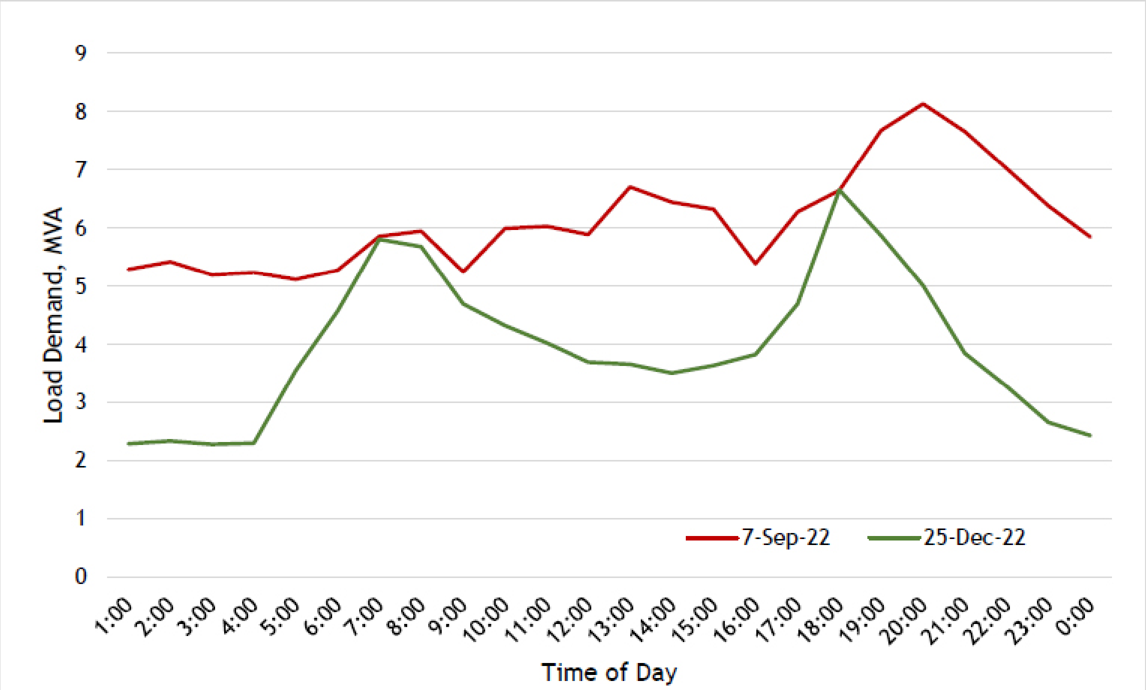
Figure 43: Load Profile of Lalpur 132 kV Substation



The load curve of Attariya substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

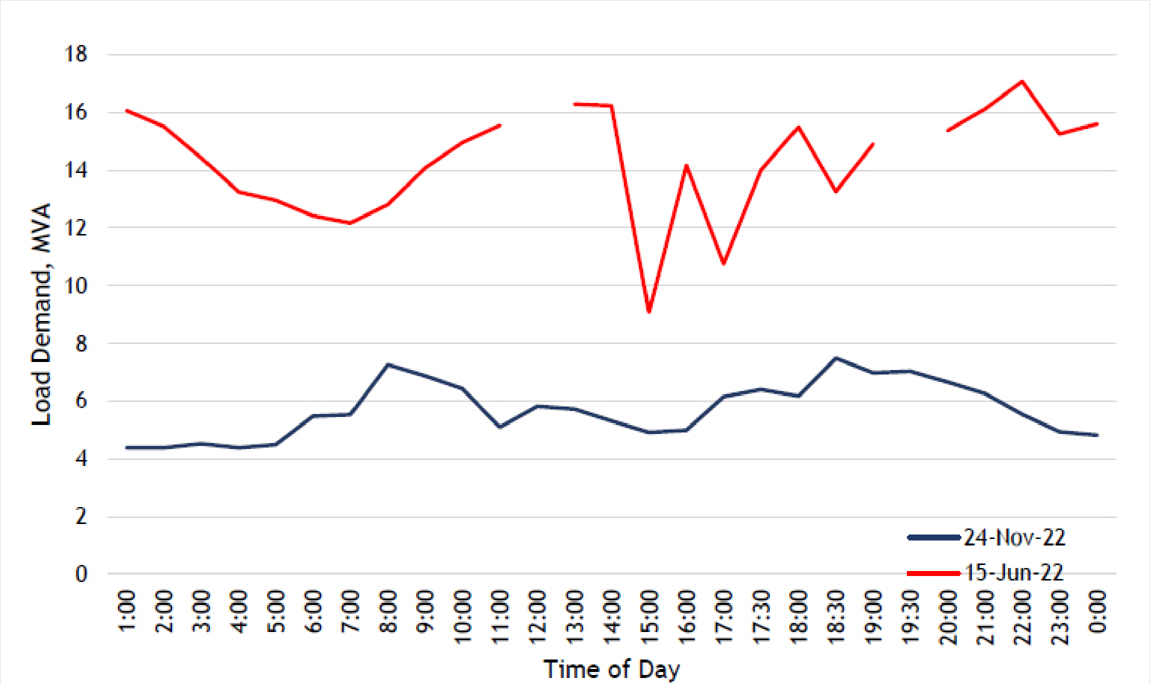
Figure 44: Load Profile of Attariya 132 kV Substation

Figure 45 to Figure 47 present the load profile of 33 kV substations.



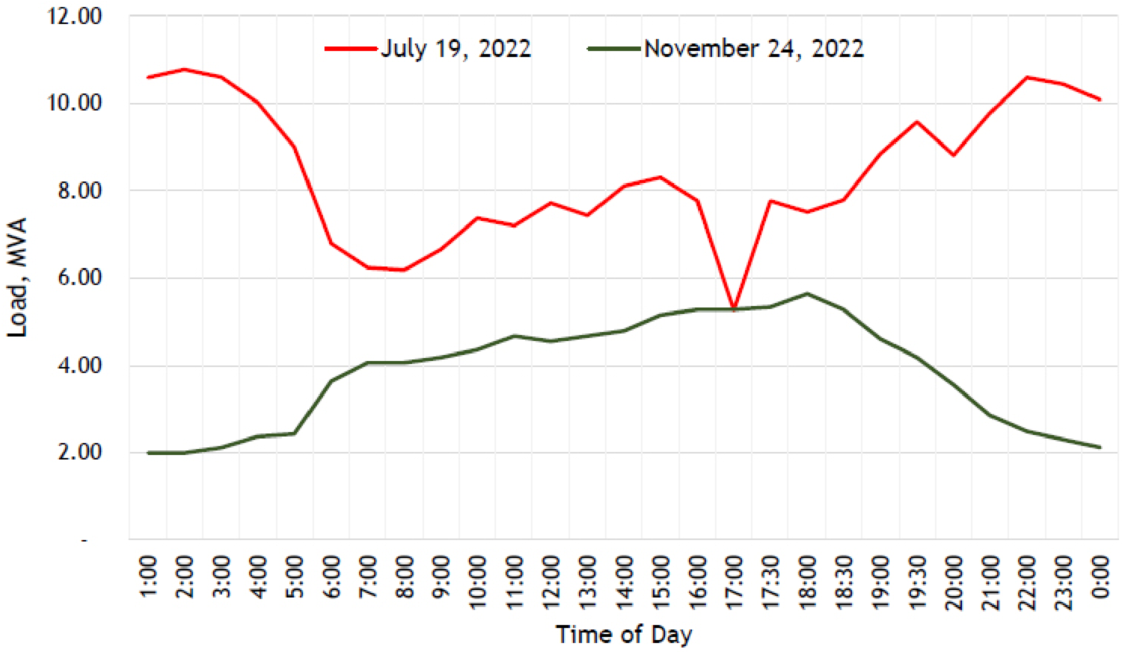
The load curve of Surkhet substation showns that the consumtion pattern is dominted by residental load and is dependent on season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 45: Load Profile of Budbudi (Surkhet) 33 kV Substation



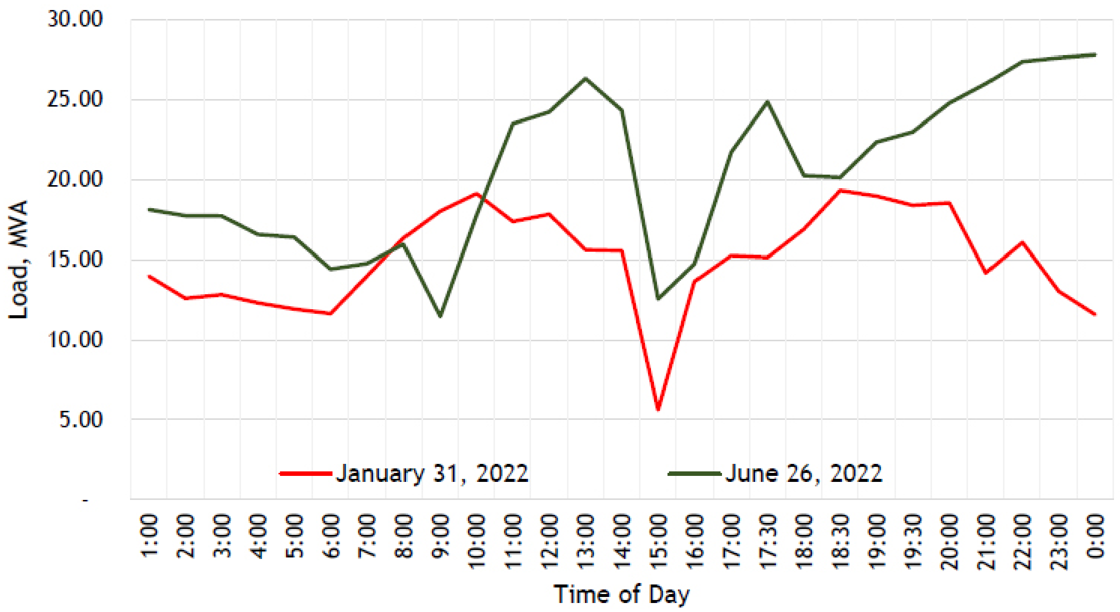
The load curve of Attariya substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load (The break in the curve is due

Figure 46: Load Profile of Dhangadhi 33 kV Feeder at Attariya Substation



The load curve of Lalpur substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 47: Load Profile of 33 kV Jhalari Feeder at Lalpur Substation



The load curve of Nepalgunj substation showns that the consumtion pattern of the consumers is highly dependent on the season. Since the area experience higher temperature during summer, the load is dominated by cooling load.

Figure 48: Load curve of 33 kV Nepalgunj Feeder Kohalpur Substation

From the load patterns of 33 kV substations depicted in Figures 45 to 48, it is observed that the load is higher during winter in hilly areas while the opposite is true in the Terai area. Load profile has large peak in the evening for 2/3 hours and smaller peak in the morning. Attariya-Dhangadhi line is overloaded and voltage drop exists at Surkhet, Rajapur, Belauri areas due to long sub-transmission line and load at the tail end. Battery storage system could be installed at these substations to alleviate the present overloading problem.

The Surkhet substation is supplied from Kohalpur 132 kV S/S. The load curve indicates more frequent line outages during rainy season due to long line passing through forest areas. It is observed that after restoration of supply, the demand surges which is attributed to large number of batteries installed in the households. Two small hydro power plants connected at Dailekh substation help improve the voltage situation of the area whenever supply is available. Installation of solar photo voltaic with storage system will help improve the supply situation in the area.

4 DISTRIBUTED ENERGY RESOURCES AND GRID

Distributed renewable energy (DRE) technologies refer to the inclusion of generators onto the existing power system network particularly at points closer to the load. These generators can be powered by various renewable energy sources. DRE incorporates a wide range of renewable technologies including solar power, wind turbines, geothermal, hydro, biogas, energy storage and ocean thermal energy conversion systems. DRE has also the potential to mitigate congestion in transmission lines, reduce the impact of electricity price fluctuations, strengthen energy security and provide greater stability to the electricity grid. As a stand-alone system, renewable energy-based power plants often require a backup energy generator and a backup energy storage system due to the intermittent and unexpected nature of its availability. The former is utilized to facilitate the provision of electricity when the renewable energy source is not available, and the latter is a means to store excess electricity generated by DREs. This chapter first describes the various kind of DREs, followed by the Energy Storage Technologies and discusses their impact on the grid.

4.1 Distributed Energy Technologies

By connecting a renewable energy system to an existing power grid, it is possible to bypass the need of additional components such as generators and battery systems, as the grid now acts as a backup power generator by providing electricity during downtime and by accepting excess electricity generated during surplus availability. DRE technologies are presented in Figure 49 and are discussed in the following sections.

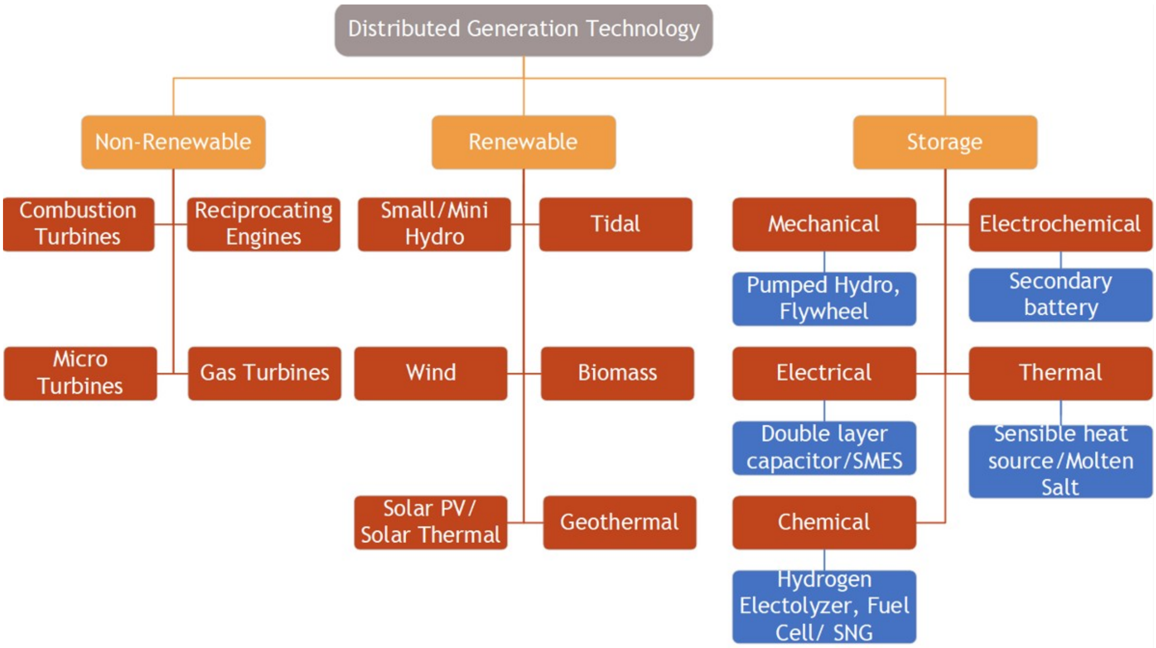


Figure 49: Distributed Generation Technologies with storage system

4.1.1 Solar

Nepal gets most of its electricity from hydropower sources, but it is looking to expand the role of solar power in its energy mix. The average global solar radiation in Nepal varies from 3.6-6.2 kWh/m²/day, sun shines for about 300 days a year, the number of sunshine hours amounts almost 2100 hours per year with an average of 6.8 hours of sunshine each day and average insolation intensity about 4.7 kWhm²/day (Figure 50). As per the published report of AEPC, 2008 under Solar & Wind Energy Resource Assessment in Nepal (SWERA), the commercial potential of solar power for grid connection is 2,100 MW.

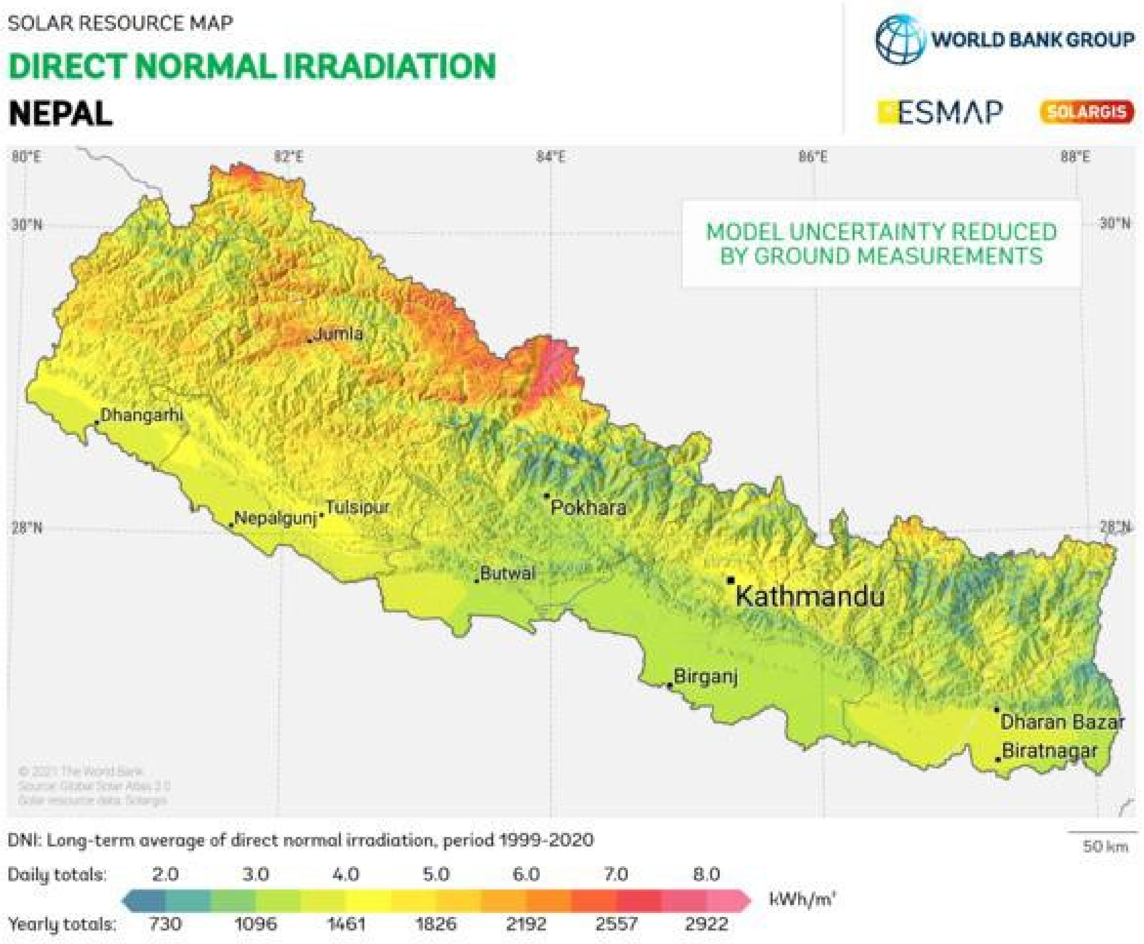


Figure 50: Solar Irradiation map of Nepal (Source: World Bank)

At present forty-four solar projects of 1239.69 MW capacity have obtained survey license, twenty-two projects of 137.56 MW have obtained construction license. Twenty projects of 197.4 MW have applied for survey license and two projects of 15 MW have applied for construction license. Presently, 49.76 MW solar plants are already in operation. As per the study carried out by National Planning Commission, 127 MWp in Madhesh Province and 85 MWp in Lumbini Province with total installed capacity of 212 MWp were selected through financial analysis. The highest number and installed capacity of Solar PV sites in the country were selected in Province 2 due to absence of any hydropower potential. Thus, solar power helps reduce power outages in winter seasons when hydropower potential is reduced. Furthermore, these solar plants are expected to increase the reliability of the power supply system and also minimize the transmission losses during the supply of power close to load centres.

4.1.2 Wind

Wind turbines capture wind energy by lifting and turning large blades. Most turbines have two or three. These blades are connected to a rotor which is also connected to a main shaft. When rotated, the shaft (which is connected to a gear box) spins a generator to create electricity. The wind data are not sufficient to make a realistic assessment of the wind energy. The extreme wind speed is as high as 46.76 m/s, and 238 kW/m^2 power density. The annual average energy potential is about 3.387 MWh/m^2. Various studies conducted at different times show there is low potential of wind. The potential area of wind power in the country is about 6,074 km^2 with wind power density greater than 300 $watt/m^2$. More than 3,000 MW of electricity could be generated at 5 MW/km^2. Only, few small scale wind turbines are installed in Nepal. Three projects with a total capacity of 5MW have applied for licenses to develop wind projects however none of the project have been installed so far.

4.1.3 Hydro

Hydroelectricity is generated by the force or energy of moving water. Similar to wind power, flowing water is channeled through turning blades that are connected to a shaft and electrical generator. While smaller power stations generally rely on naturally flowing water sources, larger stations need dams to store the water required to produce power – many of which are built to hold irrigation or drinking water, ensuring as much value from the resource is extracted as possible.

Electricity supply of Nepal is hydro based. At present total installed power plant capacity is 2,265 MW, out of which, 74 MW is off-grid, and 2191 MW is connected to grid. Among the grid connected generation facilities, 49.76 MW is solar, 53.4 MW is thermal, 6 MW is biomass, and the rest 2,082 MW is hydro.

4.1.4 Tidal

Tidal energy is power produced by the surge of ocean waters during the rise and fall of tides. This is possible in countries connected with sea/ocean. In case of land-locked country like Nepal, exploiting tidal energy is not possible.

4.1.5 Biomass

Biomass is a fuel developed from organic materials, such as sugar cane residue, forest debris, crops and manure. The energy in biomass can be converted into electricity, heat or biofuels; however, the methods for extracting energy from biomass can vary depending on the materials used.

About 77% of energy consumption of Nepal is supplied by traditional biomass energy, which includes the firewood, cattle dung and agricultural residues. As per the National Census 2011, nearly 4 million out of 5.4 million households in Nepal are still using the traditional biomass energy including firewood for cooking. Six MW of biomass plan is already in operation.

4.1.6 Geothermal

Geothermal energy is heat from the earth, sourced from shallow ground, hot water or hot rock found kilometers beneath the earth's surface. Geothermal energy in the form of hot water are available at many places in Nepal. But it is not available in the form of steam to run steam turbine and generate electricity.

4.2 Energy Storage technologies

Flexibility and resilience in power distribution is becoming increasingly important to deal with the rising share of variable renewables brought on by decarbonization of the energy system, as well as the rising simultaneous load from power electronics, manufacturing facilities, heat pumps, and the charging of electric vehicles. Battery Energy Storage Systems (BESS) are the primary candidate for dealing with electrical grid flexibility and resilience through applications such as peak shaving. Batteries are of particular interest due to their relatively high energy density, lack of geographic restrictions, minimal noise, and low maintenance requirements. Battery Energy Storage Systems play a pivotal role between renewable energy supplies and responding to electricity demand. Energy supplied from renewable sources, or the electrical grid, is available for instant consumption and many factors such as variance in solar arrays or electricity market demand significantly impact the cost of electricity. Co-locating energy storage with demand, such as by placing it in factories and medical facilities, has several important advantages. These advantages include peak shaving of both import from the grid and export from embedded renewables. Battery Energy Storage Systems provide backup power, delay infrastructure reinforcements, improve power quality, and increase self-consumption of embedded renewables.

Energy storage helps capture generated energy and deliver effectively for future use, but this can be done in more than one way. This article encapsulates the various methods used for storing energy. Energy storage technologies encompass a variety of systems, which can be classified into five broad categories, these are: mechanical, electrochemical (or batteries), thermal, electrical, and hydrogen storage technologies (Figure 51).

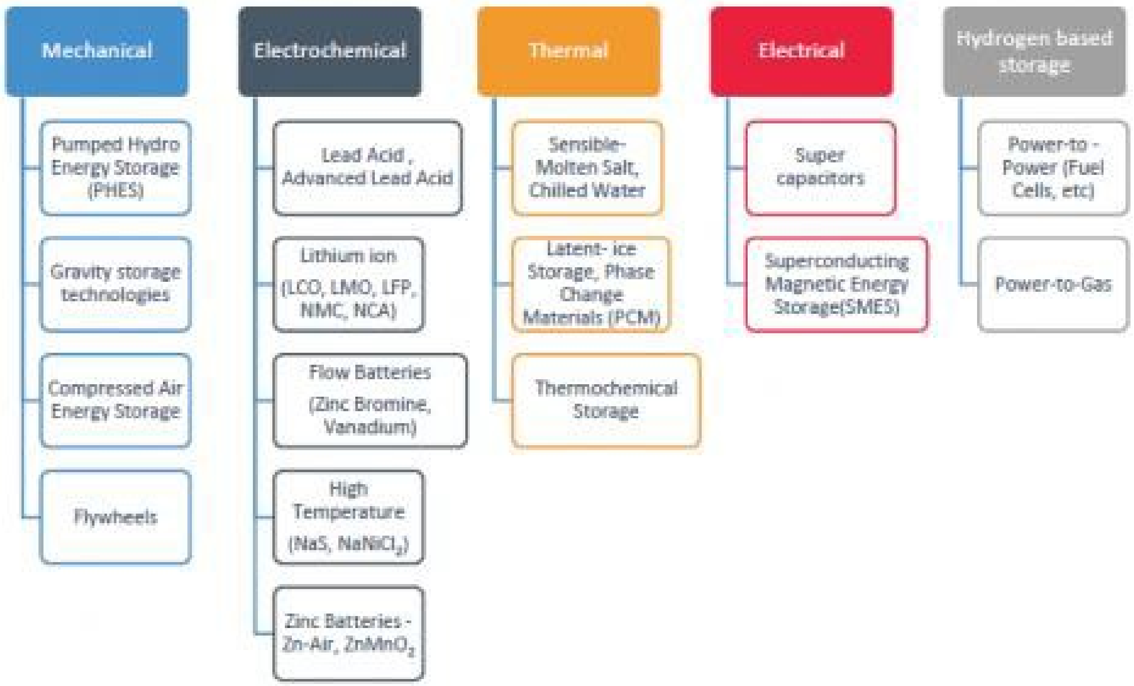


Figure 51: Different types of energy storage system

Advanced energy storage technologies are capable of dispatching electricity within milliseconds or seconds and can provide power back-up ranging from a few minutes to many hours. The suitable duration (long or short) of storage, scale of systems (in MW and MWh) and response time are technology dependent making it important to choose the appropriate technology as per the application requirements and constraints.

4.2.1 Mechanical Storage

These technologies store energy in the form of gravitational potential energy, kinetic energy (of motion), or potential energy of compression. It includes Pumped Hydro Storage (PHS), Gravity Energy Storage, Compressed Air Energy Storage (CAES) and Flywheels storage technologies.

4.2.1.1 Pumped Hydro Storage (PHS)

In these systems, the energy is stored as the potential energy of water kept on a higher elevation. Generally, this involves pumping water into a large reservoir at a high elevation—usually located on the top of a mountain or hill. When energy is required, the water in the reservoir is guided through a hydroelectric turbine, which converts the energy of flowing water to electricity. PHS is often used to store energy for long durations (8-24 hours).

4.2.1.2 Gravity Storage Technologies

Gravity based energy storage technologies use the same principle as PHS systems. However, the important difference is that cement or bricks, or rocks are used as the mass moving up or down instead of water. The important advantage of this is that the size of the systems is much smaller due to the higher density of these solids compared to water. Additionally, the requirement of specific geological features can be avoided.

4.2.1.3 Compressed Air Energy Storage (CAES)

A CAES system uses excess electrical energy to compress air using an electrically driven pump, which is stored either in an underground cave or above ground in high-pressure containers. When excess or low-cost electricity is available from the grid, it is used to run an electric compressor, which compresses air and stores it under high pressure. When electrical energy is required, the compressed air is directed towards a modified gas turbine, which converts the stored energy to electricity.

4.2.1.4 Flywheel Energy Storage (FES)

Flywheels store electrical energy as rotational energy in a heavy cylindrical rotating mass. Flywheel energy storage systems typically consist of a large rotating cylinder supported on a stator. Stored electric energy increases with the square of the speed of the rotating mass, so materials that can withstand high velocities and centrifugal forces are essential for its construction. In general, flywheels are very suitable for high power applications due to their capacity to absorb and release energy in a very short duration of time.

4.2.2 Electrochemical Storage

Electrochemical storage technologies include various battery technologies that use different electrochemical reactions to store electricity namely lead-acid batteries, lithium-ion (Li- ion) batteries, sodium-sulfur batteries (NAS), flow batteries, Zn-air batteries, and super capacitors. The batteries, depending on type, may be suitable for a short duration (few minutes) or long duration (8+ hours) applications. While considering a battery system for stationary storage applications, the cycle life and the roundtrip energy efficiency (%) of the batteries must be considered.

There are many different types of batteries used in battery storage systems and new types of batteries are being introduced into the market all the time. Some of the major battery types are discussed here in brief.

1. Lithium-ion (Li-ion) batteries

2. Lead-acid batteries
3. Redox flow batteries
4. Sodium-sulfur batteries
5. Nickel-cadmium
6. Nickel Metal Hydride

4.2.2.1 Attributes of different Battery Storage Technologies

Battery energy storage system adoption is expanding at a rapid rate and so are the technologies that power the systems. New types of batteries are being developed constantly. The comparative analysis of different attributes corresponding to the battery storage technologies can be seen in Table 2. Lead-acid is in use for a long time and the main advantage of this technology is the very low price. Lead- acid technology is suitable for different stationary applications because of good efficiency and the high cell voltage. But lead-acid battery technology has the low number of lifetime cycles. Lithium-ion is now the most advanced and the most used battery technology. According to the Table 2, lithium-ion battery technology is the most suitable for different applications because of highest specific power and energy, highest power and energy density, highest cell voltage and highest efficiency. But lithium-ion battery technology has the highest price in comparison to other technologies.

Nickel-cadmium is good because of the ability of operation in extreme conditions with very low and high temperatures, but because of bad environmental impact, nickel-cadmium is replaced with the nickel-metal hydride technology. For extremely cold and hot working conditions, the most suitable technology is nickel- metal hydride. It has relatively high power and energy density and low price, but with some lower efficiency.

Table 2: Attributes of different types of battery storage technologies

CHARACTERISTICS	PB-ACID	LI-ION	NICD	NIMH	NAS	VRFB
Specific energy [Wh/kg]	25 - 50	80 - 250	30 - 80	40 - 110	150 - 240	10 - 130
Specific power [W/kg]	150 - 400	200 - 2000	80 - 300	200 - 300	90 - 230	50 - 150
Energy density [kWh/m^3]	25 - 90	95 - 500	15 - 150	40 - 300	150 - 350	10 - 33
Power density [kW/m^3]	10 - 400	50 - 800	40 - 140	10 - 600	1.2 - 50	2.5 - 33

CHARACTERISTICS	PB-ACID	LI-ION	NICD	NIMH	NAS	VRFB
Energy cost [$/kWh]	40 -170	500 - 2100	680 - 1300	170 - 640	250 - 420	130 - 850
Power cost [$/kW]	250 - 500	1000 - 3400	420 - 1300	200 - 470	850 - 2500	500 - 1300
Lifetime [years]	2 - 15	5 - 15	10 - 20	2 - 15	10 - 15	5 - 15
Lifetime cycles [cycles]	250 - 2000	100 - 10000	1000 - 5000	300 - 1800	2500 - 40000	10000 - 16000
Cell voltage [V]	2 - 2.1	2.5 - 5	1.2 - 1.3	1.2 - 1.35	1.8 - 2.71	1.2 - 1.4
Efficiency [%]	63 - 90	75 - 97	60 - 90	50 - 80	75 - 90	75 - 90

4.2.2.2 Lead-acid Batteries

Lead-acid batteries are the most widely used rechargeable battery technology in the world and have been used in energy storage systems for decades. Lead-acid (Pb-acid) technology has been in use for a long time, it is easy and cheap for installation and maintenance, so this is the main reason for wide use of this technology and this technology is also one of the most common for stationary applications worldwide. Lead- acid batteries have ability to perform a deep discharge when it is required and the main problem with lead-acid batteries is that battery performance largely depends on temperature. Nominal voltage of this technology cell is around 2 volts. Lead-acid battery technology is based on positive and negative electrodes submerged into electrolyte which is a combination of sulfuric acid and water, lead dioxide is used as a positive electrode and lead is used as a negative electrode. Lead-acid battery technology cell is shown in Figure 52.

Some advantages of the lead-acid technology are low cost, high cell voltage, suitability for intermittent charge applications and good ability of recycling. Disadvantages are limited energy density and the number. of lifetime cycles which is lower in comparison to other technologies.

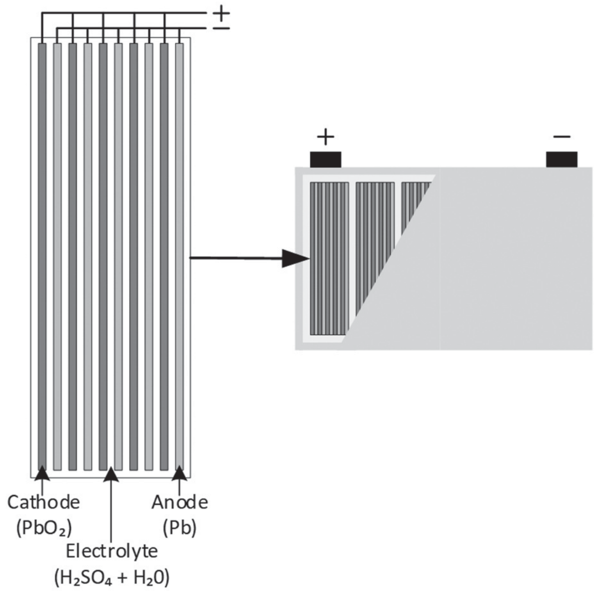


Figure 52: Lead-acid battery cell

4.2.2.3 Redox Flow Batteries

Vanadium-redox flow battery (VRFB) is a new technology which promises a lot because of the very good characteristics. This technology has a long lifetime, very fast response time and long storage time which is ideal for long-term energy storage. Power and energy of VRFB are independent, power depends on the number and size of the cells and energy depends on the available electrolyte, respectively tank size. Redox flow batteries have chemical and oxidation reactions that help store energy in liquid electrolyte solutions which flow through a battery of electrochemical cells during charge and discharge. Redox flow batteries minimize environmental risk and improve response time to demand. Instead of the typical battery where the electrolyte system is encapsulated between electrodes and limited to the volume of the secondary battery, the electrolytes in a redox flow battery are circulated from a reservoir tank. Working principle of the VRFB technology is shown in figure below. VRFB technology is based on two tanks in which vanadium ions electrolytes are stored, one electrolyte is positive and the other is negative. Flow of electrons is caused by oxidation and reduction processes in the ion selective membrane through which electrolytes are being pumped. Response time of this technology is fast because electrolyte flow does not change, regardless of whether battery is charging or discharging. During, discharge, an electron is released from the negative side of the battery and is eventually accepted through a reduction reaction on the positive side of the battery. According to the Department of Energy report, rapid improvements are expected in the overall cost, performance, life, technology readiness levels, and manufacturing readiness levels, but the round-trip efficiency of redox flow batteries is low. The Energy Storage Association (ESA) says RFB batteries are best for large projects that require power in the tens of kilowatts to tens of megawatts range. According to the ESA, storage tanks and flow controls are inexpensive and easy to scale and electrochemical stacks offer power ratings in the tens to hundreds of kilowatts.

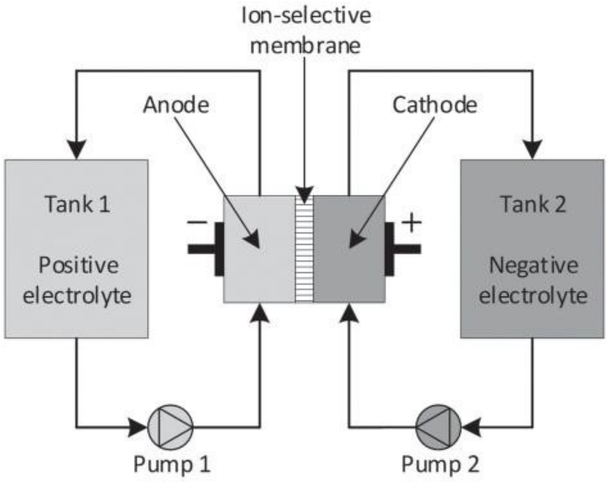


Figure 53: Vanadium-redox flow battery working principle

Advantages of the vanadium-redox flow battery technology are high operating safety, high number of lifetime cycles, low operation and maintenance cost and deep discharging capability. Disadvantages are low energy density and the large space required for technology placement. Vanadium-redox flow batteries are future storage technology with the ability of long-time energy storage. VRFB technology has the high number of lifetime cycles. Main disadvantages of this technology are very low energy and power density and large space required for battery placement.

Flow batteries are ideal energy storage solutions for large-scale applications, as they can discharge for up to 10 hours at a time. This is quite a large discharge time, especially when compared to other battery types that can only discharge up to two hours at a time. The main difference that separates them from other rechargeable battery types, like lithium ion batteries, is their unique design. This design separates fluid into two exterior tanks, where electrons flow through electrochemical cells and a membrane that separates the electrons. The size of these exterior tanks determines the amount of electricity that can be generated; the larger the tank size, the larger the amount of electricity that can be generated.

4.2.2.4 Sodium-sulfur Batteries

Sodium-sulfur (NaS) battery technology is one of the most suitable for use in energy storage systems because of the high energy density. NaS battery cell cross section is shown in Figure 58. This technology is based on the use of sodium as anode and sulfur as cathode, electrolyte is beta alumina ceramics. For this technology it is interesting that electrolyte is also a separator. NaS technology has a low internal cell resistance because of the use a ceramic electrolyte and this is good for two reasons. With the low resistance, power to weight ratio is being increased and heat produced during the charging process is being decreased. Typically working temperature of the sodium-sulfur batteries is between 300°C and 350°C. Reason for high temperature is to keep electrodes in a liquid state. High temperature decreases efficiency of the cycle which increases the number of operation cycles. The round-trip efficiency is high in the 90% range. Sodium-sulfur batteries are made up of molten sulfur and molten sodium, the sulfur is positive, while the sodium is negative. Sodium-based batteries are more sustainable than lithium-ion batteries since there is an abundant amount of sodium in the earth’s crust. The Energy Storage Association states that this technology is being used currently in Japan and Abu Dhabi.

For applications that require a high number of life- time cycles, the most suitable technology is sodium- sulfur because of the high number of lifetime cycles. Sodium-sulfur battery technology has high specific energy and energy density, high cell voltage and good efficiency. Main disadvantage of sodium-sulfur technology is the high working temperature.

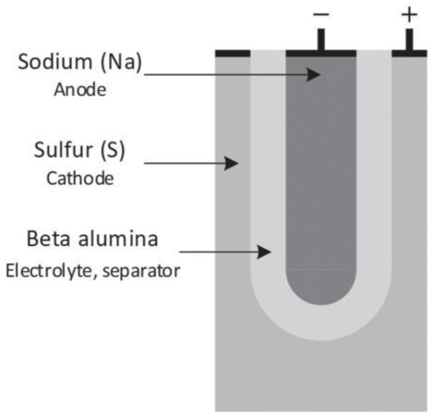


Figure 54:Sodium-sulfur battery working principle

4.2.2.5 Nickel Cadmium Batteries

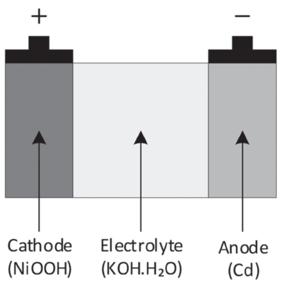


Figure 55: Nickel-cadmium battery cross section

Nickel-cadmium (Ni-Cd) technology is in use for a long time in applications that require a long battery life and in difficult environmental conditions because this battery technology is cheap and robust. Nickel- cadmium technology is based on cathode made from nickel oxide hydroxide and anode made from metallic cadmium while electrolyte used for Ni-Cd batteries is potassium hydroxide. Cross section of the nickel- cadmium battery is shown in Figure 55. Ni-Cd batteries can be charged with a high charge rate which means that the battery is charging with a current much higher than a nominal current is, but in this case the charging process must be stopped when the battery is full, otherwise the battery will heat very fast which leads to damage. The main problem with Ni-Cd batteries is a memory effect which means that battery loses full capacity if it is slightly discharging and re- charging every time during a certain period.

Advantages of NiCd technology are low maintenance cost, the number of lifetime cycles, suitability for long- term storage and ability to resist electrical and physical stress. Disadvantages are high cost in comparison to the lead-acid technology, limited energy density, toxic and caustic elements in batteries and the memory effects. Detailed characteristics of NiCd battery technology are shown in Table 2.

4.2.2.6 Nickel-metal Hydride

Nickel-metal hydride (Ni-MH) technology has been used in several applications such as energy storage for smart energy systems, robust battery systems which work at high temperatures, hybrid electric cars and public transport. Ni-MH battery cell cross section with the main parts is shown in Figure 56. Nickel-metal hydride technology is based on the negative electrode made from hydrogen-absorbing alloys which have the possibility to absorb releasing hydrogen and the positive electrode made from nickel oxy- hydroxide. There is a separator which separates positive and negative electrodes to prevent shorting between electrodes. Electrolyte used in this technology is potassium hydroxide (KOH). There is a current collector made of metal which minimizes the internal battery resistance. To release gases produced during the overcharging or shorting there is a self-sealing safety vent.

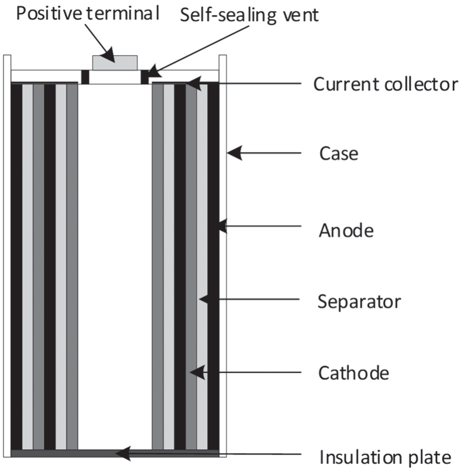


Figure 56: Nickel-metal hydride battery cross section

Some advantages of NiMH technology are long battery lifetime, high number of lifetime cycles, good performance at the high temperatures, high energy density, good ability of recycling and the high tolerance to battery overcharging and over discharging.

Disadvantages are high cost in comparison to the lead-acid technology and bad performance at the low working temperatures.

4.2.2.7 Lithium-ion Batteries

The most common type of battery used in energy storage systems is lithium-ion batteries. In fact, lithium-ion batteries make up 90% of the global grid battery storage market. A Lithium-ion battery is the type of battery that you are most likely to be familiar with. Lithium-ion batteries are used in cell phones and laptops. A lithium-ion battery is lightweight and are likely more expensive than some of the other options out there.

According to the U.S. Department of Energy's 2019 Energy Storage Technology and Cost Characterization Report, for a 4-hour energy storage system, lithium-ion batteries are the best option when you consider cost, performance, calendar and cycle life, and technology maturity. Lithium-ion (Li-ion) technology is one of the most advanced battery technologies widely used today. Cell- phones, smartphones, tablets, laptops, all gadgets are powered with the Li-ion battery. There are many pros of the lithium-ion technology: high power, energy capacity, long battery lifetime and relatively low weight and because of these pros, Li-ion technology is being used to power hybrid and electric vehicles. Lithium-ion battery working principle is given in Figure 57. Li-ion cells consist of two electrodes, anode and cathode. Graphite is used as anode and the lithium metal oxide Is used as cathode.. The lithium salt in organic solvent is used as electrolyte. Working principle of this technology is based on LI-ions moving from cathode to anode when battery is in charging process and from anode to cathode when battery is in discharging process. The cathode of the lithium-ion batteries can be made up of different materials including cobalt oxide, manganese oxide, Phosphate, nickel, maganese, cobalt, manganate etc.

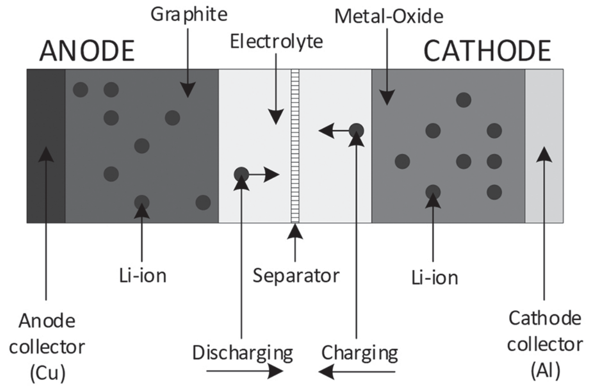


Figure 57: Lithium-ion technology working principle

Advantages of the lithium-ion technology are long battery lifetime, the number of lifetime cycles, high energy density, low maintenance cost and there is no memory effect. Disadvantages are high cost in comparison to other technologies, poor performance at high temperature and the request for protective circuits.

4.2.2.8 Attributes of Different Lithium-Ion Batteries

The Lithium-ion type batteries are widely popular these days in consumer goods from mobile phones to electric vehicles. As Lithium mining is a tedious task, multiple variations of Lithium-ion based batteries are observed in the market. A descriptive analysis is presented here of different technologies of Lithium-ion including the market landscape as it is suitable for most of the battery related applications.

Lithium-ion based batteries are dry batteries comprised of lithium, nickel, cobalt, copper, and aluminium that are referred to as lithium-ion batteries. The percentage compositions of these metals vary depending on the type of lithium-ion battery. As a result, the many types of commercially available batteries provide energy, safety, longevity, affordability, and performance. Lithium Cobalt Oxide (LCO) and Lithium Nickel Manganese Cobalt Oxide (LNMCO) are the two most frequent types of lithium-ion batteries now in use. LCO has the biggest market share (37%) among these, owing to its widespread use in small portable devices such as phones, tablets, laptops, and cameras. Nickel Manganese Cobalt (NMC) is the second most popular metal, accounting for 29% of the market, and is mostly utilized in electric vehicles and medical gadgets.

Table 3: Market Share, Usage & key components of types of Lithium Ion based batteries

TYPE OF BATTERY	TECHNOLOGY	CHEMISTRY	KEY METALS	GLOBAL MARKET SHARE	USAGE
LCO	Lithium Cobalt Oxide	LiCoO2	Cobalt	37%	Cell phones, Laptops
NMC	Lithium Nickel Managanese Cobalt Oxide	LiNiMnCoO2	Cobalt - 19% Manganese - 17% Nickel - 19% Lithium Carbonate - 3.5% Others - 41.5%	29%	Power tools, Electric Vehicles, Medical devices
LMO	Lithium Manganese Oxide	LiMn2O4	Cobalt - 2.5% Manganese - 21% Nickel - 7% Lithium Carbonate - 3.5% Others - 66%	21%	Electric Vehicles, consumer electronics
NCA	Lithium Nickel Aluminium Cobalt Oxide	LiNiCoAlO2	Cobalt - 6% Nickel - 35% Lithium Carbonate - 3.5% Others - 55%	7%	EV, satellites
LFP	Lithium Iron Phosphate	LiFePO4	Iron, Phosphate	5%	Starter batteries, light storage and 2W, 3W EV

(Reference: Benchmark Mineral Indices, 2021)

NMC and LFP batteries are commonly utilized worldwide. According to several industry sources, NMC batteries have a normal life of 5-7 years, while LFP batteries have a life of 5-15 years. In the last 3-4 years, NMC batteries have been increasingly popular due to lower energy density, mostly in electric vehicles, streetlights, and other small stationary storage battery applications. LFP batteries, on the other hand, have recently begun to acquire traction in the utility scale adaptation due to higher lifecycle and faster ramp up times. Also, these are comparatively lower in price as compared to NMC. Researchers are currently working on a chemical ratio of 8:1:1 for NMC batteries in order to lower prices by reducing cobalt's share of the overall battery mix.

Contrary to the popular belief, there are many different types of lithium-ion batteries. Six of them, that have been listed above are commercially established. There are many other Lithium chemistries (e.g Li-S) undergoing research. It should be noted that each battery has different energy density, power density, reliability and safety. The different battery chemistries allow scientists to create batteries as per user's requirement. Power density and energy density are inversely related and come at the cost of each other i.e., increase in power density results in a decrease in energy density and vice versa.

Table 4: Technical characteristics of different Li-on technology-based battery types (Source: Highland Analysis)

BATTERY CHEMISTRY	TEMP MIN (℃)	TEMP MAX (℃)	CELL VOLTAGE (VOLTS)	SELF-DISCHARGE (% / MONTH)	CYCLES TIMES (MAX)	WEIGHT
NiCd	-20	60	1.2	20	800	Heavy
NiMH	-20	70	1.2	30	500	Middle
Low Self Discharge NiMH	-20	70	1.2	1	2000	Middle
Li-ion (LCO)	-40	70	3.6	10	1000	Light
Li-ion (LFP)	-40	80	3.2	5	12000	Light
LiPo (LCO)	-40	80	3.7	10	1000	Lightest
Li-Ti (LTO)	-40	55	2.4	5	20000	Light
LMO	-	85	3.7	-	700	Heavy

4.2.2.8.1 Competitive Landscape

The technologies in the global lithium-ion battery market have undergone significant changes in recent years, with lithium-ion technologies evolving from low energy density to high energy densities. The rising wave of new technologies, such as nickel-cobalt-aluminium (NCA) and nickel manganese cobalt (LI-NMC), are creating significant potential in electric vehicle application and driving the demand for lithium-ion battery technologies.

In the lithium-ion battery market, various battery technologies, such as lithium nickel manganese cobalt (NMC), lithium iron phosphate (LFP), lithium cobalt oxide (LCO), lithium-titanate-oxide (LTO), lithium manganese oxide (LMO), and lithium nickel cobalt aluminium oxide (NCA), are used in various end use industries. Increasing adoption of electric vehicles due to stringent government regulations to reduce carbon emissions, government incentives to promote electric vehicles, and rising demand for lithium-ion batteries in industrial and power storage application are creating new opportunities for lithium-ion battery technologies.

Emerging technology trends, which have a direct impact on the dynamics of the industry, include lithium air batteries, usage of silicon alloy anodes in lithium-ion batteries, and new generation lithium-ion batteries with new families of disruptive active materials. CATL, BYD, Duracell, EnerSys, GS Yuasa, Johnson Controls, LG Chem, and Panasonic Corporation are among the major technology providers in the lithium-ion battery market.

The Lucintel study finds that the total market size of the lithium-ion battery market is anticipated to be $215.9 billion in 2027, and it is forecast to grow at 21% from 2021 to 2027. Lithium nickel manganese cobalt (LI-NMC) technology is the largest segment of the lithium-ion battery market, and it is expected to witness the highest growth due to its high-power density, lowest self-heating rate, and good charge and discharge cycle.

The lithium-ion battery market is fragmented. The major companies in the market include Panasonic Corporation, Tesla Inc., Samsung SDI, LG Chem Ltd, and Contemporary Amperex Technology Co. Ltd (CATL), among others. The major players and their market presence can be seen in the table below:

Table 5: Competitive landscape of battery manufacturers

RANK	COMPANY	2021 MARKET SHARE	COUNTRY	TYPE
1	CATL	32.5%	China	LFP, NMC, Na ion-based batteries
2	LG Energy Solution	21.5%	Korea	NMC, NCMA, LFP
3	Panasonic	14.7%	Japan	NCA, NMC
4	BYD	6.9%	China	LFP, NMC
5	Samsung SDI	5.4%	Korea	Li Ion, LFP
6	SK Innovation	5.1%	Korea	Li Ion
7	CALB	2.7%	China	Li Ion, NMC
8	AESC	2.0%	Japan	NMC, LFP

RANK	COMPANY	2021 MARKET	COUNTRY	TYPE
9	Guoxuan	2.0%	China	NMC, LFP
10	PEVE	1.3%	Japan	Li Ion

According to data from SNE Research, the top three battery makers—CATL, LG, and, Panasonic—combine for nearly 70% of the EV battery manufacturing market.[7] LFP batteries offer lower prices and stability by using phosphoric acid and iron as the primary materials attracting Tesla and others to pursue these batteries in their vehicles. They are relatively safer from fire risks, lower in energy density, and heavier in weight. The, Chinese companies predominantly manufacture them. Contrastingly lithium-ion batteries contain expensive metals such as nickel, cobalt, and manganese. Due, to these ESS trends are gradually shifting toward LFP batteries. The share of LFP batteries in the global battery market will likely surge from 10% in 2015 to 30% in 2030.[8] In the same period, lithium-ion batteries will likely contract from 70% to 30%. The ESS for LFP market is dominated by LG Energy Solution and CATL.

4.2.2.8.2 Tier Status

Battery mega factories are coming online and into production at a phenomenal rate. There are now 99 mega factories in the pipeline, with over 2,000 gigawatt hours (GWh) of capacity in the industry's pipeline for 2028. But not all batteries are the same – the battery industry can be roughly split into three tiers in a pyramid structure, with the top tier of producers occupied by the behemoths of the industry such as Tesla, Panasonic, Samsung and LG Chem and CATL. The second has major battery companies such as BYD*, SK Innovation. Finally, the third tier has a number of companies such as GEELY and Farasis, with many of the new Chinese producers sitting within tier 3. Typically, manufacturers in the higher tiers follow a more stringent qualification process for sourcing raw materials. This results in higher quality and specification requirements, large sample sizes, and longer qualification times. There is no specific tiering system like Bloomberg and PVinfo for solar modules and inverters. However, developers and investors refer to the BMI (Benchmark Mineral Intelligence) for classifications of tier manufacturing for batteries. Not all lithium-ion batteries can be used in all electric vehicles. For industry, there is a fine balance of what Benchmark calls the 'Three Qs' of quality, quantity and qualification. Every three months, Benchmark assesses each

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[7] https://elements.visualcapitalist.com/ranked-top-10-ev-battery-makers/

[8] https://www.benchmarkminerals.com/about/

* However, in two quarters in 2021 it was ranked as tier1

lithium-ion battery cell producer into the following three tiers:

Tier 1:

- Qualified to supply multinational automotive OEMs / EV producers outside of China
- Supplier to domestic Chinese EV market
- >5 GWh of annual cumulative capacity (equivalent at time of assessment)

Tier 2:

- Not yet qualified to supply multinational automotive OEMs / EV producers outside of China
- Qualified to supply domestic Chinese EV manufacturers
- Qualified to supply non-EV applications
- >1GWh of annual cumulative capacity (equivalent at time of assessment)

Tier 3:

- Not yet qualified to supply EV end markets
- >1GWh of annual cumulative capacity (equivalent at time of assessment)
- Primary focus: non EV markets including portable and stationary

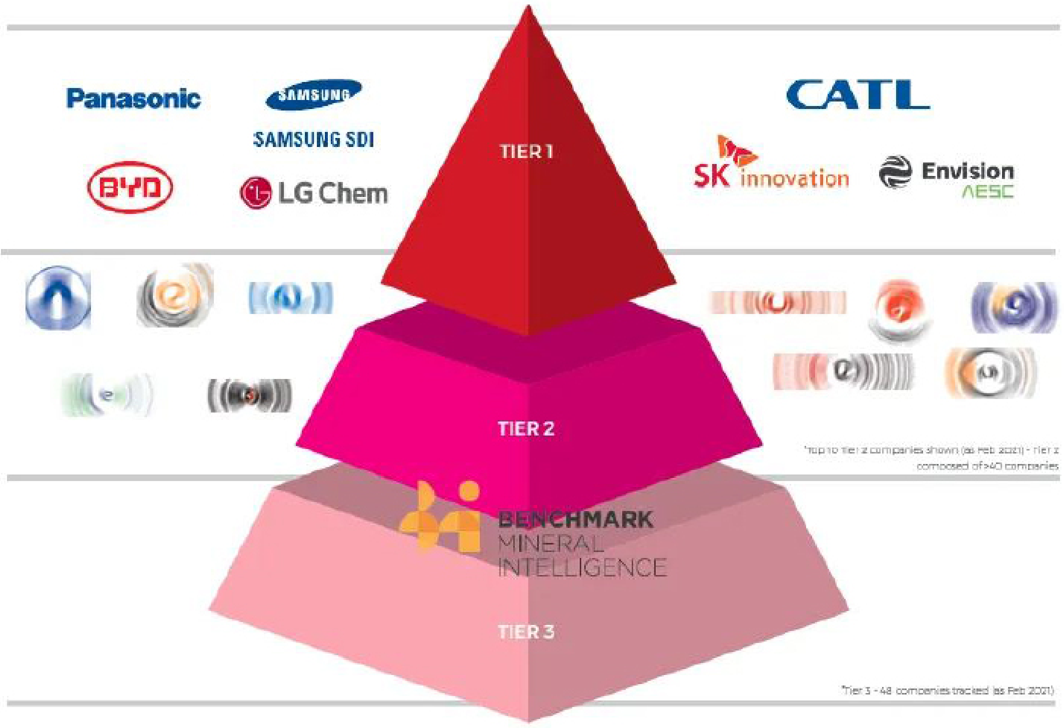

Figure 58: Tier Classification of battery manufacturers (BMI, Q1-2021)

4.2.2.9 Comparative Analysis Lithium Ion and Flow Batteries

To expand on the differences between the battery technologies namely lithium ion and flow batteries a comparative analysis is presented in Table 6: discussed above based on cost, longevity, power density, safety and space efficiency.

Table 6: Comparative analysis between LFP and flow batteries

PARAMETER	LFP	REDOX FLOW BATTERIES
Longevity in terms of storage	Low	High
Space Required	Low	High
Life Expectancy	Low	High
Stability (Safety)	Low	High
Power Density	High	Low
Overall Costs (including Raw Material)	Low	High

The differences between the battery technologies discussed above based on cost, longevity, power density, safety and space efficiency, can be expanded on:

4.2.2.9.1 Cost

Often considered one of the most important differences between flow batteries and lithium ion batteries is these technologies' costs. Flow batteries have relatively low charge and discharge rates that require a relatively large surface area to occur. This, along with more pumps, plumbing and maintenance than lithium-ion batteries, and the industry immaturity of flow batteries makes them the more expensive option.

4.2.2.9.2 Longevity

Flow batteries have almost an unlimited battery cycle life because of the absence of phase-to-phase chemical reactions. This technology can by cycled every day for up to 30 years. This absence also means the absence of degrading material and therefore a longer life span. On the contrary, lithium-ion batteries that are cycled every day will only last up to eight years.

4.2.2.9.3 Power Density

Flow batteries have a smaller power density than lithium-ion batteries but are ideal for consistent energy delivery (in a lesser amount than lithium-ion batteries) for up to 10 hours (longer period than lithium-ion batteries). Lithium-ion batteries can deliver a relatively large amounts of energy, but these deliveries can only last for up to two hours.

4.2.2.9.4 Safety

Safety is another one of the differences between flow batteries and lithium-ion ones that is considered the most important. Flow batteries are generally considered the safer technology because they don't contain flammable materials, and the materials that they do contain, such as vanadium, are often environmentally friendly.

4.2.2.9.5 Space Efficiency

Flow batteries are heavier than lithium-ion batteries and they also take up more space due to their considerably sized tanks. In comparison, lithium-ion batteries are more portable and won't take up as much of your space.

These key differences between flow batteries and lithium-ion batteries can determine which technology is the best solution. In summary, if main priority when it comes to battery energy storage systems is either longevity or safety, flow batteries are likely the ideal technology. If main energy storage system priority is either cost or space efficiency lithium-ion batteries are likely the idea technology for you. If power density is main concern, either technology could suit unique needs, depending on the length of battery cycle required. Redox flow batteries offer an economical, low vulnerability means to store electrical energy at grid scale. Redox flow batteries also offer greater flexibility to independently tailor power rating and energy rating for a given application than other electrochemical means for storing electrical energy. Redox flow batteries are suitable for energy storage applications with power ratings from tens of kW to tens of MW and storage durations of two to 10 hours. On the downward side of flow batteries are lower round-trip efficiency (flow batteries average 70% to 85%, versus 90% to 95% for Li-ion), lower energy density and therefore larger footprint and technology's vulnerability to spikes in the price of vanadium and high capital cost.

However, looking at the current adaptation lithium-ion batteries dominate the stationary storage market. They now account for over 90% of global installations of electrochemical energy storage.[9] There have been only few installations up on a couple of major projects namely 800MWh project in China by Rongke Power/UniEnergy that came online in in 2022, 200MWh project in South Australia which is in development through manufacturer CellCube, while the biggest VRFB installation in the world today is a 15MW/60MWh system brought online in northern Japan by maker Sumitomo Electric a few years ago. There is an over-reliance on lithium in the market today, but if VRFB manufacturing and deployment can scale up, continuous growth in the industry could be unlocked. However, looking at the current market context lithium-ion batteries are easier to adopt with streamlined supply chain, upcoming of gigafactory levels of production, which is further going to enhance the unit economics of production.

4.2.3 Thermal Storage

The principle of storage of energy in thermal energy storage systems is conceptually different from electrochemical or mechanical energy storage systems. Here, the energy by heating or cooling down appropriate materials using excess electrical energy. When required, the reverse process is used to recover the energy. This category of technologies includes ice-based storage systems, hot and chilled water storage, molten salt storage and rock storage technologies.

4.2.3.1 Sensible Heat Storage

Available energy is stored in the form of an increase or decrease in temperature of a material, which can be used to meet a heating or cooling demand. One of the most well- known technologies of this type is molten salt storage. This type of storage is generally coupled with Concentrated Solar Power (CSP) plants where the heat generated is used to increase the temperature of molten salt. Another important technology in this space is hot and chilled

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[9] "Vanadium redox flow batteries: Identifying opportunities and enablers".

water storage. These are especially relevant where a large part of the electrical load is for space heating or cooling applications.

4.2.3.2 Latent Heat Storage

In these systems, the energy is stored in a material that undergoes a phase change (transition between solid and liquid) as it stores and releases energy. Examples include ice storage tanks for domestic or industrial cooling applications. During periods of excess energy and low demand (usually night-time), the liquid water is converted into ice and stored in large tanks. When the cooling load increases during the daytime and afternoon, the ice is melted to provide space cooling to the connected buildings. Two companies active in this space are Calmac and Ice Bear Energy Systems. Another type of technology in this category is phase change materials (PCMs). PCMs are specific material compositions that melt at a particular temperature of interest.

4.2.3.3 Thermochemical Storage

The third category of thermal storage involves storing energy in reversible chemical reactions. Compared to the other two technologies these are much more compact and lightweight. There are multiple variations of this technology most of which are currently in the initial prototype development stage.

4.2.4 Electrical Storage

Super capacitors and Superconducting Magnetic Energy Storage (SMES) systems store electricity in electric and electromagnetic fields with minimal loss of energy. A few small SMES systems have become commercially available, mainly used for power quality control in manufacturing plants such as microchip fabrication facilities. These technologies are ideal for storing and release high levels of energy over short bursts due to their lower price in $/kW (power).

4.2.5 Hydrogen Storage Technologies (Power-to-Gas)

The basic concept of hydrogen storage technologies is to use electricity to perform electrolysis of water to produce hydrogen and oxygen. The hydrogen produced is stored in high pressure containers and can be used as a fuel for direct combustion (cooking and heating applications) or for electricity generation via Proton Exchange Membrane (PEM) Fuel Cells.

4.3 Effects of DRE on the Grid

The DRE capacity is also a critical factor when making a connection to the main grid since every connection point has a maximum amount of power that it can accommodate above which the system could become unstable. Such capacity of grid to host the DREs is known as renewable energy hosting capacity of the grid. The electricity grid to accommodate higher percentage of renewable energy would need large quantities of conventional back up power and huge energy storage. These would be necessary to compensate for natural variations in the amount of power generated depending on the time of day, season and other factors such as amount of sunlight and wind at any given time. Since today's electricity grid cannot handle this variability, the cost of adopting the renewable energy sources is much more expensive than it should be.

Under the centralized generation paradigm, electricity is mainly produced at large generation facilities, shipped though the transmission and distribution grids to the end consumers. However, the recent quest for energy efficiency and reliability and reduction of greenhouse gas emissions led to explore possibilities to alter the current generation paradigm and increase its overall performances. In this context, one of the best candidates to complement or even replace the existing paradigm is distributed generation where electricity is produced next to its point of use.

Distributed generation, also called on-site generation, involves generation of electricity from sources located near the consumer. A distributed generation system is designed to employ small-scale power generation technologies to produce electricity close to the end consumers of the power. DREs have both pros and cons when integrated to the grid. These pros and cons are discussed in this sub-section.

4.3.1 Impact on Loss

Typically, DREs are of smaller size which allows different DRE technologies to be installed close to the load such as roof top PV plant. As the generation supplies the local load, the transmission loss in the system can be reduced. For a higher penetration of renewable energies such loss reduction can be significant.

However, if the penetration of DREs is higher than the hosting capacity, they could infer more power loss in the system during back flow of power to the grid.

4.3.2 Impact on Voltage

Most of the DREs make use of inverter for grid interconnection. Modern technologies for smart inverters allow them to inject reactive power in the grid. Such capability of injecting both active and reactive power in the grid makes DREs suitable for voltage improvement. However, this could also mean the voltage could rise higher should the DREs be connected to the far end of the feeder. Hence, a system analysis is essential to allow the limit of DRE injection in a feeder. However, if a large PV is connected close to the substation, then such voltage rise issue does not arise (See Figure 59 and Figure 60).

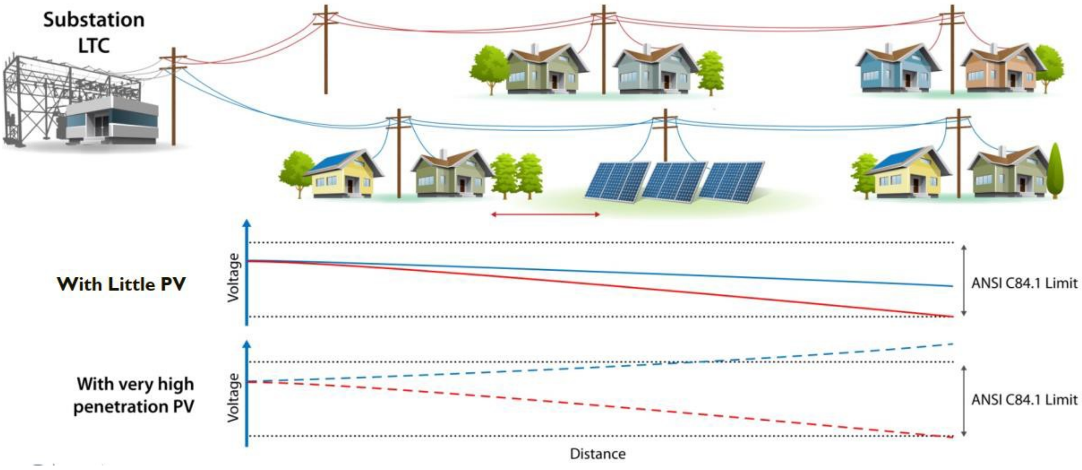

Figure 59: Voltage impact of high penetration of PV (Source: NREL, Sunshot)

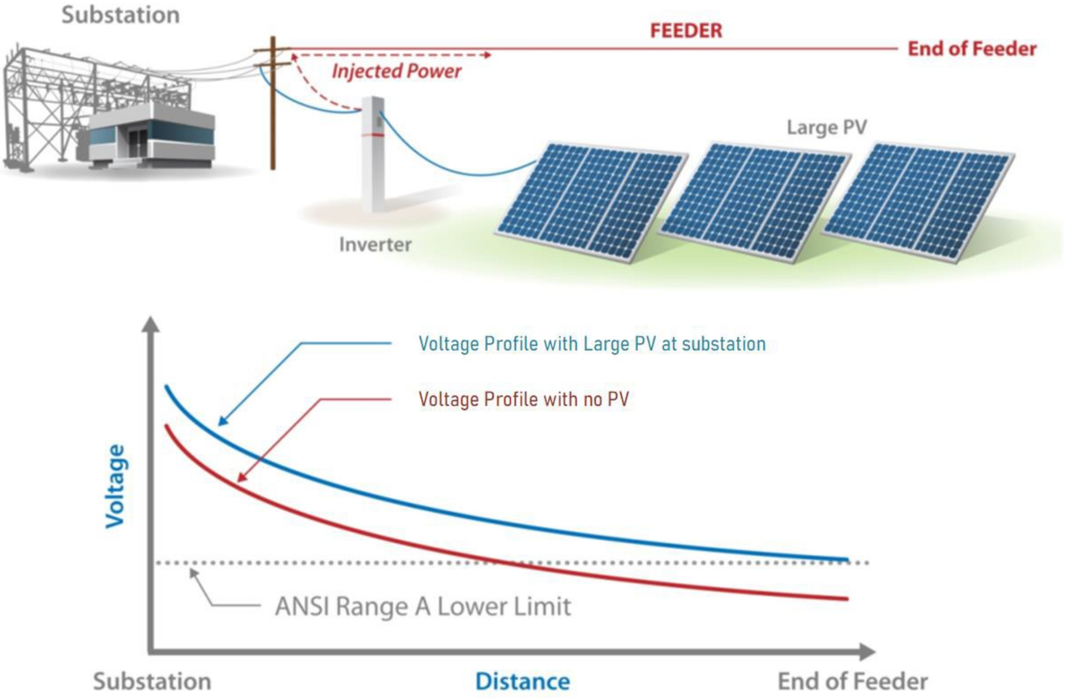

Figure 60: Voltage drop compensation by Large PV system at substation[10] (Source: Modified from Sunshot)

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[10] Such compensation comes with the possibility of voltage violation at the sending end. The source image describes how the line drop compensation-controlled voltage regulator allows undervoltage at the end of the feeder when the PV generator injects power

4.3.3 Islanding

Islanding is the state of operation of a DRE in which while in isolation from the grid but yet connected as grid-connect DRE. However, such islanding could result into unwanted voltage and frequency levels causing severe impact to the grid. Anti-islanding features are included in modern DRE inverters as per the grid connection standard, however, if other energy sources such as diesel generators without anti-islanding feature is present in the line section and happens to mimic the grid, then serious issues may arise.

4.3.4 Protection Coordination

DREs could impact the protection coordination of feeder designed to operate in radial topology. Figure 61 shows how a DRE could impact in overcurrent relay setting.

4.3.5 Irregular input

DRE output is regulated with the modern technology, however various DREs such as PV, Wind, Tidal, etc. are inherently intermittent in nature. This could result in absence of power supplied by DREs for a short period. The utility must manage reserve energy source to prevent failure of the grid, which could be tricky as well as expensive.

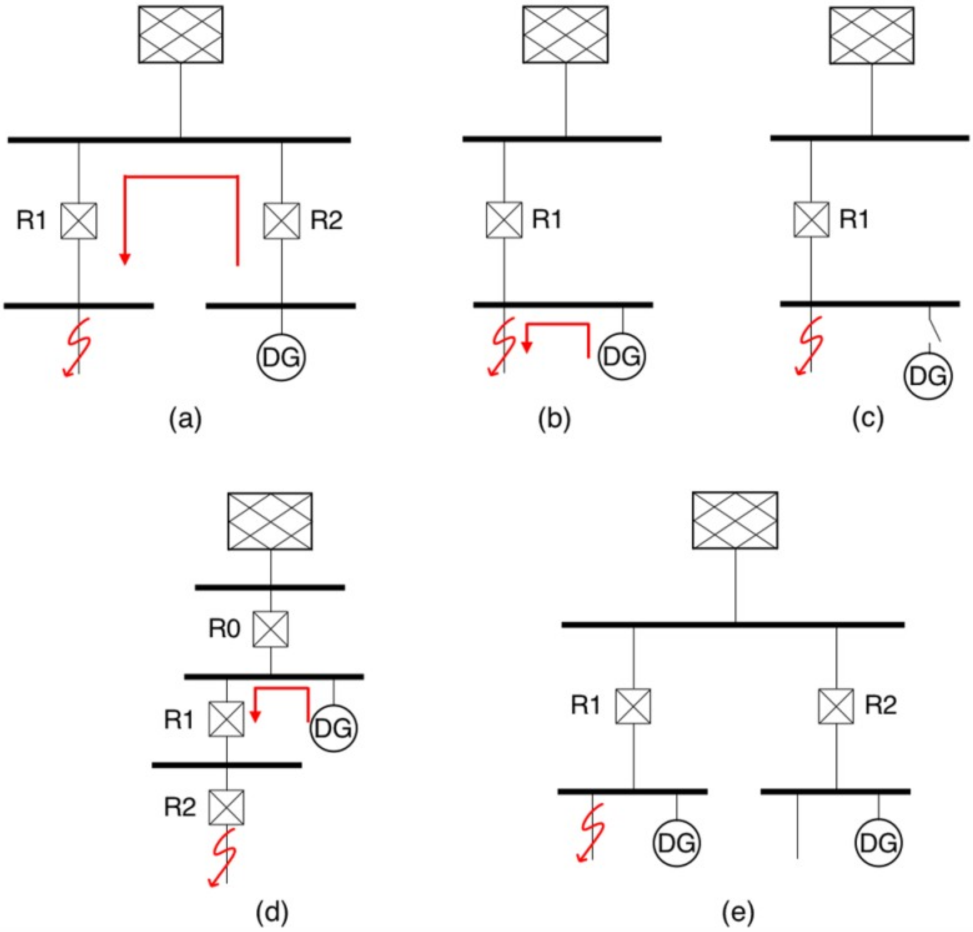


Figure 61: Overview of DREs impact on overcurrent relay (a) False tripping, (b) Blinding of Protection (c) Loss of DRE (d) Loss of relay coordination, and (e) Unsuitable settings for islanded mode (Source: Kumar D.S., 2017 and Gandhi et. al 2020)

4.3.6 Duck Curve Effect

Duck curve effect is one of the most popular impact of PVs in the grid. The PVs inject active power during the daytime into the grid. So, the grid substation sees the load in the duck shaped curve. Figure 62 shows the duck curve observed in California-by-California Independent System Operator (CAISO).

Such a curve has severe impact in the transmission grid business. The capacity of the grid has to be developed to maintain the peak demand, which from the Figure 62 is during 7 pm; however, the energy supplied by the grid is reduced significantly. This results in high investment cost with low return. DRE developers should consider such impacts to the grid during planning phase.

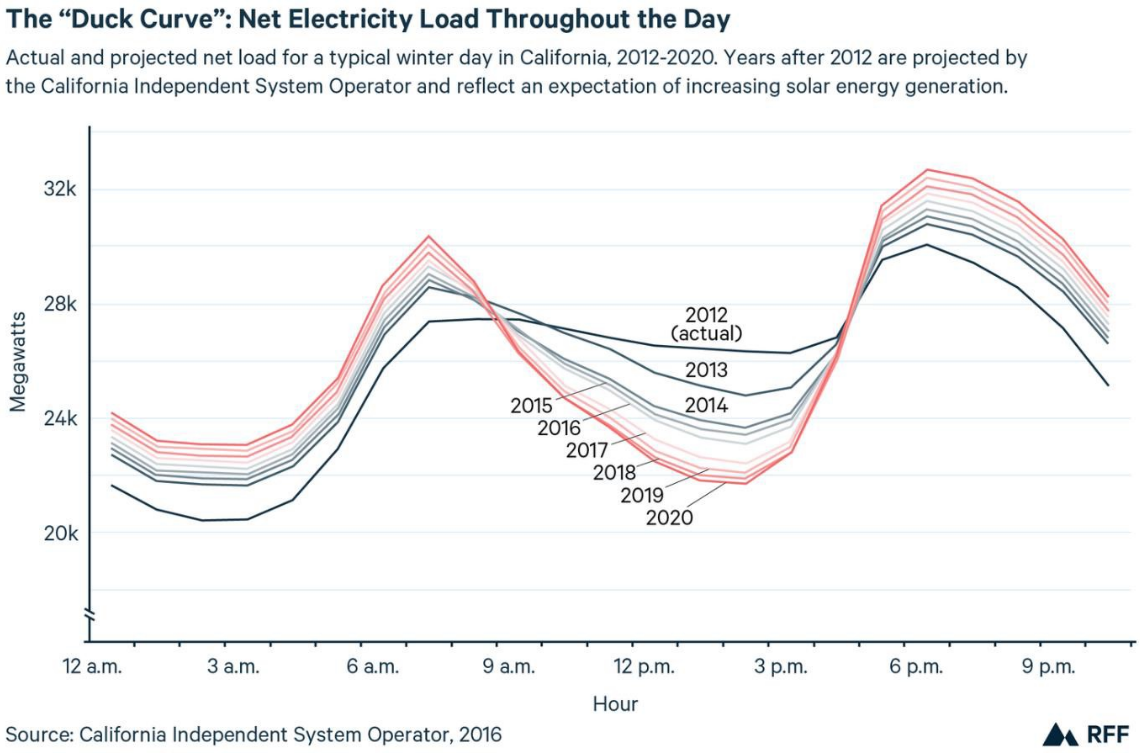


Figure 62: Duck Curve observed in California (Source: RFF, CAISO)

4.4 Role of Energy Storage on the Grid

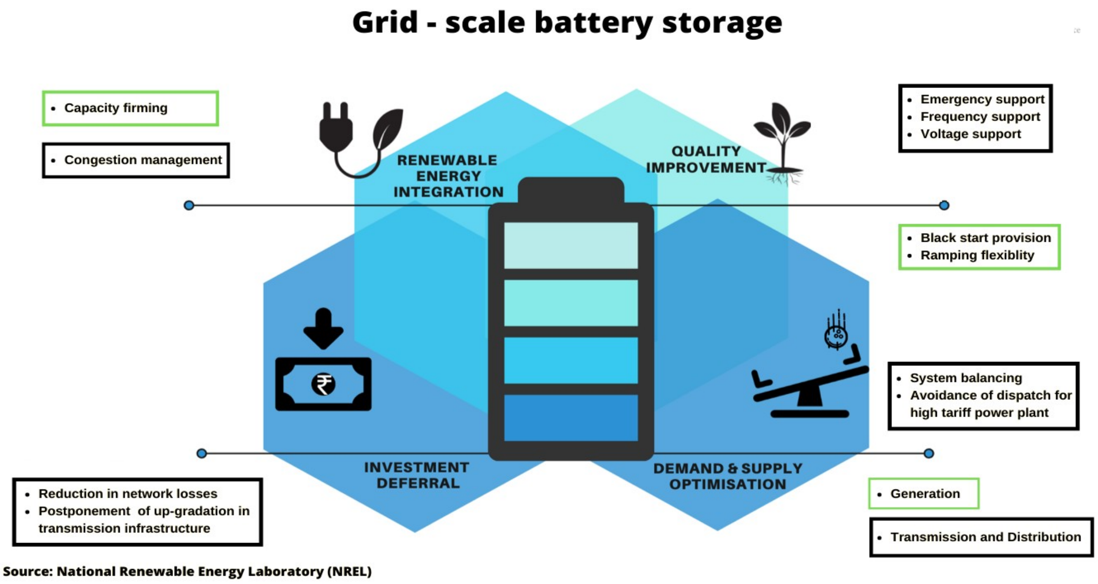
Nepal is currently undergoing an energy transition, with an increased share of renewable energy and the shift towards real-time electricity markets. These have exposed various players, particularly electric utilities and system operators, to more risks associated with system imbalances. Instances of power curtailment, and the need to ramp up or down power plants, have also increased.

Electricity stored in batteries is dispatchable, offers fast response times, and faces fewer technical restrictions when compared to typical generation sources. Therefore, battery storage can support several grid-level applications to effectively mitigate the risks mentioned above. The infographic shown below captures key applications of battery storage in the electricity grid. BESS systems can provide a range of benefits and support functions to the power grid, including:

- Frequency regulation;
- Ancillary services/grid stability – BESS systems can charge and discharge quickly, making them ideal for balancing the grid on demand or production side;
- Voltage support/stabilization;

- Emergency response systems – BESS systems can provide emergency response services of frequency regulation, ramping and voltage support in a manner that is close to energy reliability services from synchronous facilities;
- Operating reserves;
- Reduction of grid congestion;
- Ramp rate control;
- Energy arbitrage;
- Capacity firming;
- Peak shaving;
- Black start.

Choosing batteries for energy storage can be beneficial for several reasons. First off, battery storage ideas have no limits regarding location—one doesn't need to provide huge water tanks or underground air reservoirs. Owing to its availability and flexibility, a BESS can fit in well with applications that require varying power and storage capacity levels. Moreover, modern battery technologies tilt toward light weight, cost-efficiency, safety, and environmental friendliness. Let's consider the use cases of a battery energy storage system and the essential problems it can solve.


Grid - scale battery storage

Source: National Renewable Energy Laboratory (NREL)

Figure 63: Benefits of Grid – Scale battery storage system

4.4.1 Balancing Supply and Demand

One BESS system gaining popularity involves a bank of lithium-ion batteries with bidirectional converters that can absorb or inject active or reactive power at designated set points through a power conversion system (PCS) to the electricity grid along with a battery management system (BMS) to monitor battery condition and charge rate as well as estimate the amount of usable electrical energy stored in the battery pack. Benefits of BESS units include capacity to rapidly compensate for peak loading with a high energy demand that causes a slight change in frequency, ramp control, and capacity firming when output drops (i.e., wind falls or clouds come over). The compensation is accomplished by supplying an adjustable range of real or reactive power, replacing spinning reserve capacity to cope with generator failure or unexpected transmission loss, enhanced capacity to bootstrap after a blackout and/or loss of generation capacity, storage of low-cost power and capacity to level out power flow and delay costly upgrades. Additional applications of big battery RE storage technologies include the following: (i) reducing the need for ‘peaking plants’ (high-cost, highly responsive fossil-fuel powered plants that can be used to meet peak loads); and (ii) deferring the need for costly upgrading and augmentation of transmission and distribution networks to improve their ability to handling peak loads. There are, however, different grid dynamics depending on whether the RE generation and big battery storage is distributed or centralized. When distributed generation is combined with distributed storage, it ‘knocks off the peak’ because, from a whole-grid perspective, it is the equivalent of a reduction in demand. The demand peak still occurs but it is supplied by small generators and storage units that are outside of the control of market operator. Ideally, this would translate into a reduced need for peaking oil and coal plants and reduced need for the network to carry the peak load. However, a distributed generation and storage system would have limited capacity to respond in real time and in a coordinated fashion to larger-scale load trends; hence, a preferred approach would be the combination of distributed energy storage technologies with a centrally directed decision system.

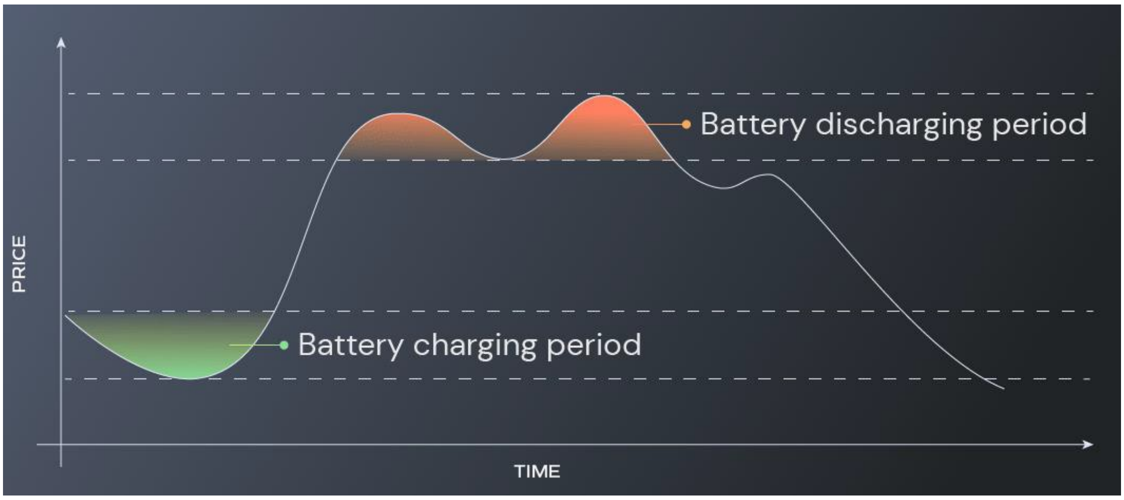


Figure 64: Peak shaving with BESS (Source: Exro)

Peak shaving is a strategy for avoiding peak demand charges on the electrical grid by quickly reducing power consumption during intervals of high demand and conversely consuming power during low demands to charge the battery bank. Peak shaving can be accomplished by either switching off equipment or by utilizing energy storage such as on-site battery storage systems. The objective of peak shaving is to eliminate short-term spikes in demand and reduce overall cost associated with usage of electricity. Peaking capacity can be a concern for grid storage system operators. The operators must ensure that during peak demand times, the grid has enough energy to avoid being overrun with demand. This is where the battery energy storage system (BESS) that collects energy and releases it when needed comes in as a backup. Grid-scale battery systems are able to supplement the growing peak capacity requirements, so the energy generation does not need to increase overall capacity to accommodate these extreme conditions. The battery system will charge during off-peak times and discharge to the grid during peak times, supporting the power grid's expensive distribution transformer equipment and deferring the need for the distribution company to add more infrastructure by 'peak shaving'. Supporting reliability at the distribution system level to mitigate the impact of peak load on distribution transformer equipment and managing the load, it will also provide voltage regulation, improve power factor and provide frequency regulation services. The, community energy storage system can also assist the local network in the event of power outages and equipment failures. It can provide black start function to power equipment, helping it to back online quickly and without the need for external generators like diesel engines. It will also provide up to 4-6 hours of backup power to local services providers including industries, hospitals and commercial complexes, as well as hundreds of local residential electricity customers.

Battery energy storage systems are dispatchable; they can be configured to strategically charge and discharge at the optimal times to reduce demand charges. Battery energy storage systems can guarantee that no power above a predetermined threshold will be drawn from the grid during peak times. They can automatically detect when power usage exceeds a pre-determined threshold and switch from the grid or solar panels to batteries until the additional demand is over. When demand goes back down the batteries recharge.

4.4.2 Energy Time-Shift (Arbitrage)

Electricity prices fluctuate at different times, having both rises and falls. Battery energy storage systems allow for energy time-shifting—energy is purchased at a low price during off-peak periods and sold or used when the price increases. Thus, irrespective of the season and electricity demand, BESSs can equalize energy prices and minimize risks.

4.4.3 Backup Power

A BESS can supply backup power in case of an electricity grid failure until complete power restoration. Larger storage capacity and integration with renewable energy sources enable BESSs to back up energy for longer periods. By operating as an uninterruptable power supply (UPS), a commercial battery storage solution can be a time and money saver as it eliminates downtime.

4.4.4 Black-Start Capability

A BESS can replace a diesel or natural gas generator used by power plants to restore power generation after blackouts by leveraging its black-start capabilities. Based on battery storage, power systems can restart after a total shutdown without using external electricity networks. The fast response time of a BESS helps systems recover in the shortest possible time.

4.4.5 Frequency Control

Battery storage systems can regulate frequency in the grid, making sure its value lies within the required range. If the amount of generated power disagrees with the actual electricity demand, the frequency can either exceed or fall below its nominal value. Such discrepancies may result in temporary disconnections, power failures, or blackouts. BESSs can immediately react to power interruptions, providing sub-second frequency response, and stabilize the grid. A BESS can likewise ensure voltage stability, maintaining its level within the specified range.

4.4.6 Renewable Energy Integration

Integrating battery energy storage systems with intermittent renewable energy sources opens the door to inexpensive electricity continuously available to on-grid, off-grid, and hybrid systems. More recently, clean energy has gained popularity as an economically viable and eco-friendly alternative to fossil fuels. According to the International Energy Agency (IEA), renewables increased their share in global electricity generation from 27% in 2019 to 29% in 2020. Moreover, it is projected to reach 45% by 2040. The proliferation of renewable energy-enabled storage solutions is extensively supported and incentivized by governments through subsidies and lower tax rates. Battery storage technology enhances the efficiency of renewables. It makes them a reliable energy source for a variety of applications, including households with photovoltaics (PVs), off-grid commercial facilities, and isolated communities, such as islands and remote rural areas. A BESS assists grid-tied and hybrid solar and wind systems with energy time-shift and demand-side management. For example, in windy weather, the system can power homes and charge batteries during on-peak and off-peak times respectively. Later, the battery energy storage system can be used when the electricity demand is high and the variable energy resource is unavailable.

4.4.7 Transmission and Distribution (T&D) Deferral

Battery energy storage can eliminate the need to build new transmission and distribution systems or update existing T&D assets that lack capacity or become obsolete. By storing excess energy and providing reserve capacity, a BESS can take the load off overloaded T&D lines and prevent congestion in transmission systems.

4.4.8 Weak Grid Islanding

Adding a battery storage system together with solar will help strengthen the grid and help provide round the clock high quality power to the transmission/distribution feeders. BESS installed in this network is particularly useful in providing ancillary services. It can also store excess energy, thus deferring investments in system upgrade. By acting as an energy reserve, it balances the difference between generation and supply. Primary frequency regulation (PFR) has so far been one of the greatest value applications driven from BESS, which occurs at transmission level. Traditionally, synchronous generators have provided this service. In the absence of BESS, a part of generator capacity performing PFR has to be reserved for this service. On top of that, the process occurs with a slow response speed. As BESS has a high-power capacity and lower discharge rate, it can provide a fast response and hence a better frequency imbalance handling capability. BESS consist of one or more batteries and can be used to balance the electric grid, provide backup power and improve grid stability. BESS stabilizes the network through frequency responses and ancillary services, BESS stabilize grid conditions and balances loads. By storing energy close to its use, they also reduce grid extension pressure.

4.5 Criteria for BESS and DRE

After developing a thorough insight on grid applications of BESS in the previous section, this section targets on establishing a site selection criterion for BESS in a power network, so that the full potential of those grid services could be harnessed. Certain applications are better targeted when BESS is deployed at certain voltage levels of the power grid. Frequency regulation, for example is a regulatory service application that usually occurs at transmission system level, but can occur at distribution level as well. Similarly, load levelling and peak shaving are generally targeted at the distribution system level. The string of batteries is connected through a DC/AC inverter/charger. Typically, there will be multiple strings of batteries and DC/AC charges to reduce the energy and power lost if there is a battery or inverter/charger failure. Depending on the AC voltage coming off the DC/AC inverter/charger, a transformer may be needed to adjust the voltage to match the low- voltage AC bus. Similarly, solar power panels can be tied into the low-voltage AC bus through a DC/AC inverter and transformer. The low-voltage AC bus is connected to the utility bus through a step-up transformer and a disconnect. With the solar PV panels, batteries, and diesel generator, a small microgrid power distribution system can maintain power to the loads when the utility grid disconnect is opened.

An alternative design would have a DC bus. If the majority of the solar PV power is stored in the batteries before distribution to the utility grid, transformer energy loss can be reduced by having solar PV power and the batteries connected on a DC bus. The major parts of a BESS are:

A typical BESS includes:

- Battery modules – connected in series and parallel for required capacity;
- Storage enclosure with thermal management;
- Power conversion system (PCS) – All the clusters from the battery system are connected to a common DC bus and further DC bus extended to PCS;
- Battery management system (BMS), which continuously monitors the voltage, temperature, fire warning and state of charge (SOC) of the battery. It regulates the charging and discharging power depending on input signal;
- Energy management system (EMS) – The control logic is executed at EMS. It will provide input signal to PCS for charge/discharge depending on control logic requirement.

A BESS is an energy source, and like any energy source that feeds the grid, it must be managed and controlled. Battery energy storage system comes especially for large scale adaptation comes in scalable containerized modules ranging from tens of kWh to MWh energy capacities. The solutions offer plug-and-play features that allow rapid installation at low installation costs. These solutions come fully integrated with a smart battery management system, power conversion system and control system.

A schematic of containerized LFP battery energy storage can be seen in Figure 65.

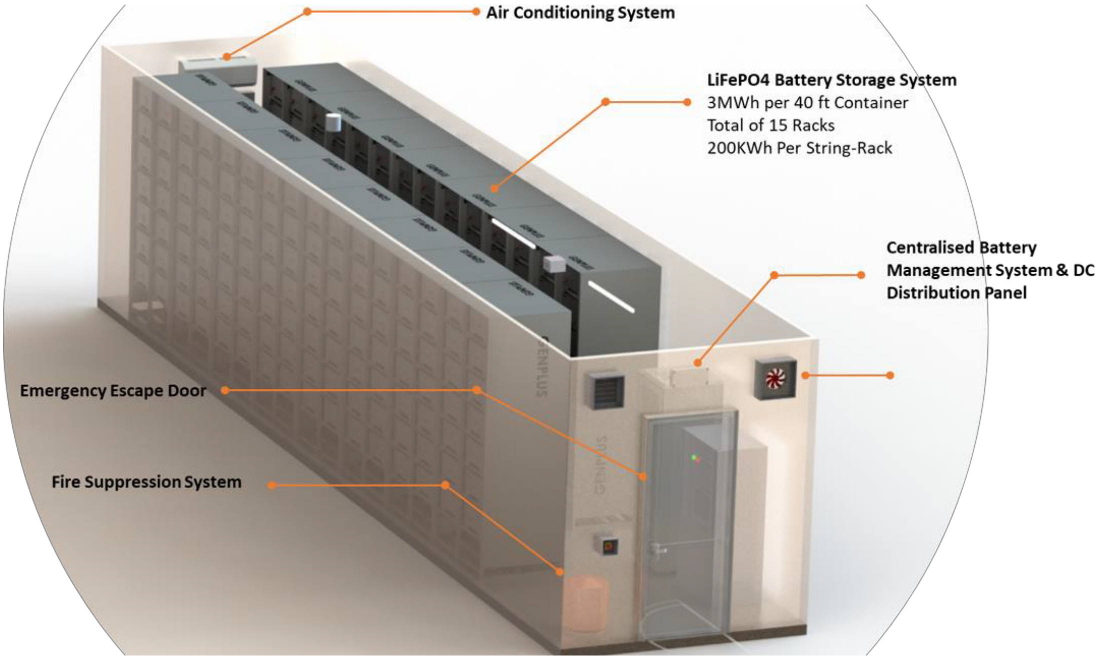


Figure 65: MW scale containerized battery storage (Source: GenPlus)

The siting of any power generation resource is important, but the immense flexibility of BESS systems mean they can be installed and utilized in any number of ways:

- Front-of-meter or behind-the-meter;
- Near to the loads/energy sources or independent/standalone;
- Co-located with variable renewable energy resources;
- Used to augment traditional power generation.

There are a variety of configurations available for BESS depending on siting. BESS can be utilized in a standalone setup, in which the BESS takes electricity from the grid when the supply is high and sends it back when the demand is high. For PV + Storage systems, four types of configurations are used.

- Independent

In this, both PV and storage systems are not physically co-located and do not share common components or control strategies. Being independent, storage responds to overall grid conditions to provide peak capacity, shift energy from off-peak to on-peak periods and provide ancillary services. Although the storage could charge from PV energy, it would only do so when grid conditions made this an economic option.

- DC Coupled (FLEXIBLE CHARGING)

In this case, the PV and storage is coupled on the DC side of a shared inverter. The inverter used is a bi-directional inverter that facilitates the storage to charge from the grid as well as from the PV.

- DC Coupled (PV-ONLY CHARGING)

This configuration is similar to DC coupled, but the storage can be charged using PV only, not from grid electricity. This is also known as the DC tightly coupled configuration.

- AC Coupled

In this case, PV and storage are co-located with two separate inverters. BESS is charged by converting the PV electricity from DC to AC and then back to DC at the BESS inverter for the BESS to store it. Since there are no shared components, the storage can still act independently of the PV system.AC coupled configurations are typically used for existing PV systems, because it's easier to just add on a second inverter, add a BESS, and then use the existing circuitry to integrate the BESS into that. DC coupled systems are more common for new PV + Storage installations. A tentative layout of 1MW battery storage can be seen in Figure 66.

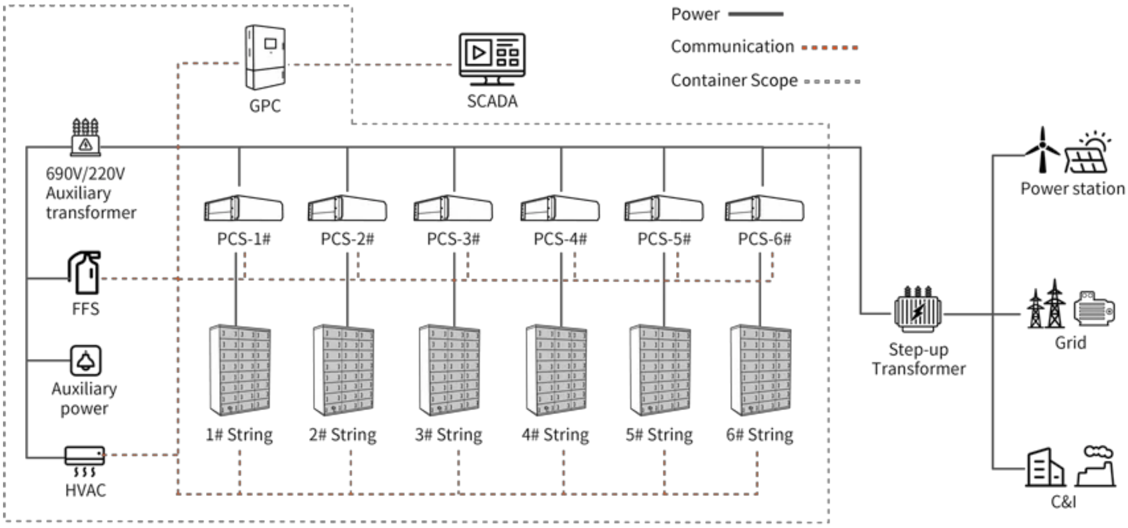


Figure 66: For the case of the study for BESS two studies were carried out.

4.6 Future trends in Grid Integration of DREs and BESS

Decarbonization, decentralization and digitization are the main three trends in the energy sector. Decarbonization refers to the transition towards a clean, carbon-free world by increasing use of renewables such as solar, wind and biofuels. Since the renewables like solar and wind are not available throughout the day, energy storage projects are to be developed to store the energy generated from renewables. Decentralization is the moving away from our current system of highly centralized energy grids, towards distributed energy production systems. Digitization is about the use of digital machines, devices, and technology to optimize energy production, infrastructure, and use. An increasing variety of zero-carbon energy sources will mean our energy networks become more complex. And decentralized grids will need intelligent solutions to monitor and manage fluctuating demand. Digital tools will help us overcome these challenges and realize much-needed changes in the energy sector.

Evidently, the grid integration requirements have become the major concern as renewable technologies such as wind and solar photovoltaic (PV) started to replace the conventional power plant slowly. In line with this, some of the new requirements and technical regulations have been established to ensure grid stability. The DREs and BESS follow the same grid interconnection standards as far as applicable. The IEEE 1547 family of standards is the critical foundation for DRE interconnection, and it establishes criteria and requirements related to performance, operation, testing, safety, and maintenance on the grid.

In case of Nepal, GoN formed Electricity Regulatory Commission (ERC) in 2019 pursuant to Electricity Regulatory Commission Act, 2017 and Electricity Regulatory Commission

Regulation, 2018 to regulate generation, transmission, distribution and trade of electricity in Nepal. The act authorizes ERC to form, execute and monitor the Grid Code and Distribution Code for the electricity services. ERC has not yet formed new Grid Code. NEA has its own grid code, which is in use since 2005 and will continue to be in use unless replaced by new Grid Code prepared by ERC. New Grid Code will define the agencies responsible for load forecasting, generation and transmission planning etc. In the absence of that the power development has not been systematic. Development of generation without due consideration of consumption has led to excess generation during wet season and inadequate generation in the dry period of the year.

NEA's Grid Code is basically prepared for the centralized generation system in which many of the features applicable for renewable energy integration are not specified. The Grid Code deals with voltage level of 66 kV and higher voltages. Grid Code does not recognize distributed renewable energy. The generators shall be synchronous generators and induction generators are not permitted, while the micro hydro power plants use induction generators. AEPC is responsible for developing and promoting distributed renewable energy in Nepal. Renewable energies in Nepal include, solar photovoltaic, solar thermal, bio-mass energy, wind energy, bio fuel bio gas and mini micro hydro power plants. AEPC mainly concentrated in areas inaccessible by national grid. In recent years, AEPC has made efforts to integrate micro/mini hydro, solar, wind energy plants to national grid once grid supply is accessible to that area. NEA is presently the single buyer of electricity in Nepal. It is facing difficulty in managing generation during wet season and importing power from India during dry season to meet the electricity demand.

Distribution system deals with voltage level of 33 kV and lower and DRE is generally connected to distribution system. However, distribution code is not yet prepared and there is no regulation and policy regarding connection of distributed energy to grid.

4.6.1 IEC 61727 Standard

IEC 61727 applies to utility-interconnected photovoltaic (PV) power systems operating in parallel with the utility and utilizing static (solid-state) non-islanding inverters for the conversion of DC to AC. This standard applies to low voltage utility distribution system for systems rated at 10 kVA or less mainly in the individual residences with single or three phase. The standard specifies the quality parameters to be met by the power delivered by the solar PV system.

4.6.2 IEEE 1547 Standard

IEEE 1547 specifies specifications for, and testing of, the interconnection and interoperability between utility electric power systems (EPSs) and DREs. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. It also includes general requirements, response to abnormal conditions, power quality, islanding, and test specifications and requirements for design, production, installation evaluation, commissioning, and periodic tests. The stated requirements are universally needed for interconnection of DRE, including synchronous machines, induction machines, or power inverters/converters and will be sufficient for most installations. The criteria and requirements are applicable to all DRE technologies interconnected to EPSs at typical primary and/or secondary distribution voltages. Installation of DRE on radial primary and secondary distribution systems is the main emphasis of this document. The IEEE 1547 has 7 sub components.

- IEEE 1547 - Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE 1547.1 - Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
- IEEE 1547.2 - Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE 1547.3 - Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems
- IEEE 1547.4 - Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
- IEEE 1547.6 - Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks
- IEEE P1547.7 - Draft Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection

4.6.3 IEEE 929 Standard

IEEE 929 specifies the level of harmonic distortion for the injected grid current. It is specified in the standard that the total harmonic distortion (THD) for the injected grid current should be lower than 5% in normal operation to avoid adverse effects on other equipment connected to the grid.

5 ANALYSIS OF BESS AND DRE INTEGRATION IN INPS WEST

Earlier chapters indicate precarious situation of existing power quality of the distribution network. As the power system of Nepal is evolving, there will be significant rise in loads as forecasted by different agencies. Current distribution network may not be able to cater the ever-increasing demand. There are two possible solutions to this problem. The first would be the expansion of the existing transmission and distribution network which includes building new substation and transmission line while the second option would be setting up distributed sources of energies like solar, battery storage and small hydro where applicable. The distributed energy resources will supply the power directly to loads thereby reducing the burden on the feeder and improving the voltage profile.

The adoption of either of the solution is highly dependent on the cost effectives of each and will be site specific. The focus now should be in adoption of distributed sources of energy and integrate with the national grid. Solar power plant has emerged as the one of the prominent DRE but its stochastic nature is one of the major drawbacks as a reserve plant is essential during unexpected low power generating situations.

In addition to the stochastic nature, other characteristic of the Solar PV plant is that it's generation is high during mid-day and drops down as the day progresses, whereas the load peaks during evening, essentially providing duck shaped load curve to the utility as discussed in the earlier chapter. In case of INPS, this curve would also allow use of peaking run-of- river type power plants in the evening. However, the practical advantage should be assessed on case-by-case basis considering the location of the PV plant in the network.

Further analysis can be based on the outcomes of the study referred above including not only solar but other DRE as well. A comprehensive study has been performed by National Planning Commission regarding the adoption of renewable source of energy in each municipality of the country (SUDDIGAA, NPC, 2018) and indicated the solar power plant being feasible on the terrain region and micro/mini hydro being feasible on the hilly/Himalayan region of the country.

In this chapter, Solar PV is unanimously considered for use as DRE in INPS. First the impact of grid integration of Solar PV without battery backup system is provided in this chapter for reference. Thereafter, PV with BESS is modelled for the transmission network in INPS West for peak shaving and weak grid islanding. Third section of this chapter presents the cases for integration of PV with BESS in distribution system of INPS. Finally, the essential modifications to the INPS for grid integration of DREs and BESS are discussed.

5.1 Effect of Integrating Solar PV in the INPS[11]

The generation of the solar varies throughout the day and has a stochastic nature. So, it is essential to study the voltage status and frequency status during transient cases of faults in the network. Ravi et. al had performed the impact analysis of two representative Solar PV plants in INPS, one of them – close to the power plant (Devighat Solar PV plant) and other - close to the load centre (Butwal Solar PV plant). Typical daily generation curve of both the plants are shown in Figure 67 and Figure 68. It is evident from the graph that the generation is peak around mid-day and drops down as the day progresses. The other factor that must be taken into consideration is the load curve of substations west of Butwal as presented in earlier sections. The peak demand of occurs around 7 P.M in the evening and during this time of the day, the generation from the solar ceases to zero. Thus, the solar power plant can have significant contribution to generation during off peak time and has no direct contribution during the peak time. The indirect contribution from solar would be in assisting in operation peaking run of river based hydro power plant. During the day time, peaking plant can store water to be used during the peak load period. However, due to only one small capacity peaking power plant (Chameliya 30 MW) in INPS West, such benefit of Solar PV plant may not be completely obtained.

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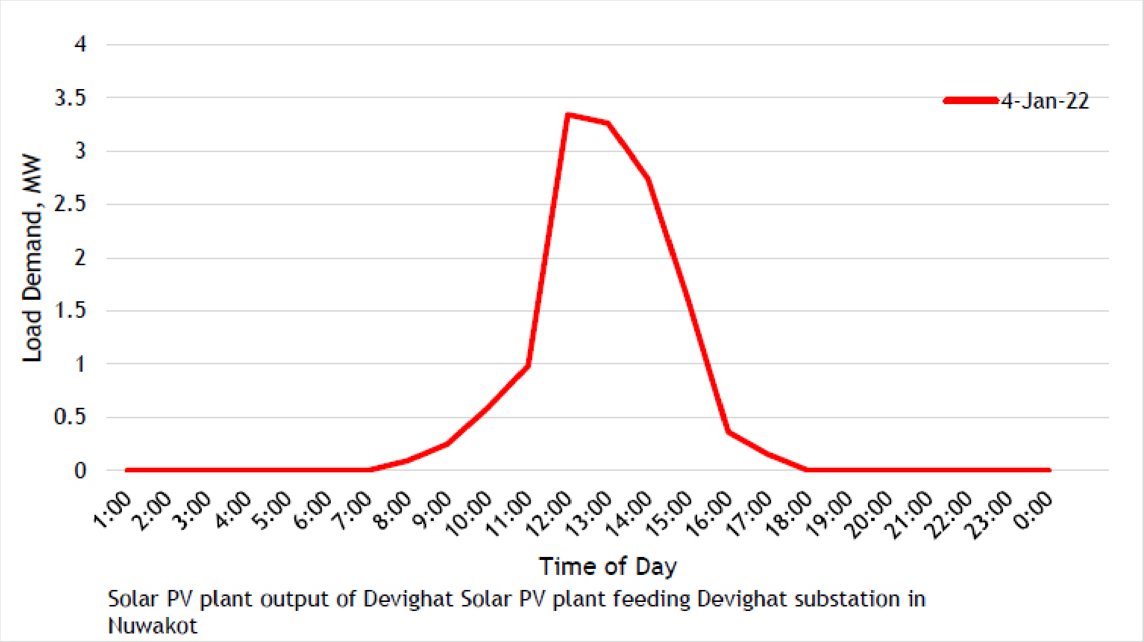
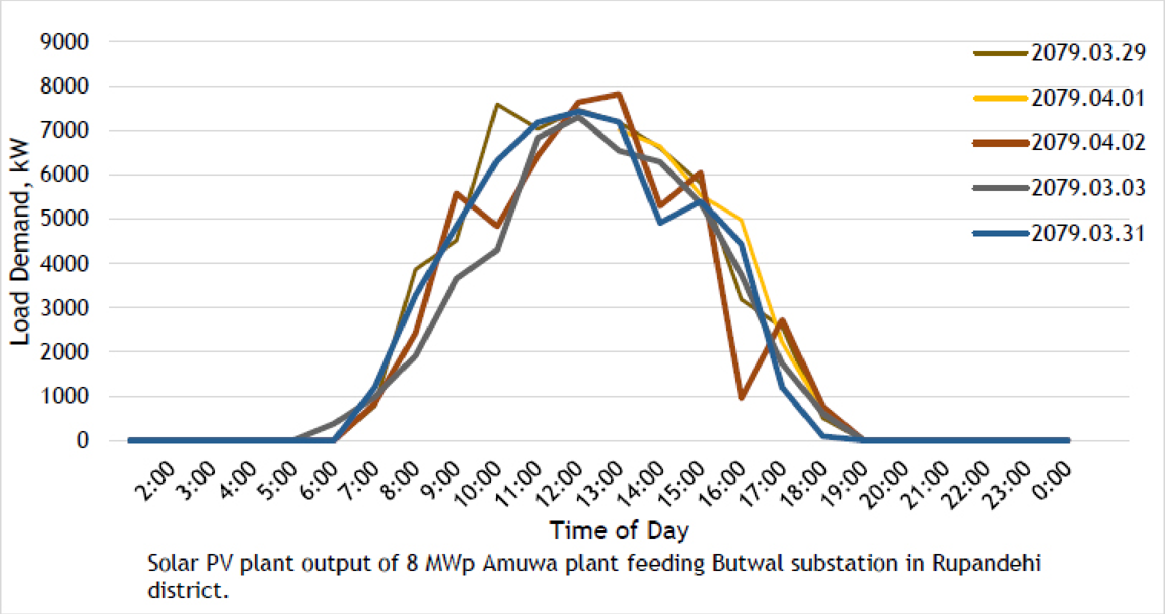
[11] Republished with permission from Stability Assessment of Grid Connected Solar PV plant placed in vicinity of Hydroelectric Plant and Load Centre in Hydro Dominated Power System, Ravi Raj Shrestha, Binay Paudyal, Prasant Basnet, Sushil Timilsina, Dayasagar Niraula, Ashish Regmi and Bibek Rai, Presented in IEMRC 2022



Solar PV plant output of Devighat Solar PV plant feeding Devighat substation in Nuwakot

Figure 67: A typical day, solar PV generation curve of Devighat Solar PV plant



Solar PV plant output of 8 MWp Amuwa plant feeding Butwal substation in Rupandehi district.

Figure 68: Output of 8 MWp Amuwa Solar PV Plant in Butwal

The effect of integrating solar power plants on voltage and frequency stability have been investigated into the hydro dominated power system of Nepal. The study has shown stable nature of voltage and frequency for solar power plant near to hydro power station while those away from the hydro station and near to load centre can exhibit oscillatory nature when disconnected from the system (Ravi et. al, 2022). The study considered the cases of Devighat and Amuwa Solar PV plants.

5.1.1 Impact Analysis of Solar PV Plant Close to Hydropower Plant

Devighat solar PV plant is evacuated at 66 kV switchyard of Devighat hydropower plant. A single circuit 66 kV transmission line connects Devighat hydropower plant with Trishuli hydropower plant while a double circuit transmission line at 66 kV connects the Devighat hydropower plant with Chapali substation. 33 kV transmission line is extended from switchyard of Devighat hydropower plant to a few 33 kV substations. Devighat solar PV Plant lies in the Hilly region, close to the hydroelectric plants namely Trishuli and Devighat HEP. Five cases have been simulated for Devighat solar PV plant. Frequency Deviation and Voltage Profile of the buses along Rotor angle stability of nearby HEPs have been observed.

- Case I: Three Phase Fault on the Transmission line from Devighat to Trishuli Substation.
- Case II: Three Phase Fault on 33 kV bus of Devighat Substation.
- Case III: Three Phase Fault on 66 kV bus of Devighat Substation.
- Case IV: Three Phase Fault on the Transmission line from Devighat to Chapali Substation.
- Case V: Tripping of Solar PV Plant without reclose.

Figure 69 presents the frequency deviation for 33 kV Devighat PV, 66 kV Devighat, and 66 kV Trishuli bus for Cases I-V. The results indicate stable behavior of the system. For Case III and IV, the frequency deviation of 33 kV bus of Devighat PV plant has spiked but has remained below ±2.5 % margin dictated by the grid code for the stability of the system. The inertia of hydropower plants located at the proximity of the solar PV plant has effectively damped the oscillations of the frequency after the removal of fault.

In all cases, the voltage appears to be within limit of ±0.05 per unit (Figure 70). The voltage of buses near the point of fault have dipped to zero during the fault but have recovered to a stable post fault value after the removal of fault with slight or no oscillations indicating stable operation.

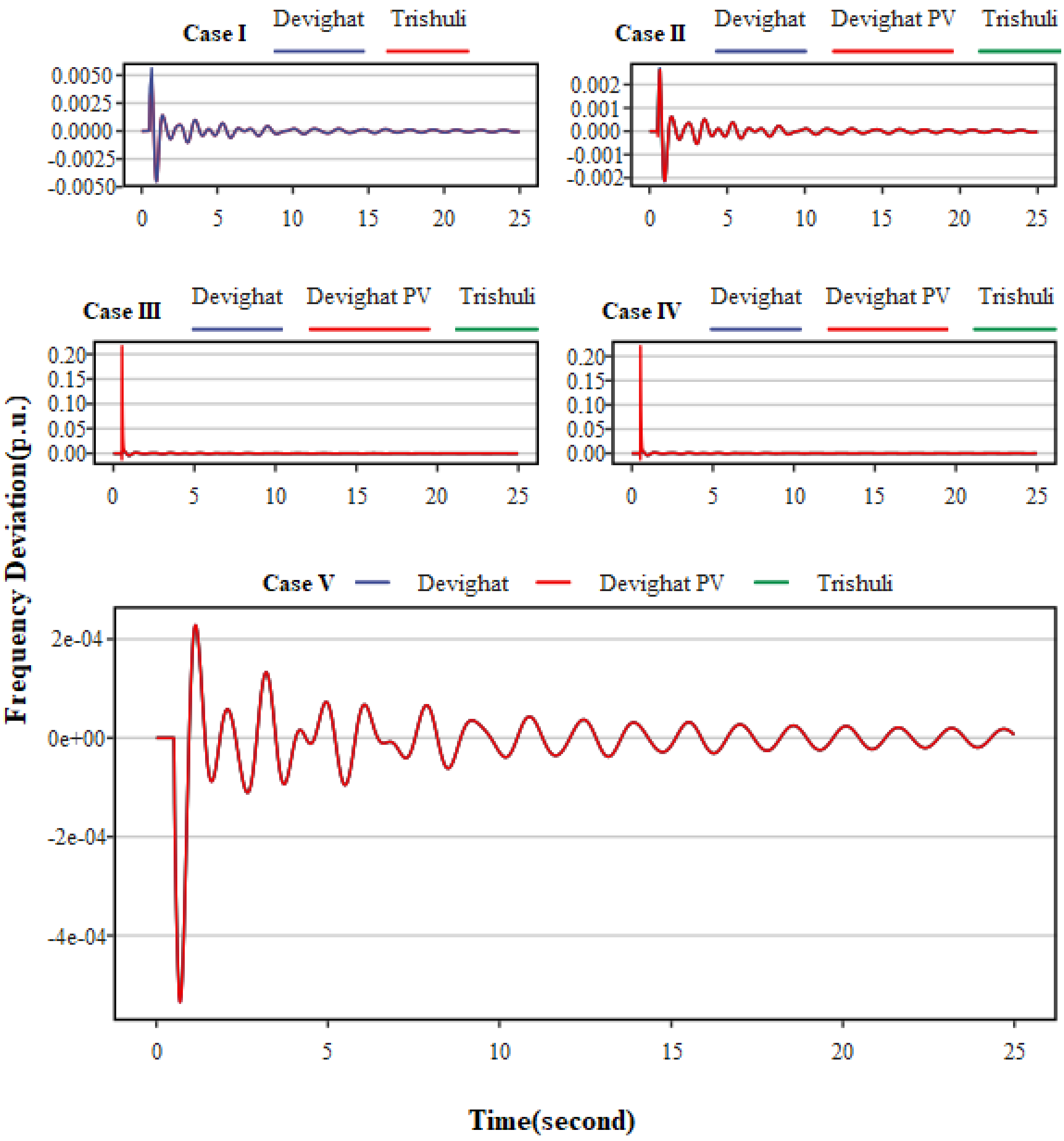


Figure 69: Frequency of 33 kV Devighat PV, 66 kV Devighat, and 66 kV Trishuli bus

5.1.2 Impact Analysis of Solar PV plant close to Load Centre

The Butwal or Amuwa solar PV plant is evacuated at 33 kV Amuwa substation. It lies in the Terai belt, close to the load centre. Frequency Deviation and Voltage Profile are observed in the simulations. Four cases have been simulated for Butwal solar PV plant.

- Case I: Three Phase Fault on the transmission line from Butwal Solar PV Plant to Amuwa Substation.
- Case II: Three Phase Fault on 33 kV bus of Amuwa Substation.
- Case III: Three Phase Fault on 33 kV bus of Butwal Solar PV Plant.

- Case IV: Tripping of Solar PV Plant without reclose.

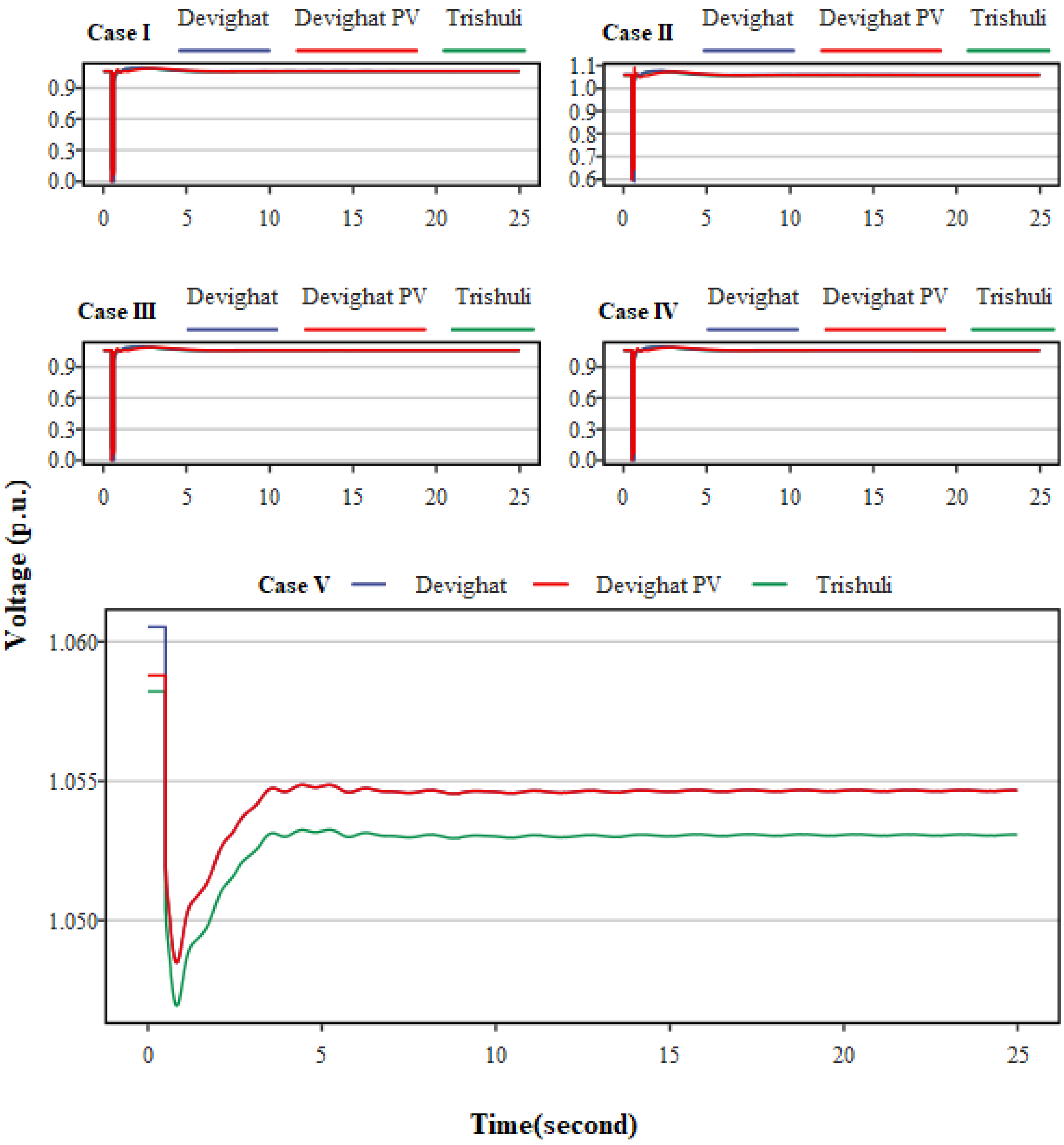


Figure 70: Voltage Profile of 33 kV Devighat PV, 66 kV Devighat and 66 kV Trishuli bus

Figure 71 presents the results for the frequency deviation for the four cases. The frequency is observed to be in oscillatory nature. The oscillations are sustained for a larger duration of time. This is the result of lack of support from plants with higher inertia, such as hydropower plants, to dampen the oscillations quickly. In the Case III, when the fault is applied on 33 kV bus connecting Solar PV plant to the substation, the frequency deviation exceeds the margins provided by grid code rendering the system unstable.

Figure 72 illustrates the voltage profile of the 33 kV bus of Butwal solar plant, Amuwa Substation and Butwal Substation for all four cases. The nature of bus voltages is similar to observations for the case with Devighat solar PV plant i.e., the voltages have dipped to zero during the fault but have recovered to a stable post fault value after the removal of fault with slight or no oscillations.

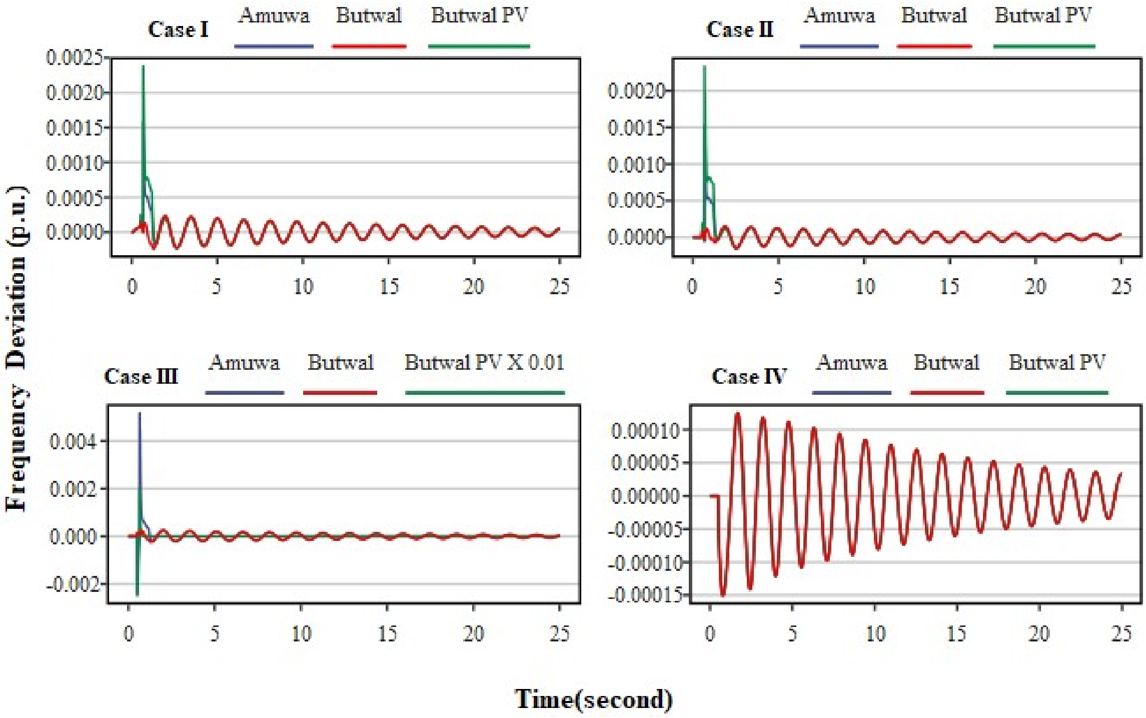


Figure 71: Frequency of 33 kV bus of Butwal Solar Plant, Amuwa Substation and Butwal Substation

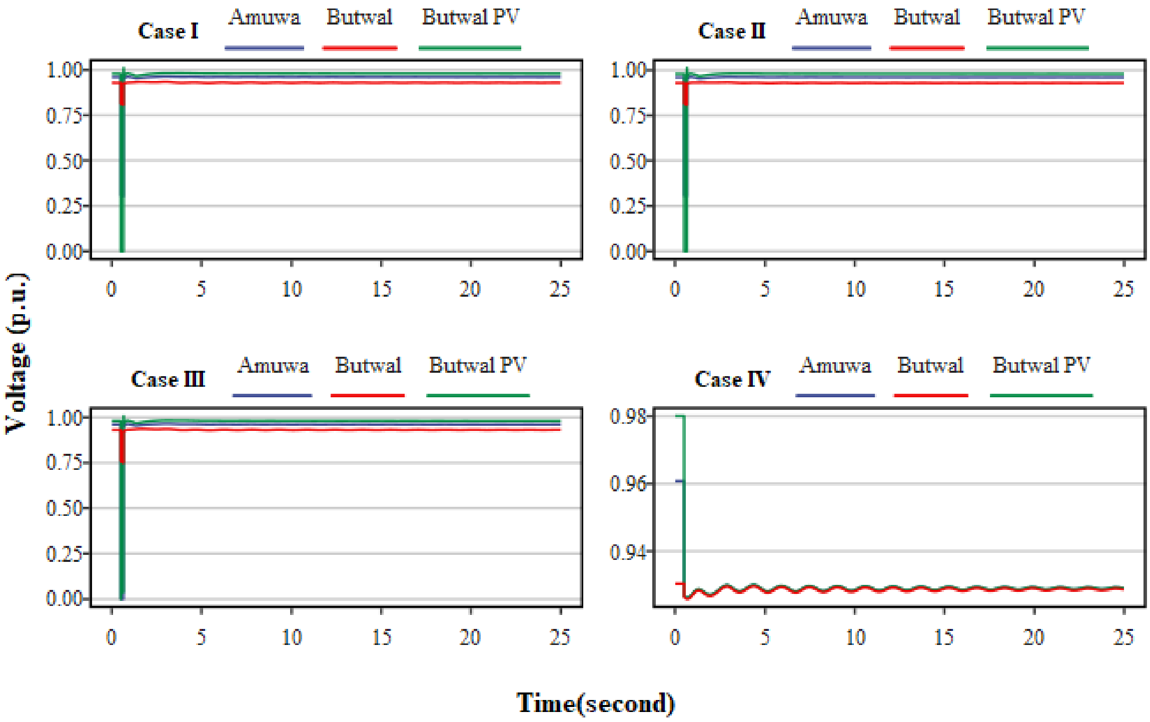


Figure 72: Voltage Profile of 33 kV bus of Butwal Solar Plant, Amuwa Substation and Butwal Substation

5.2 Effect of Integrating Solar PV with BESS in INPS West

A battery energy storage system supports the solar PV plant pacifying its stochastic nature and even supplying active power during the evening peaks. Such a system could even support a part of network islanding the weak grid. In this study, the cases of peak shaving and weak grid islanding has been observed.

For the peak shaving two sites one 33kV catering to the industries in Chanauta and similarly another in Nepalgunj catering to the industries was selected. The sites were selected as they will be able to cater to the industries where the import from India or supply from NEA will be lower. The system will be able to supply the peak to the industries by the use of batteries.

For the weak grid Islanding 33kV substation in Surkhet was considered. The transmission line emanating from 132 kV Kohalpur to 33 kV feeder in Surkhet was considered. Due to the long distance of around 54 km passing through the forest area there is frequent tripping in the line. A total of 94 hours in 2021/22 there was frequent line tripping and power outages. Thus, it serves as a suitable case for observing the weak grid islanding. A simulation was carried out for observing voltages at 33 kV of selected substations at 1 pm on a typical day. It shows that the injection of Solar PV plant serves in improving the voltage profile (See Figure 73).

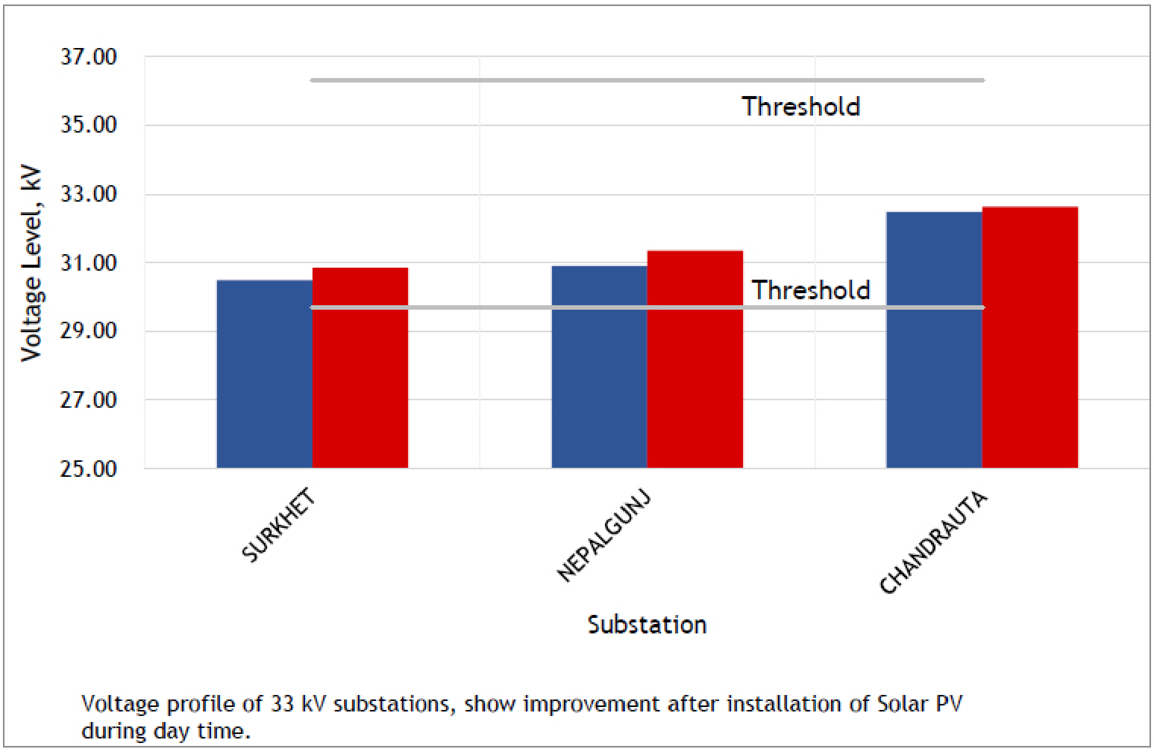


Figure 73: Voltage Improvement after injection of Solar PV plants in selected substations

In this study, optimization of Solar PV with BESS System is carried out for the peak shaving simulations and then Solar PV and BESS model are designed for all three selected sites. This section first describes the optimization approach for Nepalgunj and Chanauta site, then provides the descriptive model of the Solar and BESS system.

In addition to these, a Solar PV plant is modelled to feed-in Belauri substation of Sudurpashchim Province. The locations of the Solar PV plant in INPS is depicted in Figure 74.

For the detailed analysis for integration of DRE in medium voltage line, among others Bageshwori Feeder (with total length of 9.61 km, radial length of 2.99 km and peak load of 4.09 MVA) and Khajura Feeder (with total length 76.35 km, radial length 19.09 km and peak load of 3.86 MVA) emanating from Nepalgunj New substation could be considered. Detailed analysis of 11 kV feeders is provided in LRMP study report.

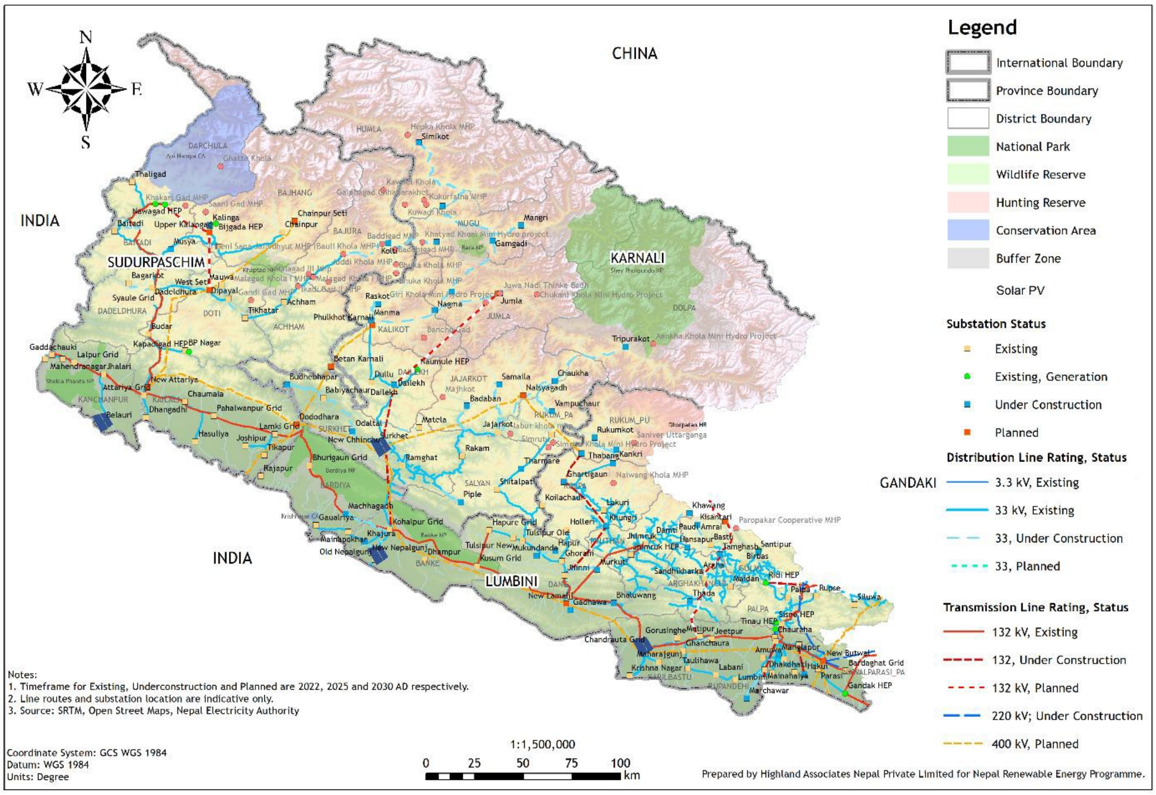


Figure 74: Selected location of Solar PV plants in INPS West

5.2.1 Optimum mix of hydro and Solar to make the system robust from reliability/security perspective in Nepalgunj

For evaluating the energy mix, the first need is to evaluate load profile for Nepalgunj. An hourly load for August 17, 2022 was taken. The load profile was taken from NEA's office (Source: Highland). Similarly, solar generation was taken from the generation from 6.5MWp/5 MW carried out from PVsyst. Since 25.6% of the generation is used for the battery charging while 74.4% is fed to the grid. Hence of the total only 74.4% of the generation was taken.

The maximum load in the site is 26.89 MVA at 4 pm whereas the corresponding solar generation at 4 pm is 2.15 MW. The peak generation is at 1 pm of 3.33 MW and load is 25.55 MVA. Hence solar at 1 pm will be able to compensate 13% of the load. The average generation from solar will be able to replace 4.35% of the load for the day (See Figure 75). The overall energy consumption in the site for the year is shown in Figure 76.

The total energy consumption for the site was 138,921.1 MWh. The maximum consumption is for the month of June with the consumption of 14,184.5 MWh. Of the total energy consumption on average for the year 35.7% of the energy was imported. The energy policy of Nepal states 10% of the total load will be supplied through DRE. Hence setting this target the optimum solar mix in the grid was estimated as shown in Figure 77.

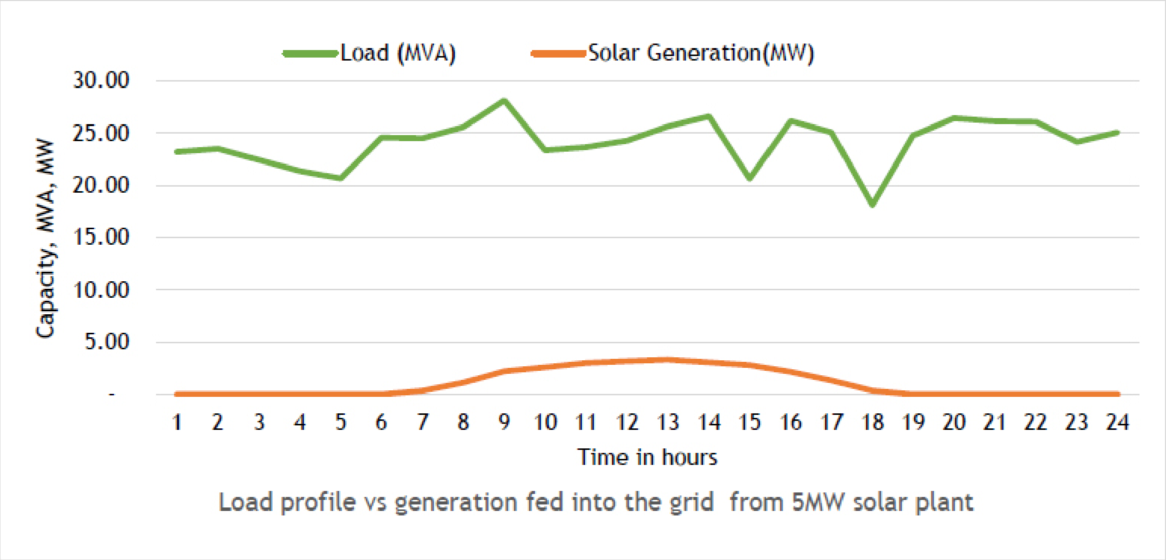


Figure 75: Load and Solar PV generation at Nepalgunj PV site

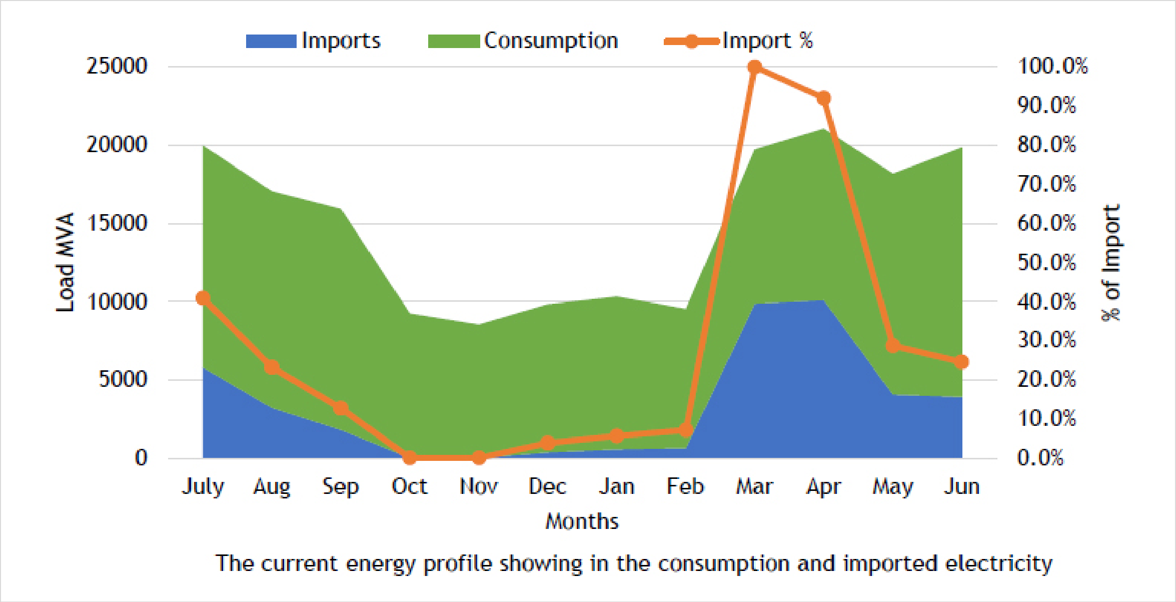
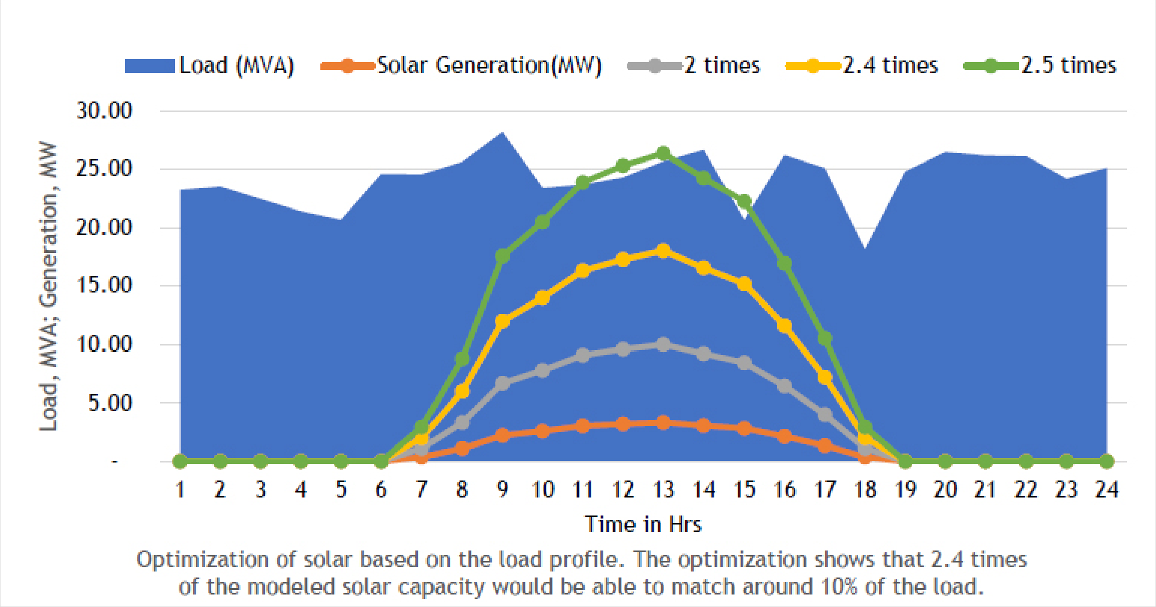


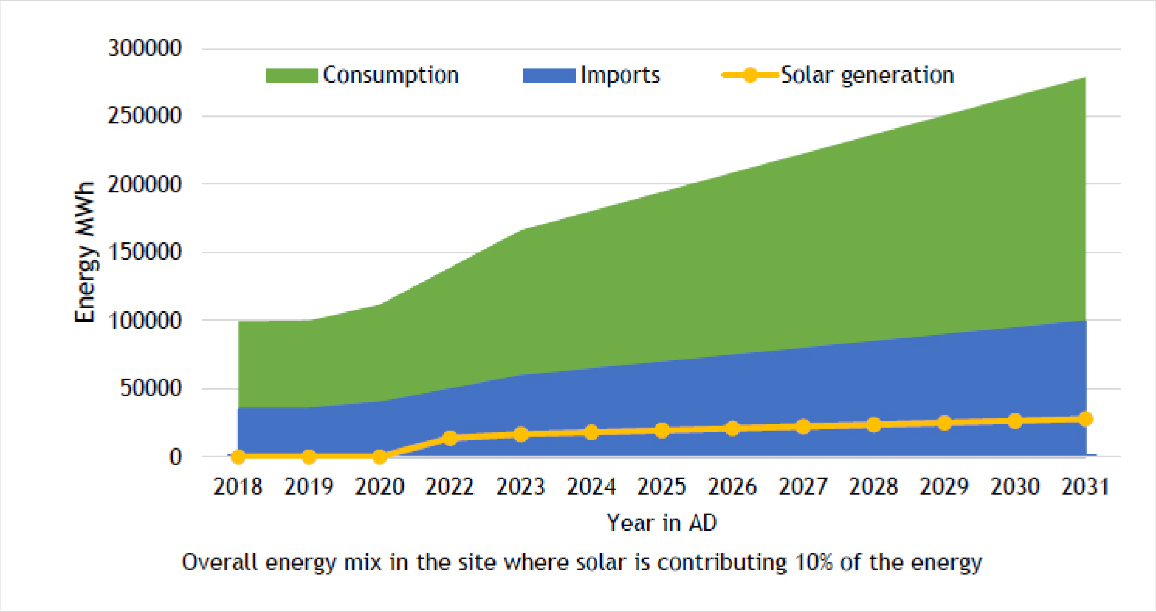
Figure 76: Overall energy at Nepalgunj PV site

Based on the current trend the optimum mix for solar would be 2.4 times the simulated energy which is 12 MW for the substation. For forecasting the size of PV to meet the load increment of the substation estimate was done taking in solar replacing 10% of energy consumption with solar. The solar energy generation matching the load can be seen in Figure 78. The total solar PV capacity to be installed and mix of solar with the load forecast can be seen in Table 7.



Optimization of solar based on the load profile. The optimization shows that 2.4 times of the modeled solar capacity would be able to match around 10% of the load.

Figure 77: Optimization of solar PV at Nepalgunj PV site



Overall energy mix in the site where solar is contributing 10% of the energy

Figure 78: Energy mix forecasting at Nepalgunj PV site

Table 7: Expected Solar PV Capacity required for Nepalgunj Substation till 2030

YEAR	CONSUMPTION (MWh)	IMPORTS (MWh)	SOLAR GENERATION (MWh)	SOLAR CAPACITY REQUIRED (MW)
2022	138921.1	49594.83	13892.11	12
2023	166308.64	59372.18	16630.86	14.3
2024	180389.99	64399.23	18039	15.6
2025	194459.51	69422.04	19445.95	16.8
2026	208518.19	74440.99	20851.82	18.0
2027	222566.91	79456.39	22256.69	19.2
2028	236606.45	84468.5	23660.65	20.4
2029	250637.5	89477.59	25063.75	21.6
2030	264660.66	94483.85	26466.07	22.8

5.2.2 Optimum mix of hydro and solar to make the system robust from reliability/security perspective in Chanauta

For evaluating the energy mix the first need to evaluate load profile for Chanauta. An hourly load for 29-04-2078 was taken. The load profile was taken from NEA's office. (Source: Highland). Similarly, solar generation was taken from the generation from 6.5MWp/5 MW carried out from PVsyst. Since 25.6% of the generation is used for the battery charging while 74.4% is fed to the grid. Hence of the total only 74.4% of the generation was taken.

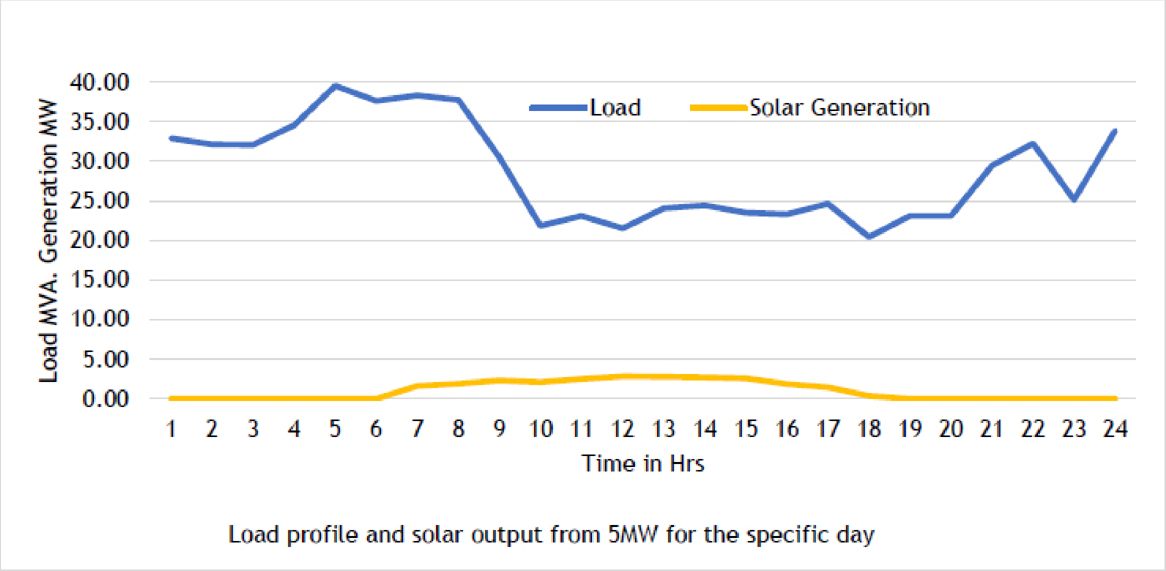


Figure 79: Load Profile and Solar PV generation at Chanauta PV site

The maximum load in the site is 38.33 MVA at 7 am whereas the corresponding solar generation at 7 am is 1.64 MW. The peak generation is at 12 pm of 2.80 MW and load is 21.53 MVA. Hence solar at 12 pm will be able to compensate 13.19% of the load. The average generation from solar will be able to replace 4.16% of the load for the day (See Figure 79). The overall energy consumption in the site for the year is shown in Figure 80.

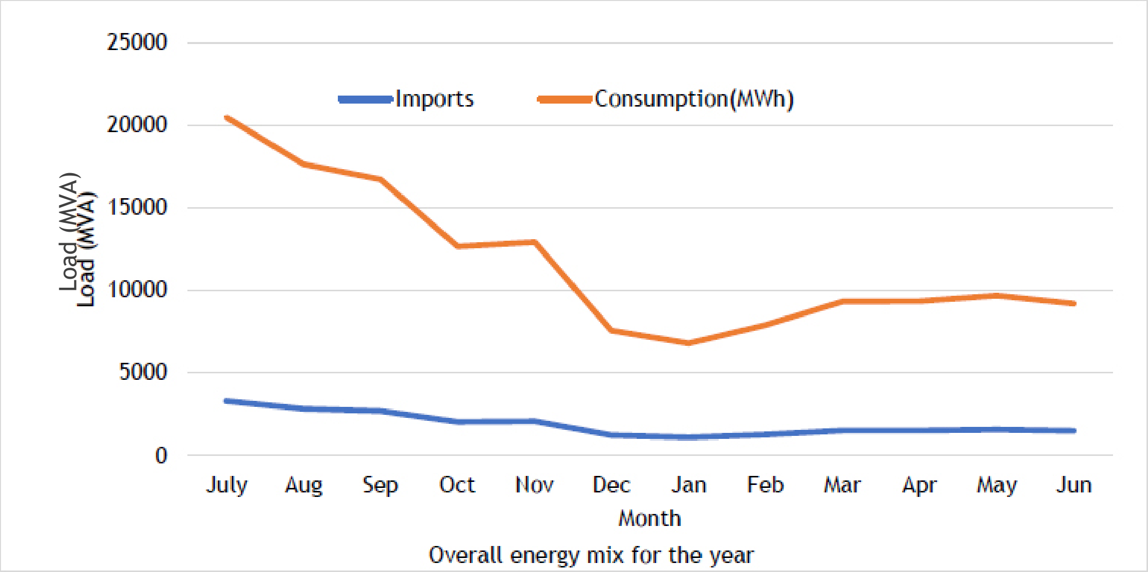


Figure 80: Overall energy mix at Chanauta PV site

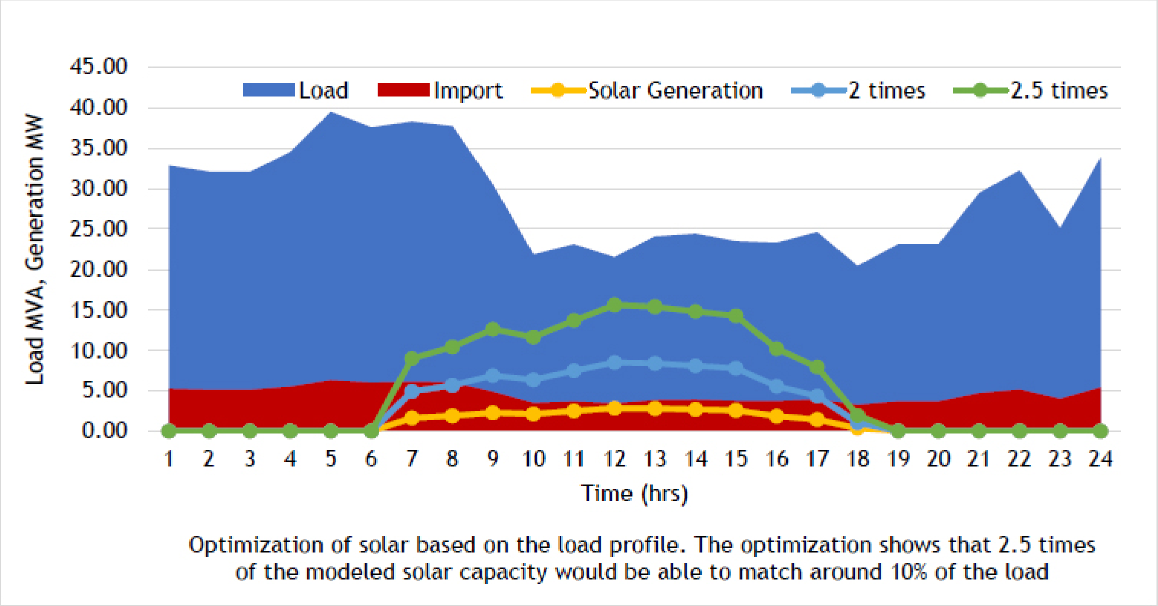


Figure 81: Solar PV output optimization at Chanauta PV site

The total energy consumption for the site was 140,275 MWh. The maximum consumption is for the month of July with the consumption of 20,494 MWh. Of the total energy consumption on average for the year 16% of the energy was imported. For the solar optimization the hourly load profile for the imported energy was incorporated. Since in terms of energy security this is really important. Hence the idea was to see the generation from different times the current generation and thus see what suits the best. The idea was to supply 10% of the energy in the substation to replace from solar.

From the Figure 81 it can be seen that by using 10 MW solar we would replace 8% of the energy whereas with 2.5 times it will replace 10.2%. Since the load was for a particular month and day in this case it replaces 10.2%, hence 2.5 times of the solar size can be considered.

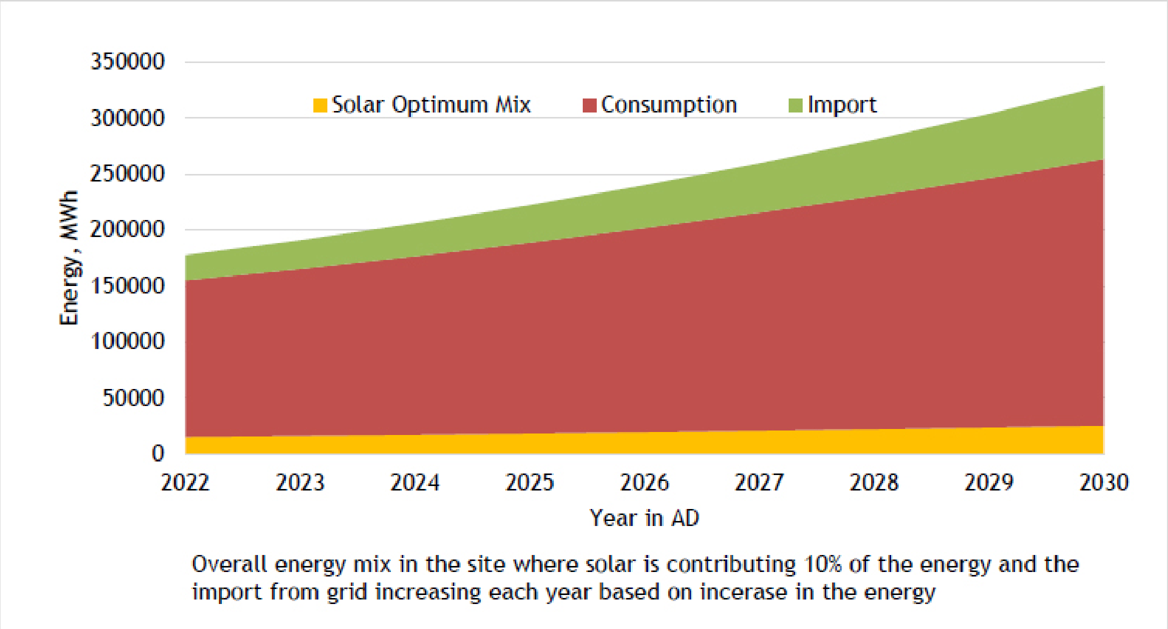


Figure 82: Energy mix forecast at Chanuta PV site

However, taking the overall scenario the best fit would be to use 12.5 MW of solar in the energy mix. Based on the current trend the optimum mix for solar would be 2.5 times the simulated energy which is 12.5 MW for the substation. For forecasting the size of PV to meet the load increment of the substation estimate was done taking in solar replacing 10% of energy with solar. Similarly for the import it was considered the import would increase with the load at 6.5%. The solar energy generation matching the load can be seen in Figure 82. The total solar PV capacity to be installed and mix of solar with the load forecast can be seen in Table 8.

Table 8: Expected Solar PV Capacity required for Chanauta Substation till 2030

YEAR	CONSUMPTION (MWh)	IMPORT (MWh)	SOLAR GENERATION (MWh)	SOLAR CAPACITY REQUIRED (MW)
2022	140275	22444	14799	12.5
2023	148675.50	25453	15685	13.2
2024	157232.03	28802	16588	14.0
2025	165788.57	32496	17491	14.8
2026	174345.10	36565	18393	15.5
2027	182901.64	41045	19296	16.3
2028	191458.18	45972	20199	17.1
2029	200014.72	51389	21102	17.8
2030	208571.25	57338	22004	18.6

5.2.3 BESS and Solar Model in Surkhet Substation

For the weak islanding system in Surkhet transmission line the parameters considered for Solar PV plant are given in Table 9. The battery chemistry considered was LFP due to its quicker response time and longer cycle life. There were total of 94 hours where there was no supply of power of grid outages. Based on the model the total energy from the solar PV was exported to the grid and in the times when the tariff was lower battery was charged. The 94 hours of no power was distributed as shown in Figure 83.

Table 9: Parameters of Solar PV with BESS modelled for Surkhet substation

PARAMETERS	VALUES	UNIT
Solar PV Capacity	6.3	MWp
AC capacity	5	MW
Peak Load	14.92	MVA
BESS capacity	15	MW
BESS capacity	60	MWh
Storage duration	4	hours

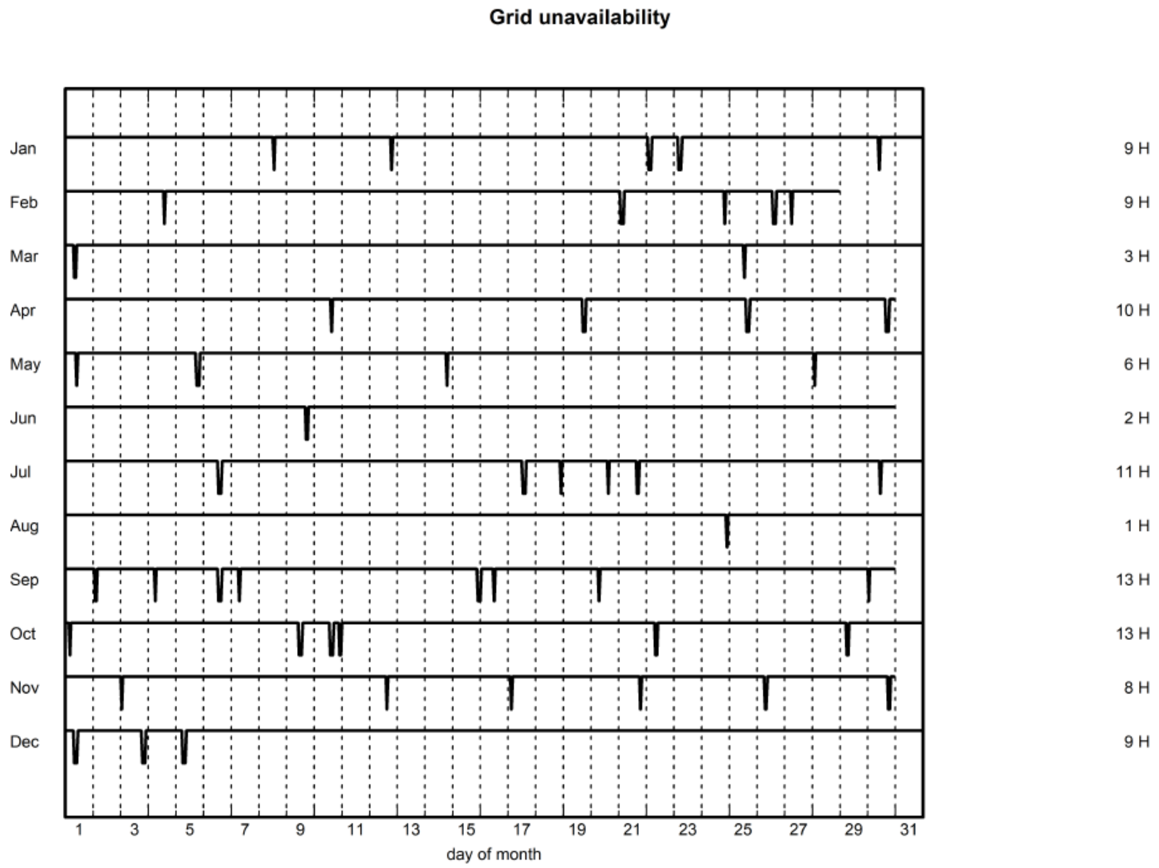
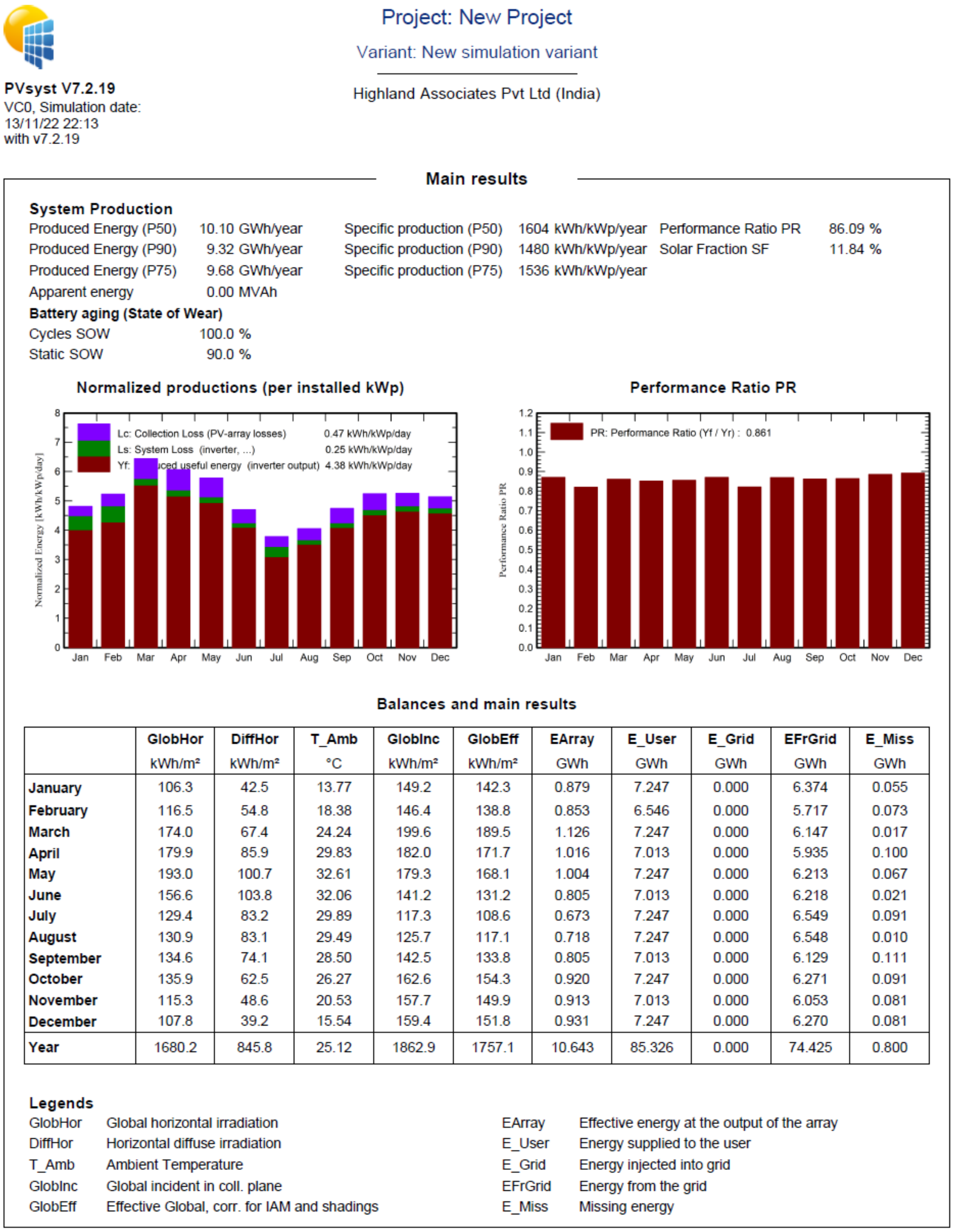


Figure 83: Grid Unavailability modelled for Surkhet substation



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with v7.2.19

Project: New Project

Variant: New simulation variant

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Main results

System Production

Produced Energy (P50)	10.10 GWh/year	Specific production (P50)	1604 kWh/kWp/year	Performance Ratio PR	86.09 %
Produced Energy (P90)	9.32 GWh/year	Specific production (P90)	1480 kWh/kWp/year	Solar Fraction SF	11.84 %
Produced Energy (P75)	9.68 GWh/year	Specific production (P75)	1536 kWh/kWp/year		
Apparent energy	0.00 MVAh				

Battery aging (State of Wear)

Cycles SOW	100.0 %
Static SOW	90.0 %

Normalized productions (per installed kWp)

Performance Ratio PR

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_User	E_Grid	EFrGrid	E_Miss
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	GWh	GWh	GWh	GWh	GWh
January	106.3	42.5	13.77	149.2	142.3	0.879	7.247	0.000	6.374	0.055
February	116.5	54.8	18.38	146.4	138.8	0.853	6.546	0.000	5.717	0.073
March	174.0	67.4	24.24	199.6	189.5	1.126	7.247	0.000	6.147	0.017
April	179.9	85.9	29.83	182.0	171.7	1.016	7.013	0.000	5.935	0.100
May	193.0	100.7	32.61	179.3	168.1	1.004	7.247	0.000	6.213	0.067
June	156.6	103.8	32.06	141.2	131.2	0.805	7.013	0.000	6.218	0.021
July	129.4	83.2	29.89	117.3	108.6	0.673	7.247	0.000	6.549	0.091
August	130.9	83.1	29.49	125.7	117.1	0.718	7.247	0.000	6.548	0.010
September	134.6	74.1	28.50	142.5	133.8	0.805	7.013	0.000	6.129	0.111
October	135.9	62.5	26.27	162.6	154.3	0.920	7.247	0.000	6.271	0.091
November	115.3	48.6	20.53	157.7	149.9	0.913	7.013	0.000	6.053	0.081
December	107.8	39.2	15.54	159.4	151.8	0.931	7.247	0.000	6.270	0.081
Year	1680.2	845.8	25.12	1862.9	1757.1	10.643	85.326	0.000	74.425	0.800

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EFrGrid	Energy from the grid
GlobEff	Effective Global, corr. for IAM and shadings	E_Miss	Missing energy

Figure 84: Results of PV modelling simulation for Surkhet Substation

The output of the simulation is shown in Figure 84. Based on the figure it can be seen that the solar fraction is 12%, which means the solar is able to supply only 12% of the load. Taking the load at 12pm the load is 9.7 MW whereas the supply is only 1.5 MW (average for all the months). If there is power outage in the grid at that time then battery will supply 8.2 MW of power, i.e., 8.2 MWh which gives a loading factor for battery of 10%.

5.2.4 BESS and Solar Model in Nepalgunj Substation

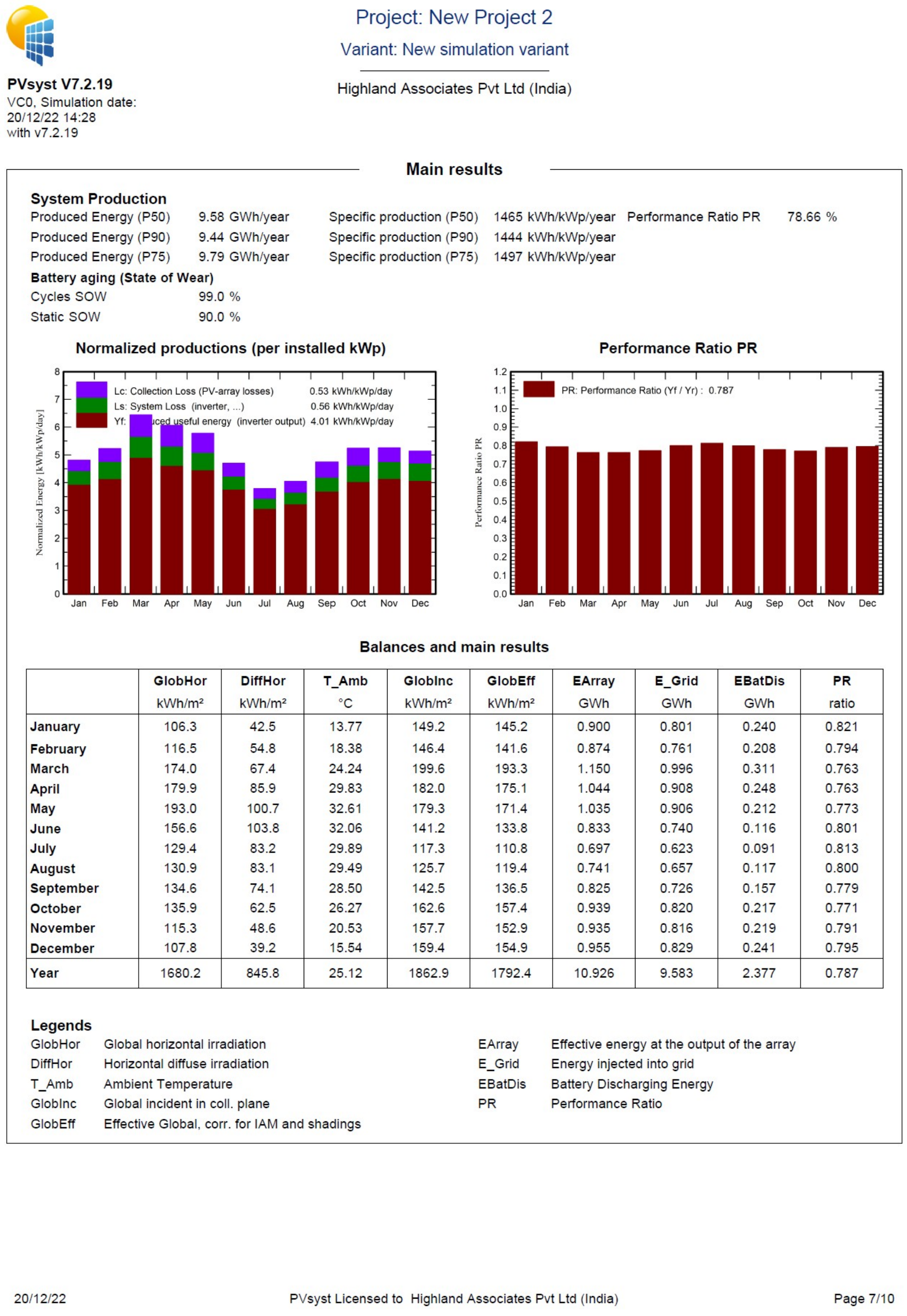
For the peak shaving in Nepalgunj transmission line the following parameters were considered. The battery chemistry considered was LFP due to its quicker response time and longer cycle life. The total storage was considered for 2 hours. The location of the substation can be seen in Figure 85.

Figure 85: Location of Nepalgunj Substation

Since there are certain areas to be able to install a 5MW system, a 5MW system was considered (Details in Table 10). Also based on the calculation above the energy generation from the system will be able to compensate for 7.24% of the total load in the substation. Based on the forecasting of the optimum level of taking in 10% for the import the load capacity to be installed is 27 MW. The output of the simulation is shown in Figure 86.

Table 10: Parameters of Solar PV with BESS modelled for Nepalgunj substation

PARAMETERS CONSIDERED	VALUES	UNIT
Solar PV Capacity	6.5	MWp
AC capacity	5	MW
Peak Load	26.89	MVA
BESS capacity	50	MWh
Storage duration	2	hours



Project: New Project 2

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

PVsyst V7.2.19
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Main results

System Production

Produced Energy (P50)	9.58 GWh/year	Specific production (P50)	1465 kWh/kWp/year	Performance Ratio PR	78.66 %
Produced Energy (P90)	9.44 GWh/year	Specific production (P90)	1444 kWh/kWp/year		
Produced Energy (P75)	9.79 GWh/year	Specific production (P75)	1497 kWh/kWp/year		

Battery aging (State of Wear)

Cycles SOW	99.0 %
Static SOW	90.0 %

Normalized productions (per installed kWp)

Performance Ratio PR

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	EBatDis GWh	PR ratio
January	106.3	42.5	13.77	149.2	145.2	0.900	0.801	0.240	0.821
February	116.5	54.8	18.38	146.4	141.6	0.874	0.761	0.208	0.794
March	174.0	67.4	24.24	199.6	193.3	1.150	0.996	0.311	0.763
April	179.9	85.9	29.83	182.0	175.1	1.044	0.908	0.248	0.763
May	193.0	100.7	32.61	179.3	171.4	1.035	0.906	0.212	0.773
June	156.6	103.8	32.06	141.2	133.8	0.833	0.740	0.116	0.801
July	129.4	83.2	29.89	117.3	110.8	0.697	0.623	0.091	0.813
August	130.9	83.1	29.49	125.7	119.4	0.741	0.657	0.117	0.800
September	134.6	74.1	28.50	142.5	136.5	0.825	0.726	0.157	0.779
October	135.9	62.5	26.27	162.6	157.4	0.939	0.820	0.217	0.771
November	115.3	48.6	20.53	157.7	152.9	0.935	0.816	0.219	0.791
December	107.8	39.2	15.54	159.4	154.9	0.955	0.829	0.241	0.795
Year	1680.2	845.8	25.12	1862.9	1792.4	10.926	9.583	2.377	0.787

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	EBatDis	Battery Discharging Energy
GlobInc	Global incident in coll. plane	PR	Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

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Figure 86: Results of PV modelling simulation for Nepalgunj Substation

Battery charging and discharging hourly for a day is shown in figure below:

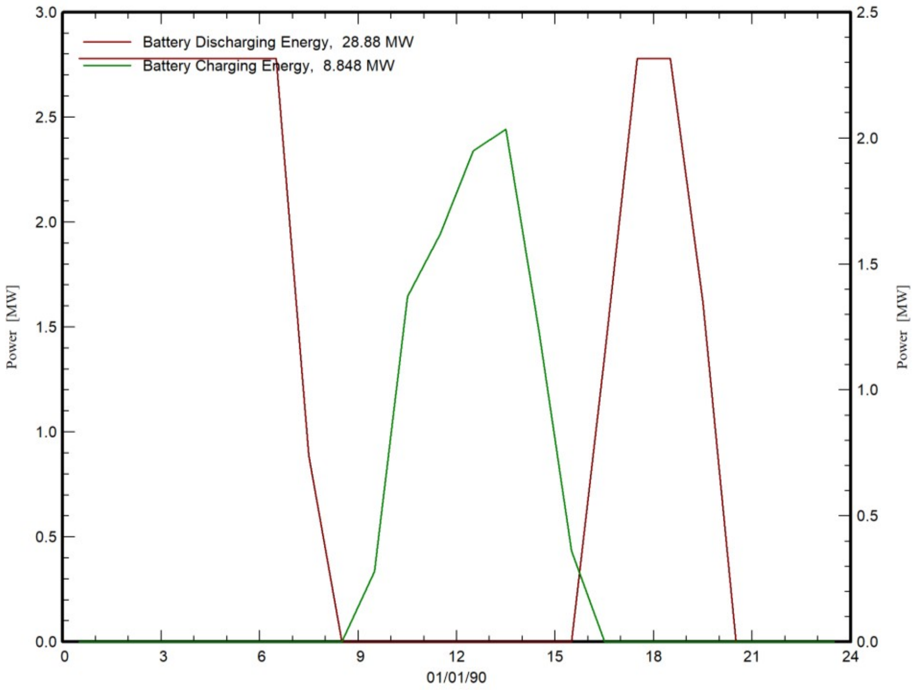


Figure 87: Daily charging and discharging from the battery

Since the total load is around 25 MW hence the battery size is able to discharge the entire load when required. Since battery discharging is for peak of 2 hours and charging time is 6 hours to not deplete the battery hence the difference is the charging and discharging.

The monthly energy use for charging and discharging for each month can be seen below:

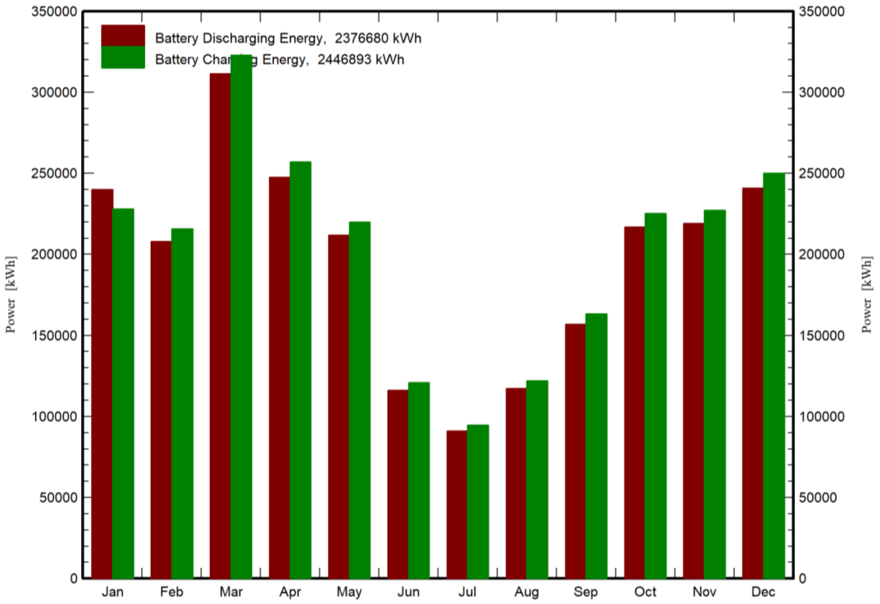


Figure 88: Monthly charging and discharging from the battery

The details of the model is in the annexure of the report.

The advantage of this BESS is that it can also help in catering to loads if there is an increase. This will help NEA in adding the loads without much upgrading the transmission network and adding new generation as battery can help balance the load. The peak load till 2030 is expected to be 51.22 MVA, hence the battery storage will still be able to cater to this peak for about 1 hour. The storage details including hours for the forecasted load till 2030 is shown in Table 11.

Table 11: Storage System estimates for Nepalgunj Substation

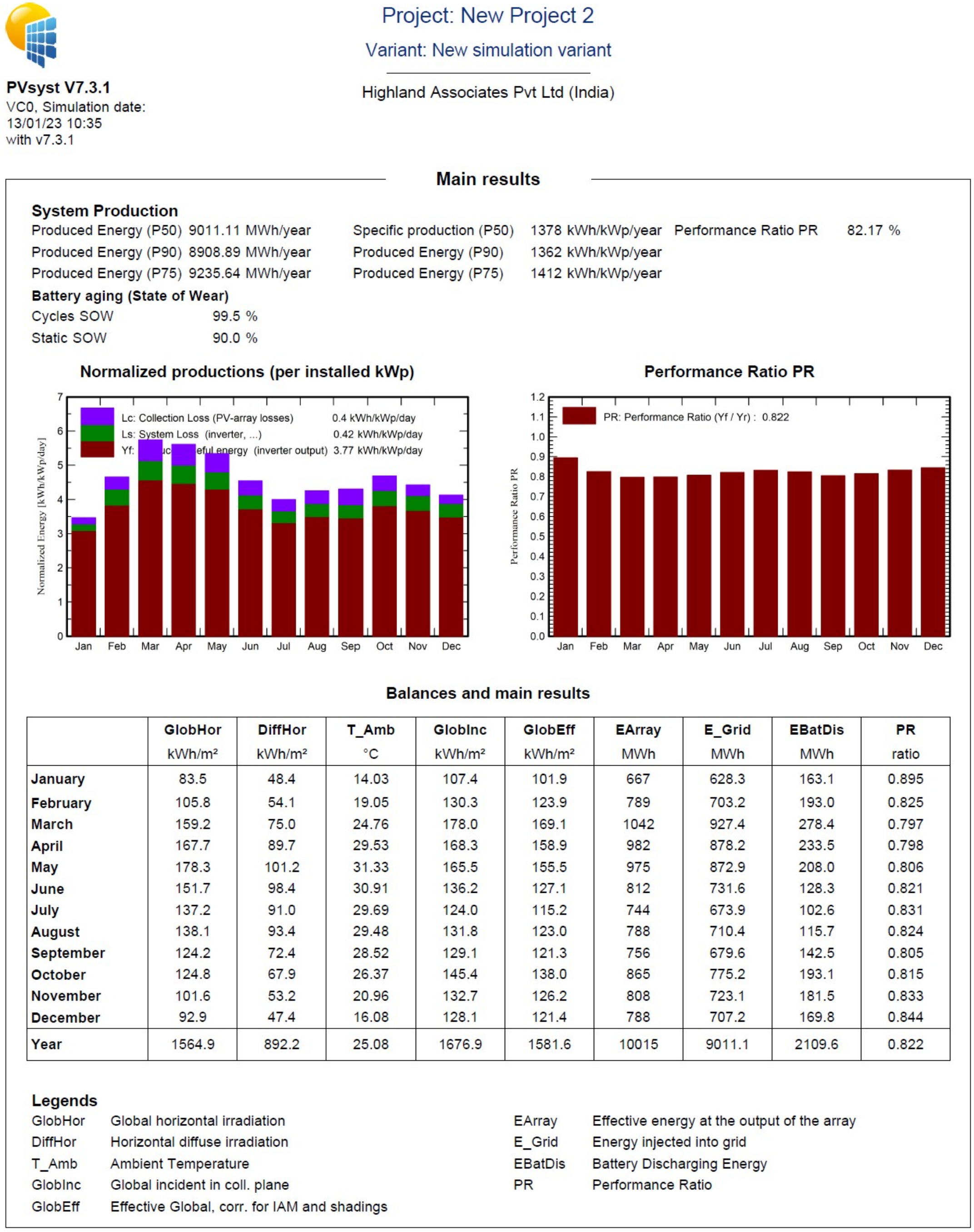
YEAR	2023	2024	2025	2026	2027	2028	2029	2030
Load (MVA)	32.19	34.92	37.65	40.36	43.0	45.80	48.50	51.22
Storage	1.55	1.43	1.33	1.24	1.16	1.09	1.03	0.98

5.2.5 BESS and Solar Model in Chanauta Substation

For the peak shaving in Chanauta substation, the parameters considered are provided in Table 12. The battery chemistry considered is LFP due to its quicker response time and longer cycle life. The total storage is considered for 2 hours. The location of the substation can be seen in Figure 90. Since there are certain area to be able to install a 5MW system, 5MW system is considered. Also based on the calculation above the energy generation from the system will be able to compensate for 8.65% of the total imports in the substation. Based on the forecasting of the optimum level of taking in 10% for the load the solar capacity to be installed is 12.5 MW. The output of the simulation is shown in Figure 88.

Table 12: Parameters of Solar PV with BESS modelled for Chandrauta substation

PARAMETERS CONSIDERED	VALUES	UNIT
Solar PV Capacity	6.5	MWp
AC capacity	5	MW
Peak Load	40	MVA
BESS capacity	80	MWh
Storage duration	2	hours



PVsyst V7.3.1
VC0, Simulation date:
13/01/23 10:35
with v7.3.1

Project: New Project 2

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

Main results

System Production

Produced Energy (P50)	9011.11 MWh/year	Specific production (P50)	1378 kWh/kWp/year	Performance Ratio PR	82.17 %
Produced Energy (P90)	8908.89 MWh/year	Produced Energy (P90)	1362 kWh/kWp/year		
Produced Energy (P75)	9235.64 MWh/year	Produced Energy (P75)	1412 kWh/kWp/year		

Battery aging (State of Wear)

Cycles SOW	99.5 %
Static SOW	90.0 %

Normalized productions (per installed kWp)

Performance Ratio PR

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	EBatDis	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	MWh	ratio
January	83.5	48.4	14.03	107.4	101.9	667	628.3	163.1	0.895
February	105.8	54.1	19.05	130.3	123.9	789	703.2	193.0	0.825
March	159.2	75.0	24.76	178.0	169.1	1042	927.4	278.4	0.797
April	167.7	89.7	29.53	168.3	158.9	982	878.2	233.5	0.798
May	178.3	101.2	31.33	165.5	155.5	975	872.9	208.0	0.806
June	151.7	98.4	30.91	136.2	127.1	812	731.6	128.3	0.821
July	137.2	91.0	29.69	124.0	115.2	744	673.9	102.6	0.831
August	138.1	93.4	29.48	131.8	123.0	788	710.4	115.7	0.824
September	124.2	72.4	28.52	129.1	121.3	756	679.6	142.5	0.805
October	124.8	67.9	26.37	145.4	138.0	865	775.2	193.1	0.815
November	101.6	53.2	20.96	132.7	126.2	808	723.1	181.5	0.833
December	92.9	47.4	16.08	128.1	121.4	788	707.2	169.8	0.844
Year	1564.9	892.2	25.08	1676.9	1581.6	10015	9011.1	2109.6	0.822

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	EBatDis	Battery Discharging Energy
GlobInc	Global incident in coll. plane	PR	Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

Figure 89: Results of PV modelling simulation for Chanauta Substation

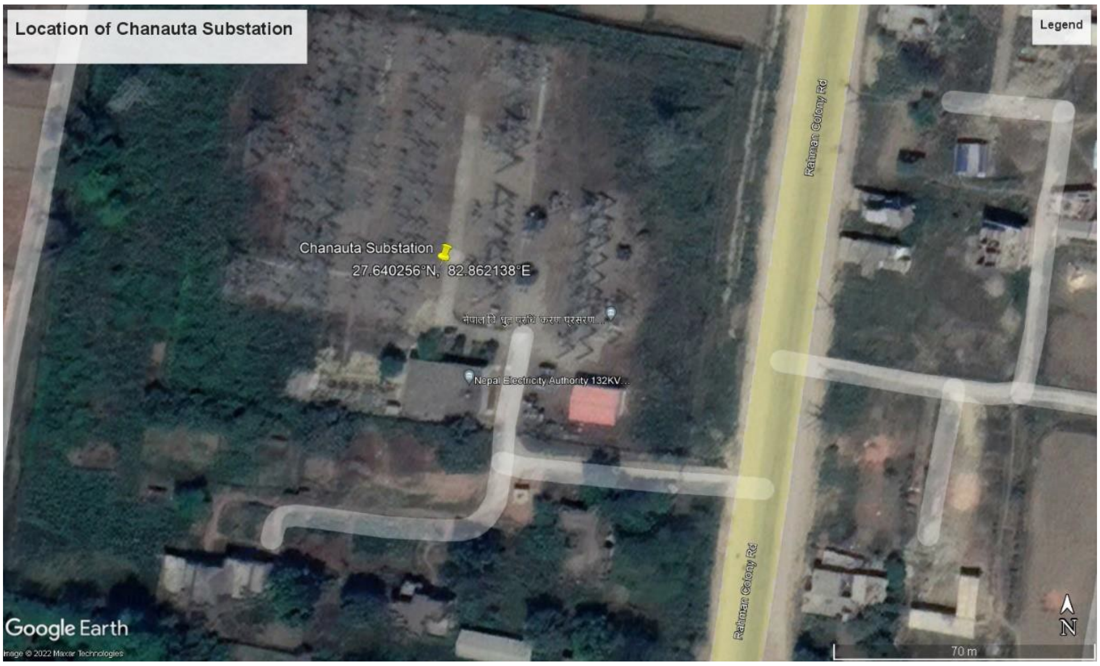


Figure 90: Location of Chanauta Substation

The advantage of this BESS is that it can also help in catering to loads if there is an increase. This will help NEA in adding the loads without much upgrading the transmission network and adding new generation as battery can help balance the load. The peak load till 2030 is expected to be 86.40 MVA, hence the battery storage will still be able to cater to this peak for 1.02 hours. The storage details including hours for the forecasted load till 2030 is shown in Table 13.

Battery charging and discharging hourly for a day is shown in figure below:

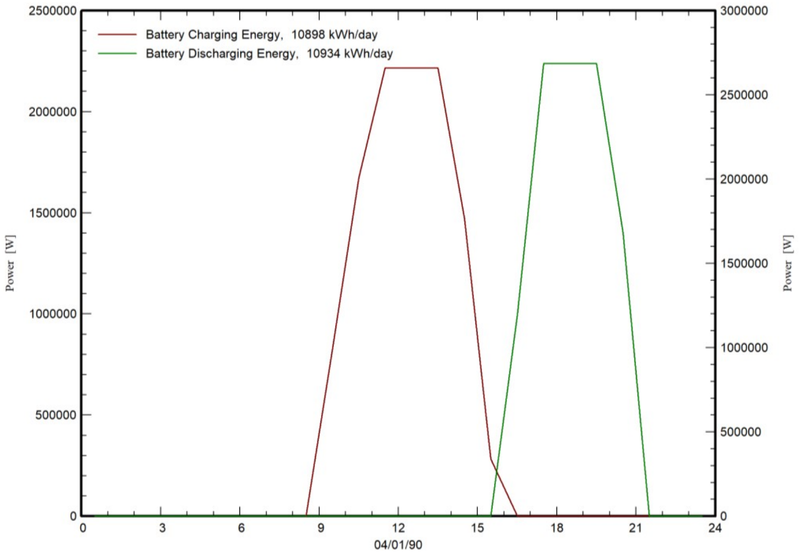


Figure 91: Daily charging and discharging from the battery

Since the total load is around 40 MW hence the battery size is able to discharge the entire load when required. Since battery discharging is for peak of 2 hours and charging time is 6 hours to not deplete the battery hence the difference is the charging and discharging.

The monthly energy use for charging and discharging for each month can be seen below

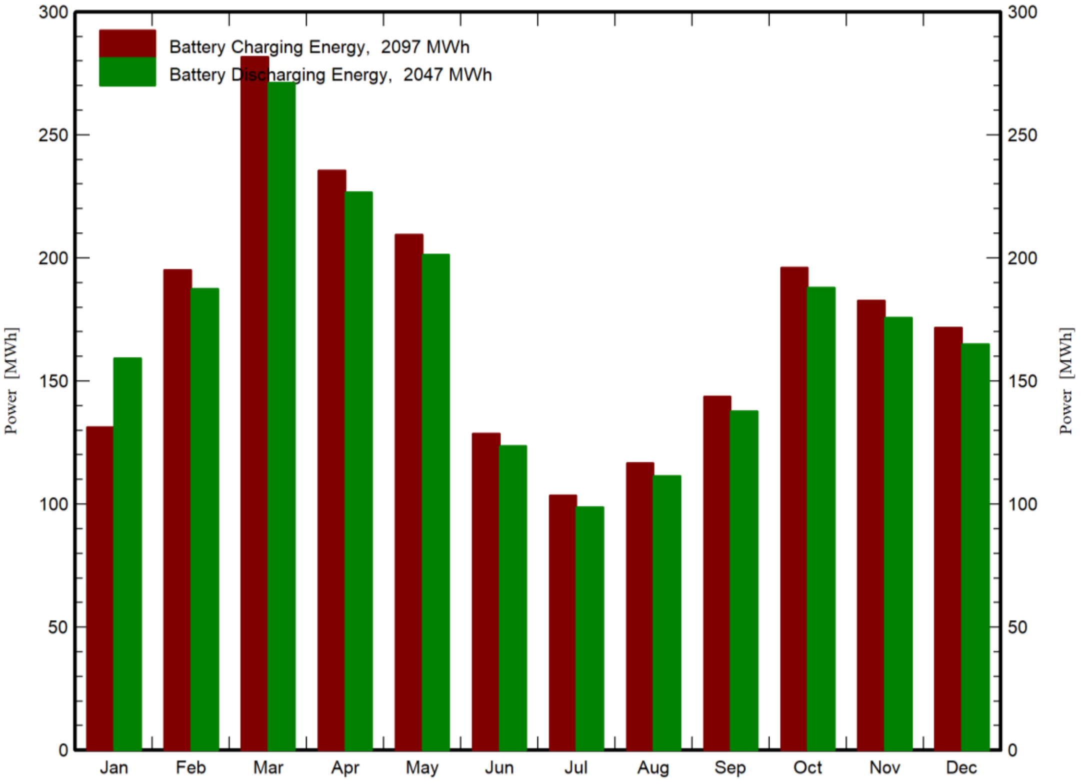


Figure 92: Yearly charging and discharging from the battery

The details of the model is in the annexure of the report.

Table 13: Storage unit estimate for Chanauta Substation till 2030

YEAR	2023	2024	2025	2026	2027	2028	2029	2030
Load (MVA)	41.85	45.62	49.73	54.20	59.10	64.40	70.20	76.52
Storage hours	1.91	1.75	1.60	1.47	1.35	1.24	1.14	1.04

5.2.6 BESS and Solar Model in Belauri Substation

To accommodate high share of renewable energy and contribute to grid stability in Belauri DC substation the parameters considered are provided in Table 14. The battery chemistry considered was LFP due to its quicker response time and longer cycle life. The total storage was considered for 4 hours meeting the solar capacity of 5MW. The location of the substation can be seen in Figure 93. Since there are certain area to be able to install a 5MW system, 5MW system was considered. The output of the simulation is shown in Figure 92.

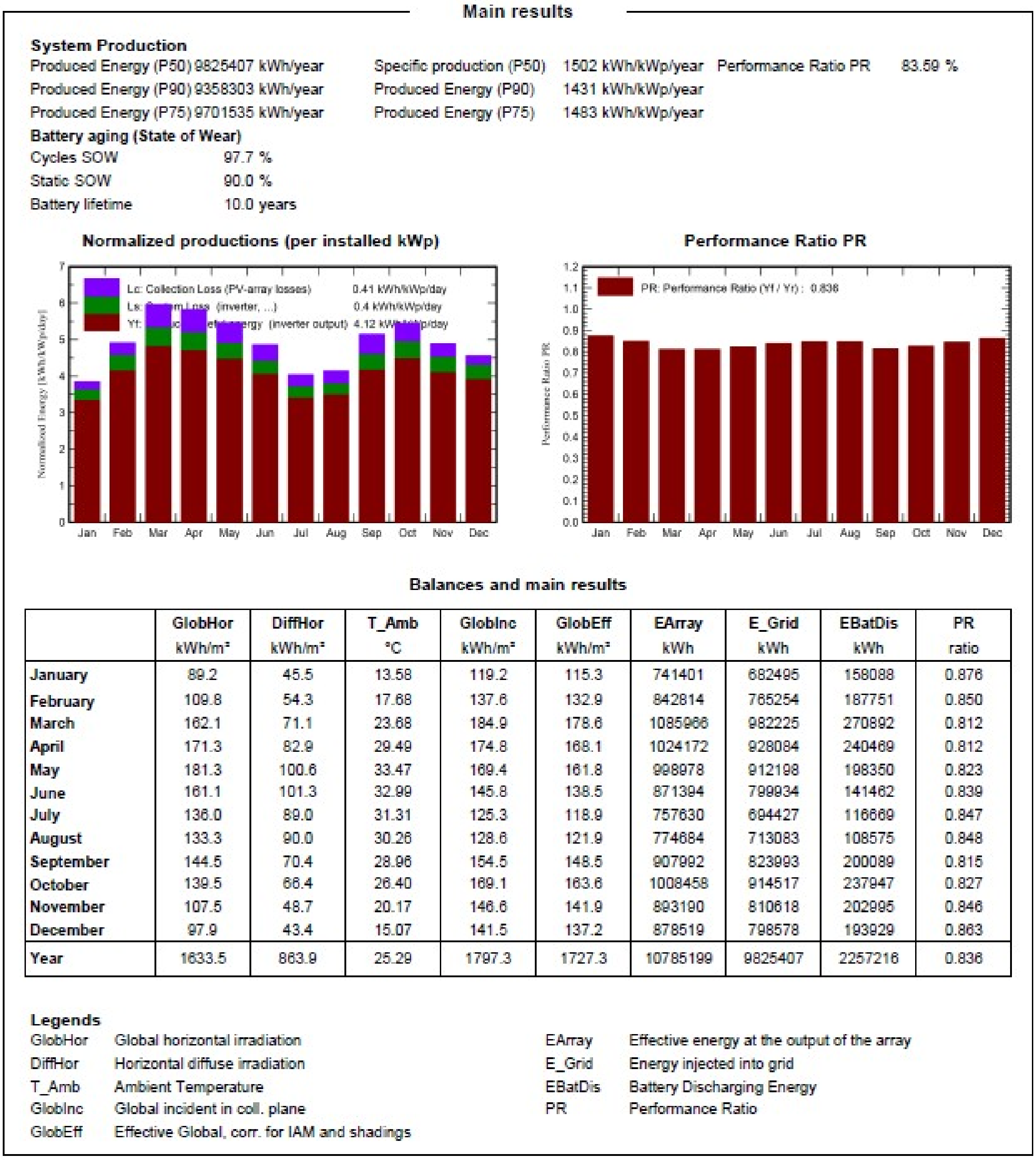
Table 14: Parameters of Solar PV with BESS modelled for Belauri substation

PARAMETERS CONSIDERED	VALUES	UNIT
Solar PV Capacity	6.5	MWp
AC capacity	5	MW
BESS capacity	5	MW
BESS capacity	20	MWh
Storage duration	4	hours

Figure 93: Location of Belauri Substation

The advantage of this BESS is that it can also help in managing the flexibility that will align peak solar generation in the middle of the day with evening peak demand. This will help

NEA in adding the loads without much upgrading the transmission network and adding new generation as battery can help balance the load.



Main results

System Production
Produced Energy (P50) 9825407 kWh/year
Produced Energy (P90) 9358303 kWh/year
Produced Energy (P75) 9701535 kWh/year

Specific production (P50)	1502 kWh/kWp/year	Performance Ratio PR	83.59 %
Produced Energy (P90)	1431 kWh/kWp/year		
Produced Energy (P75)	1483 kWh/kWp/year		

Battery aging (State of Wear)

Cycles SOW	97.7 %
Static SOW	90.0 %
Battery lifetime	10.0 years

Normalized productions (per installed kWp)

Performance Ratio PR

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EBatDis kWh	PR ratio
January	89.2	45.5	13.58	119.2	115.3	741401	682495	158088	0.876
February	109.8	54.3	17.68	137.6	132.9	842814	765254	187751	0.850
March	162.1	71.1	23.68	184.9	178.6	1085966	982225	270892	0.812
April	171.3	82.9	29.49	174.8	168.1	1024172	928084	240469	0.812
May	181.3	100.6	33.47	169.4	161.8	998978	912198	198350	0.823
June	161.1	101.3	32.99	145.8	138.5	871394	799934	141462	0.839
July	136.0	89.0	31.31	125.3	118.9	757630	694427	116669	0.847
August	133.3	90.0	30.26	128.6	121.9	774684	713083	108575	0.848
September	144.5	70.4	28.96	154.5	148.5	907992	823993	200089	0.815
October	139.5	66.4	26.40	169.1	163.6	1008458	914517	237947	0.827
November	107.5	48.7	20.17	146.6	141.9	893190	810618	202995	0.846
December	97.9	43.4	15.07	141.5	137.2	878519	798578	193929	0.863
Year	1633.5	863.9	25.29	1797.3	1727.3	10785199	9825407	2257216	0.836

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	EBatDis	Battery Discharging Energy
GlobInc	Global incident in coll. plane	PR	Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

Figure 94: Results of PV modelling simulation for Belauri Substation

The details of the model is in the annexure of the report.

Battery charging and discharging hourly for a day is shown in figure below:

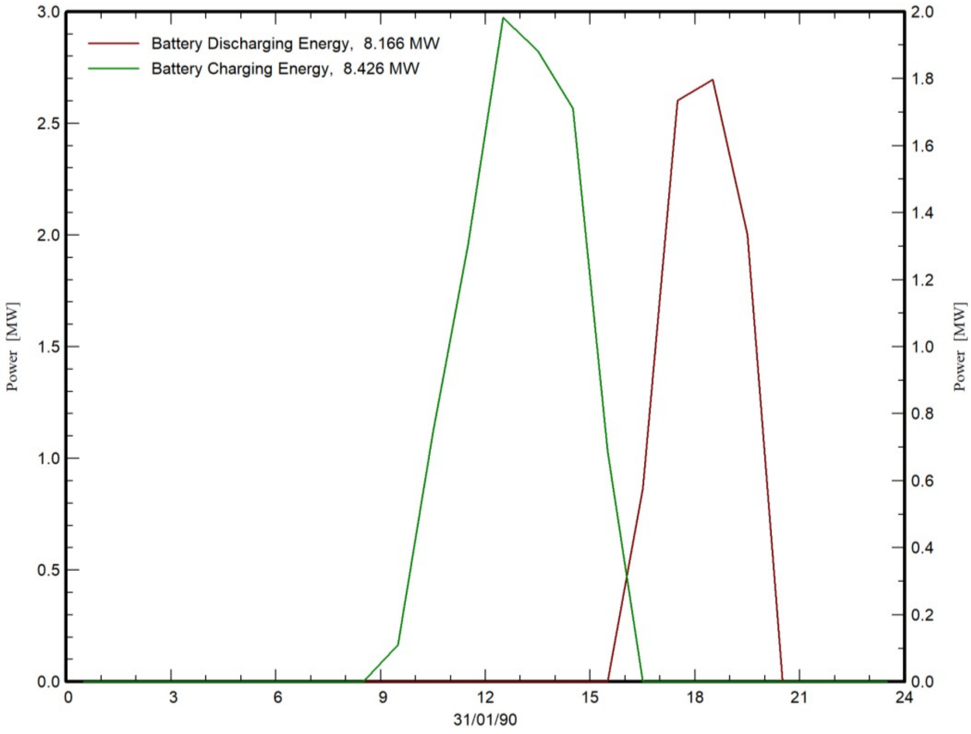


Figure 95: Daily charging and discharging from the battery

The monthly energy use for charging and discharging for each month can be seen below

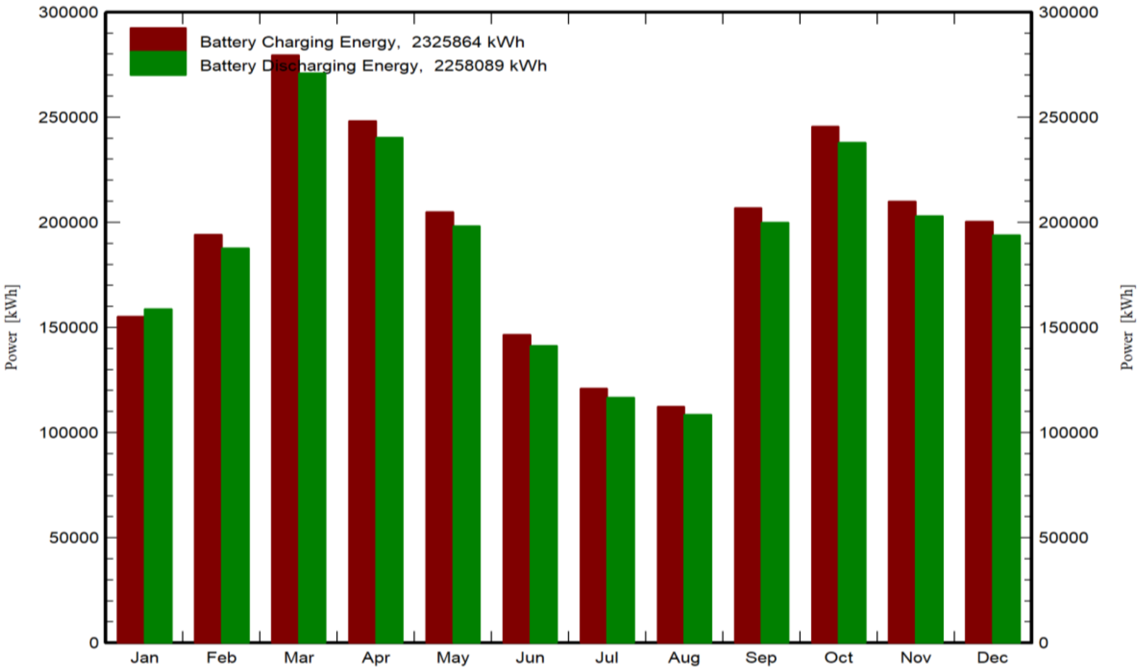


Figure 96: Yearly charging and discharging from the battery

5.3 Solar PV and BESS in Distribution Network

Distribution system comprises of the low voltage network up to 33 kV in INPS. The characteristics of conductor used in distribution system differs to that of transmission network in terms of its ratio of resistance to reactance (R/X). The higher R/X ratio results into weaker decoupling of Power-frequency and Reactive Power-Voltage unlike the transmission system. Figure 97 depicts the phasor diagram of usual loading in transmission and distribution network.

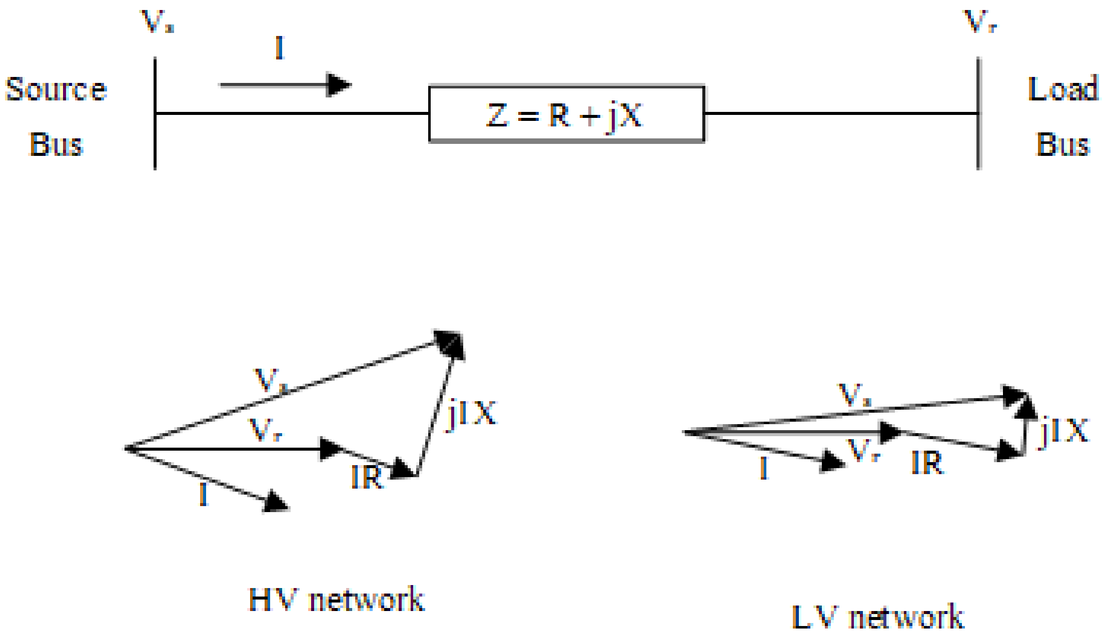


Figure 97: Phasor diagrams of High Voltage and Low Voltage network

Such characteristics of the distribution network also demands use of dedicated tools for distribution system analysis such as OpenDSS. Another significant difference is, the voltage in transmission network is improved with reactive power input whereas, that of distribution system may not be significantly improved with reactive power input alone. In other words, integrating active power at the distribution system is also essential for the voltage profile improvement. Thus, DREs play an important role in the distribution network. This section first discusses the metrics to observe in distribution system with DRE integration and thereafter describes the typical distribution network in INPS as well as impacts of DREs in INPS distribution network.

The concept of DRE hosting capacity of a feeder/network was introduced in Chapter 4. Simulation based and analytical studies are essential for the determining the hosting capacity of the distribution network. Table 15 lays out the typical metrics to observe and the requirements of such observations.

Table 15: Metrics to observe for the grid interconnection of DREs in distribution network

SN	METRICS/ISSUES	REMARKS
1	Voltage Limit	The voltage should not be higher than provided limit, else the components may fail. (See Figure 59 and Figure 60).
2	Line and Transformer Overloading (Thermal Overload)	Neither the evacuating transformer, nor the connecting feeder should be overloaded. If the limit exists for loading lower than 100% (Say 50%) then such limit may need to be satisfied.
3	Protection Issues	DREs could not work properly with the traditionally designed protection system for the distribution network. Arrangements should be made to avoid that. (For example, See Figure 61)
4	Harmonics (Power Quality)	Switching Inverters used for power evacuation of DREs may input unacceptable harmonics in the system severely impacting the power quality.
5	Power loss	Unusual operation of DRE and other factors may result in power loss.

Even though it may seem skeptic for interconnecting DG to the distribution network at first, the development of technologies based on the distributed generation grid codes and standards make them far more suitable for installation in the distribution network. Modern PV System inverters disconnect immediately as the grid fault occurs and thus reduces the safety risk due to back feed. The more important concern is the sizing of the DREs. The sizing depends on the distribution network in case-by-case basis.

Nowadays, distribution system models are available, but yet, maintaining databases of distribution system is challenging as it is constantly changing. Such change is not limited to the loading, with time even the network is upgraded, maintenance activities are carried out and even the DREs are installed on an ongoing basis. Thus, it is quite difficult to develop one model for all while analyzing a distribution system. Instead of optimizing at every move, distribution networks are analyzed with step input rule, like installing a 1MWp PV or so. It is though essential to observe that such modifications do not hamper the regular operation of the distribution, i.e., **hosting capacity** of the network**.**

To restate, Hosting capacity of a distribution network is the maximum capacity of DREs that network can host without violating its limits of operation. The most simple methodology of determining hosting capacity is checking whether the limit of performance indices is violated or not after injection of the DRE of given size. This gives the maximum hosting capacity of the network (See Figure 98). Often the maximum hosting capacity of the distribution network is determined by the utility after thorough study of its distribution network.

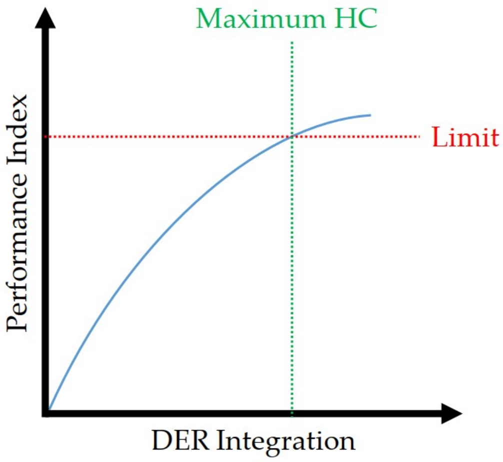


Figure 98: Concept of hosting capacity[12]

There are multiple methods of determining a hosting capacity of a distribution network. They vary depending upon the requirement of data, complexity of the system, calculation time and number of scenarios tested. They are enlisted below in Table 16. Due to the stochastic nature of the PV plants and other DREs, the time-series based simulation is preferred. However, such analysis requires descriptive details of the distribution system and DRE under consideration. In absence of these information, any outcomes could just be an approximation.

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[12] Mohammad Zain Ul Abideen, Omar Ellabban, Luluwanh al-Faigh, A review of the tools and methods for distribution networks' hosting capacity calculation, Energies, 2020

Table 16: Comparison of hosting capacity determination methods

CHARACTERISTICS	DETERMINISTIC		STOCHASTIC	OPTIMIZATION -BASED	STREAM -LINED
	CONSTANT SOURCE	TIME SERIES			
Data requirement	Small	Large	Moderate	Moderate	Moderate
Complexity	Simple	Moderate	Complex	Complex	Complex
Calculation time	Small	Moderate	Large	Large	Moderate
No. of scenarios tested	Few	Few	Many	Several	Several
Results	Approximate	Accurate	Accurate	Exact (for given constraints)	Approxim-ate

Literatures in the field have shown that reverse power flow and over voltages at the distribution network are the major consequences of the high PV penetration in the distribution network.[13] An analysis carried out by GIZ in Aug 2017, regarding integration of high shares of rooftop PV in India concludes:

- Urban feeders, which are typically short and fairly loaded could host high penetration of PV;
- Rural feeders, which are typically long and lightly loaded are more likely to generate overvoltage problems.

The results are in line with the high and low hosting capacity feeder characteristics identified by EPRI. The feeders which are short in length and have higher load demand towards the feeder end can host higher capacity of PV than the feeders that are long, use line regulators and have low voltage headroom for PV hosting.

In case of Nepal, the distribution feeders are operated in radial, similar to the typical cases elsewhere. The loading of distribution feeders is site specific and requires survey of the load in the region. Here, a typical radial distribution feeder at 11 kV is modeled (modified from IEEE 34 bus system), to mimic the distribution system of INPS. Figure 99 shows the network that was modeled in OpenDSS. The red line represents the use of ACSR Dog Conductor at 11 kV and the blue line use of ACSR Rabbit conductor. The buses are distribution transformers with

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[13] Sharma Vanika et. Al , Effects of high solar photovoltaic penetration on distribution feeders and the economic impact

loads lumped. Balanced and unbalanced three phase loads for a 24-hour period are randomly assigned. First the simulation is carried out for base case without any PV injection, thereafter cases with three variations of PV injection are observed, i.e., four cases are observed, viz,

- Case I – Base case
- Case II – Centralized PV of 3 MWp at Bus 800
- Case III – Three 1 MWp PV plant at bus 838, 848 and 854
- Case IV – One 1 MWp PV plant at bus 834

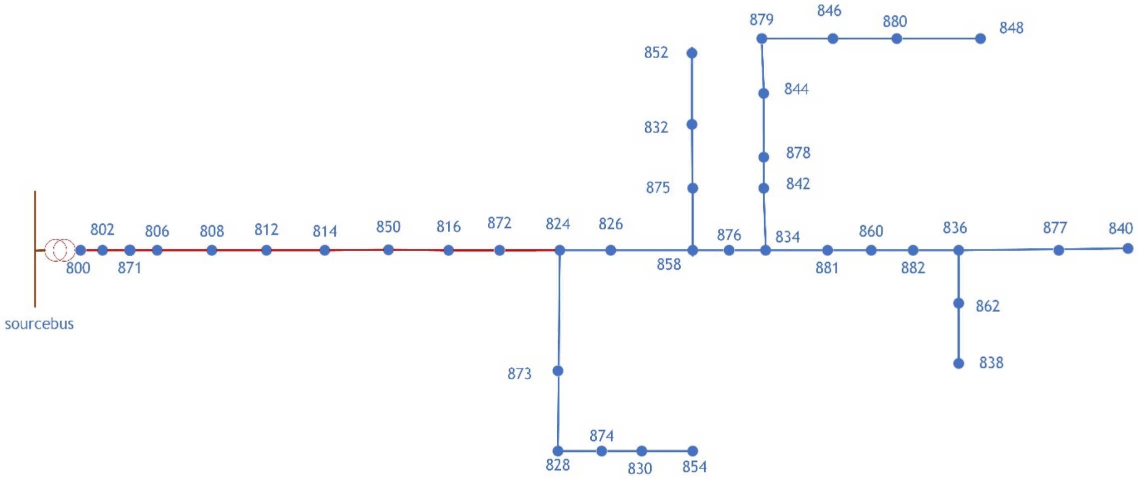


Figure 99: Radial distribution system modelled for simulation in OpenDSS

OpenDSS provides the phase voltages for each phase. The voltages of one of the phases is considered here for reference results as the PVs are modeled to be connected as three-phase source. The results are provided in Figure 100 to Figure 107.

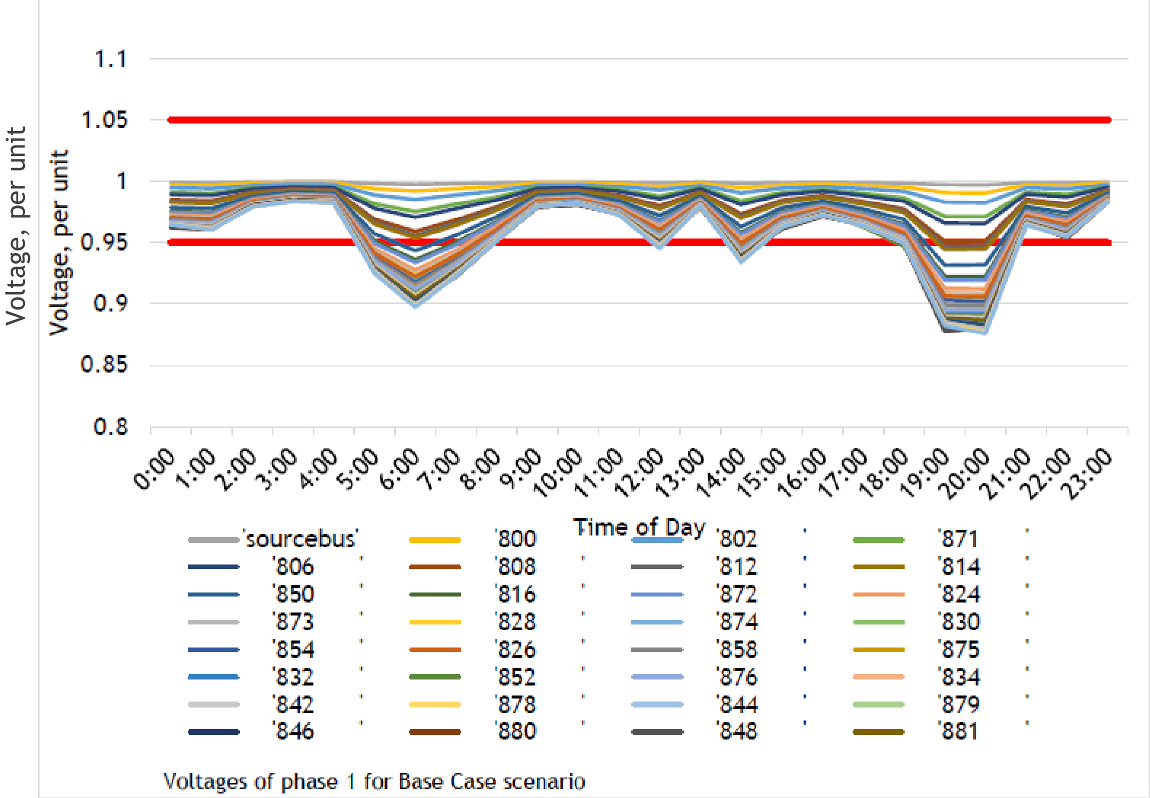


Figure 100: Voltage of model network for Case I

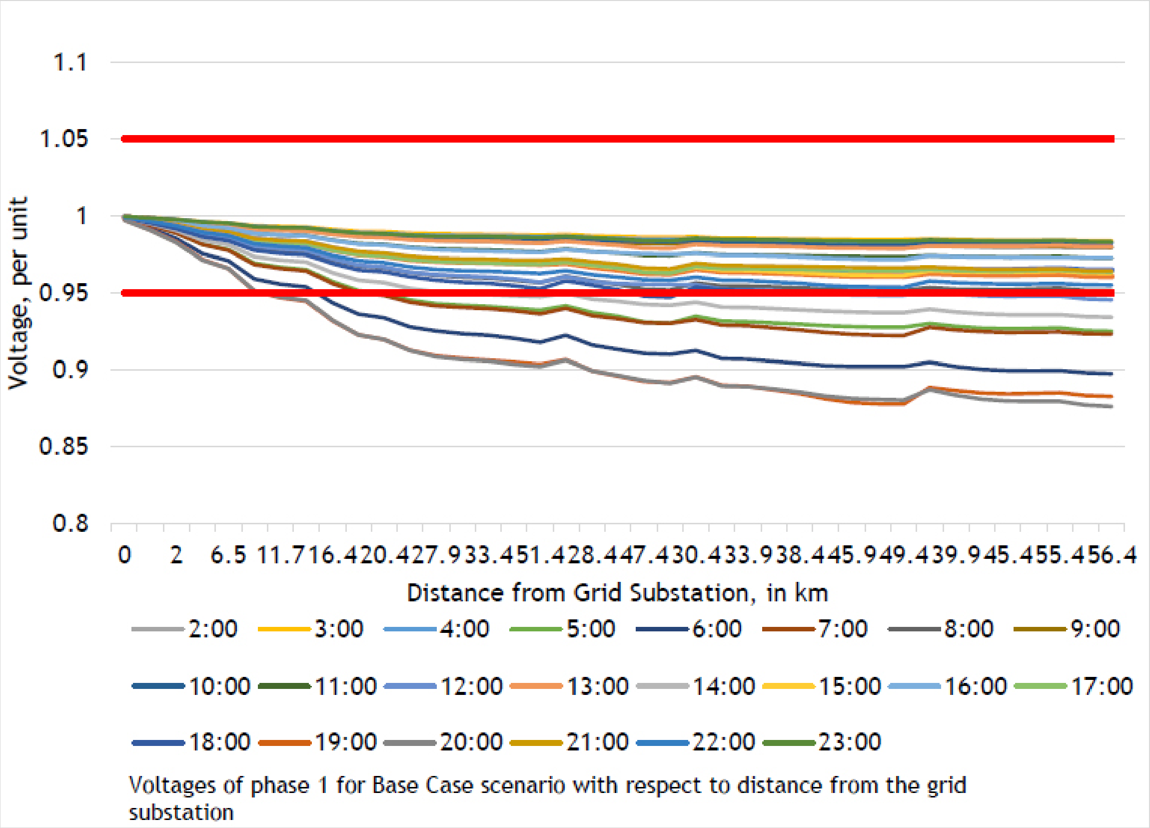
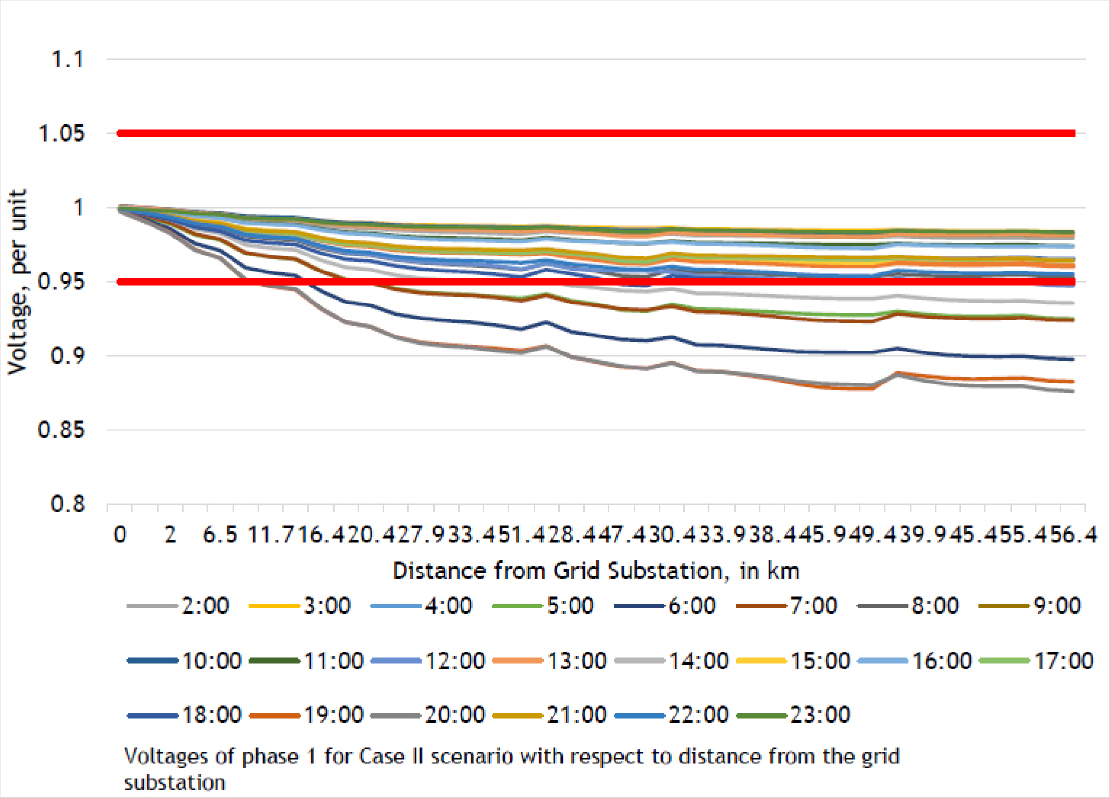
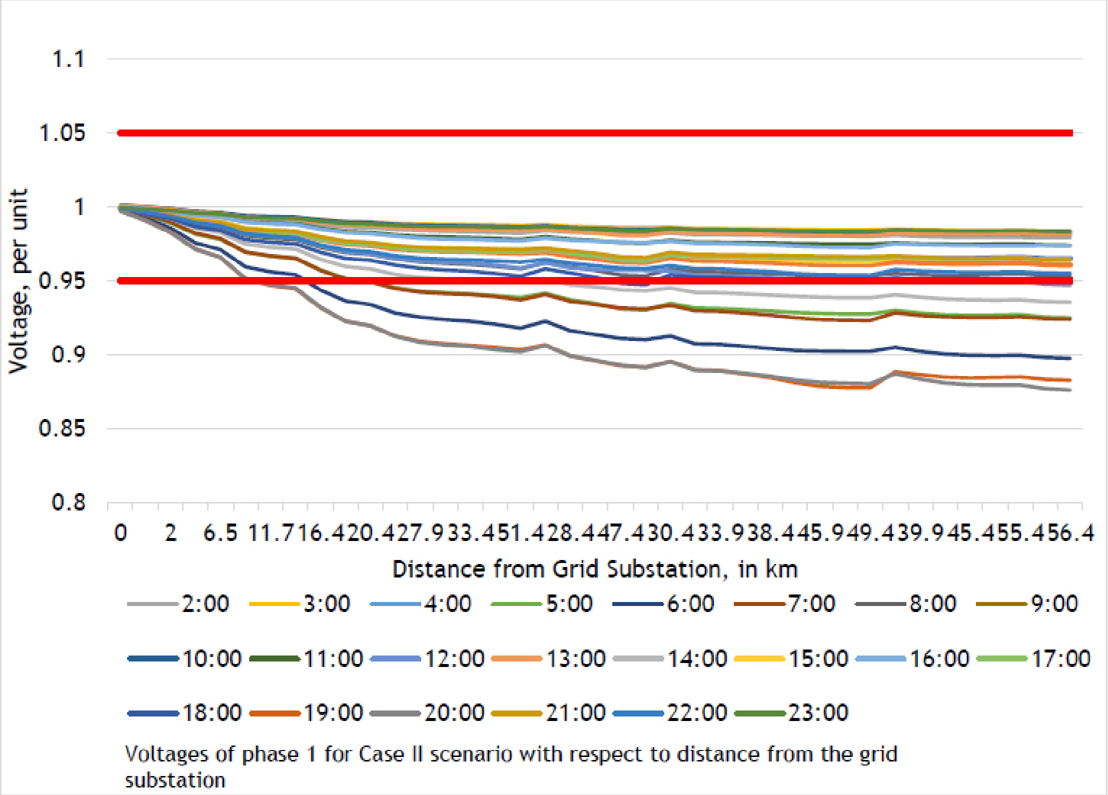


Figure 101: Voltage w.r.t distance from Grid for Case I



Voltages of phase 1 for Case II scenario with respect to distance from the grid substation

Figure 102: Voltage of model network for Case II



Voltages of phase 1 for Case II scenario with respect to distance from the grid substation

Figure 103: Voltage w.r.t distance from Grid for Case II

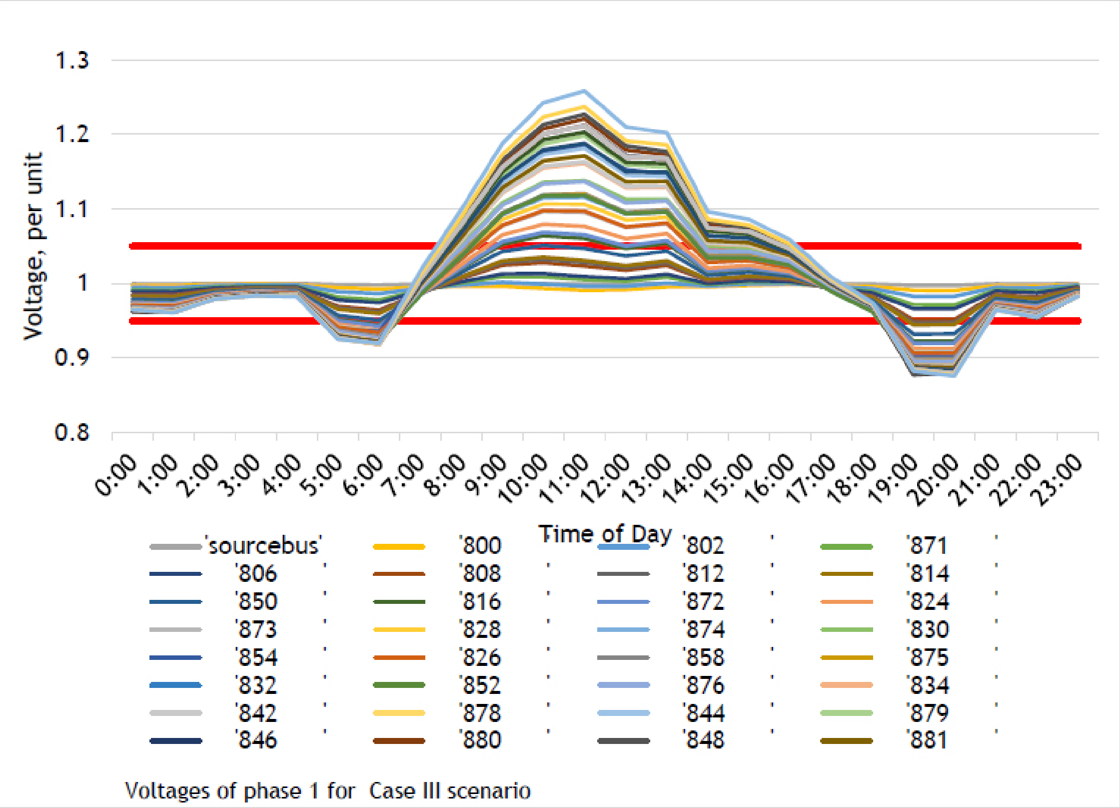


Figure 104: Voltage of model network for Case III

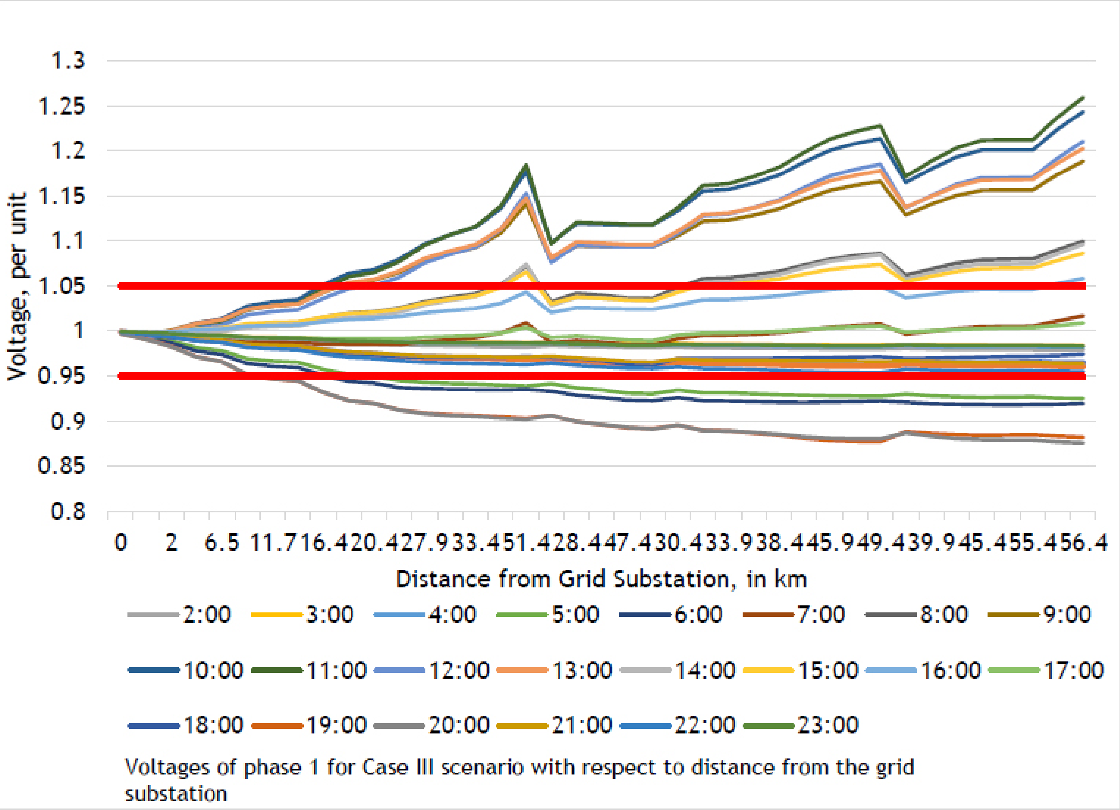
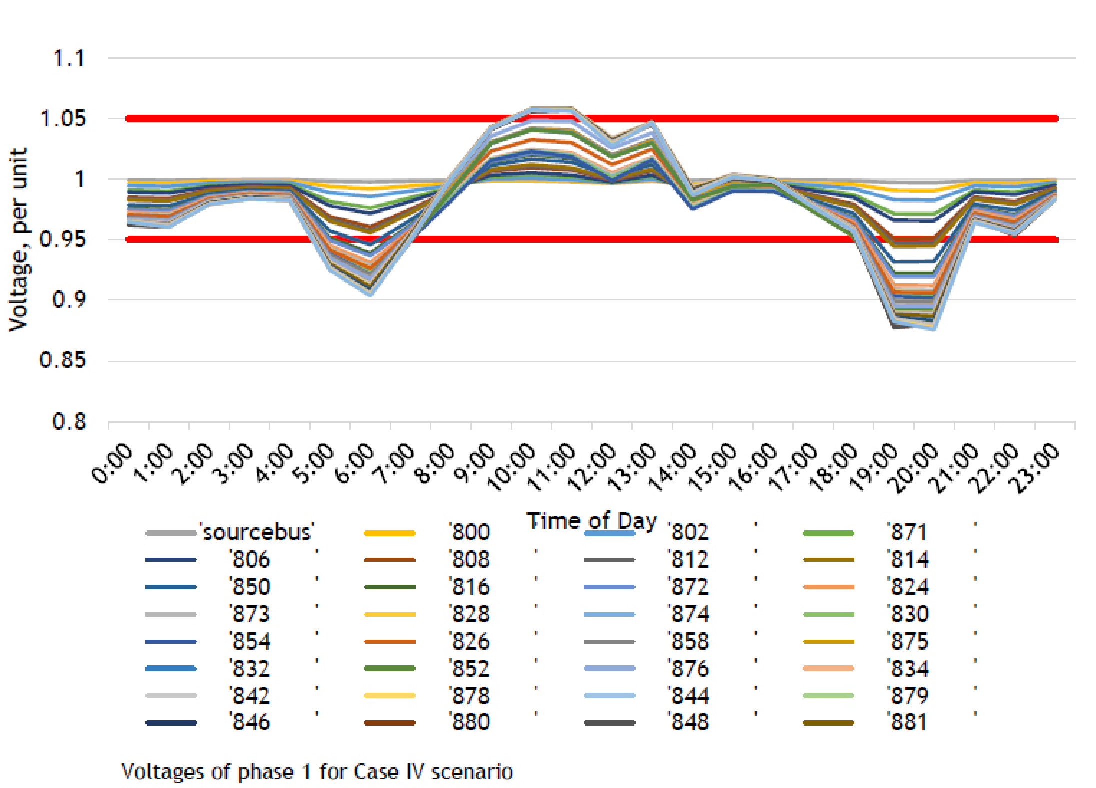
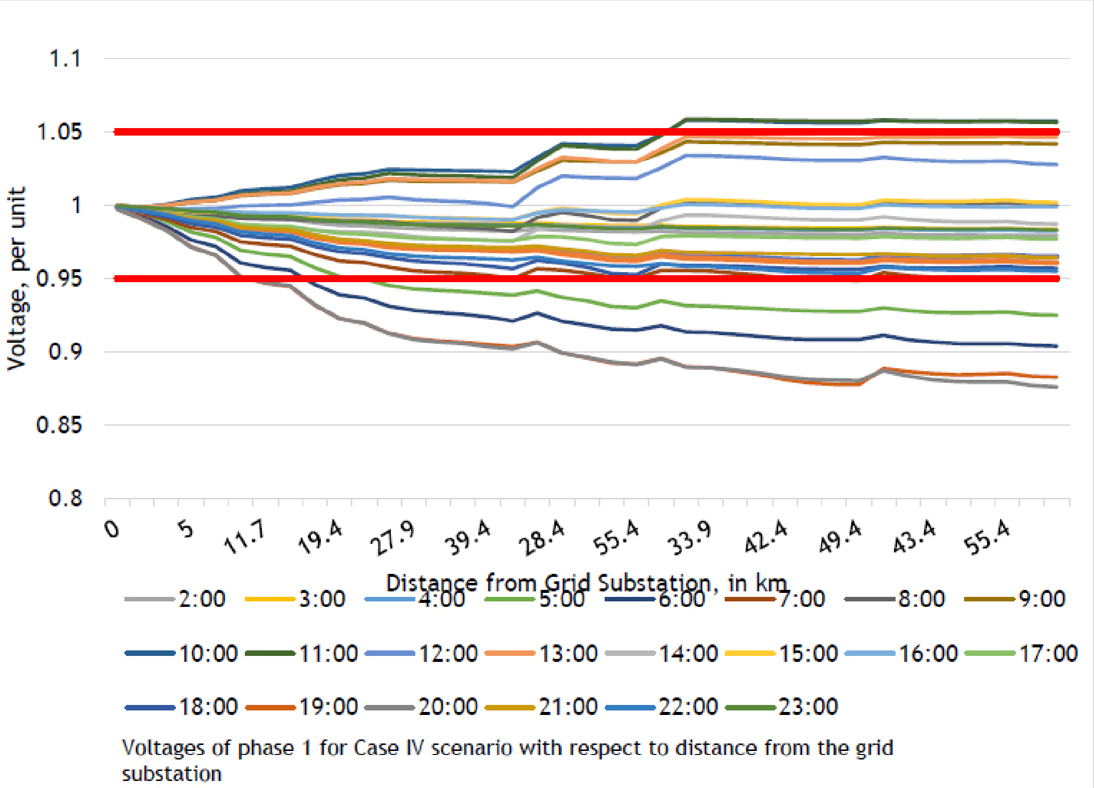


Figure 105: Voltage w.r.t distance from Grid for Case III



Voltages of phase 1 for Case IV scenario

Figure 106: Voltage of model network for Case IV



Voltages of phase 1 for Case IV scenario with respect to distance from the grid substation

Figure 107: Voltage w.r.t distance from Grid for Case IV

The results suggest that, for a typically long 11 kV line, which is the general case of Nepal, the siting and sizing of Solar PV plant depends heavily on the load characteristics of the network, as there are chances of overvoltage in the network if the PV size is larger. Hence, a grid impact study has to be carried out in any possible feeder with load survey and past feeder loading characteristics.

Adequate size of storage system along with smart control inverter and wide area voltage measurement system can limit these overvoltage issues to some extent, however, such requirement needs additional grid code modifications, as well as case-by-case basis of feeder study to observe the voltage limits. A specific study dedicated to decentralized feed- in of solar PV in MV Grids in Pakistan was carried out by GIZ, PGREF and AEDB. The study concluded that the hosting capacity and location are all feeder specific. Moreover, special attention has to be taken for the location of PV feed-in so as to avoid creation of new bottlenecks and voltage surges.

5.4 Required Modification to the National Grid to Integrate DRE

As the DER are envisaged to be connected towards the load centre itself, significant modification in the national grid might not be encountered but can be confirmed only after comprehensive analysis is performed. The distribution feeders in some section of the western part of the country is reported to be operating in overloaded condition. DER can relieve such overloading to some extent.

Small scale DREs could be connected at the low voltage distribution line or 11 kV line. These lines are generally characterized by long lines with frequent outages and voltage drops. The condition of the line has to be improved.

In the present study focus is given for connecting renewables to 33 kV and 132 kV substations. Some of the 33 kV lines are overloaded. If the level of renewable penetration increases, the line will be overloaded and could to be reinforced. Since solar sites are generally at a distance from the substation, extension of grid is required for evacuation.

Most of the hilly areas with small hydro sites is inaccessible with grid and extension of grid is required. Large scale solar and wind power sites are not available and extension of transmission line is not required.

For the injection of Solar PVs in distribution network, it is advised to demand voltage capability control from PV inverters with utility taking charge of the reactive power regime.[14]

5.5 Key Considerations for Adoption of Battery Energy Storage Systems

Developing and prioritizing regulatory objectives and aligning these with larger policy goals is key to setting the market context for the deployment of BESS. Similarly, to understand how battery storage compares to other alternative technology options available that provide similar services, it is imperative for regulators and operators to consider how BESS resources are going to be utilized before designing specifications and requirements for the development of new BESS systems. Nepal currently has no regulatory definitions of BESS or BESS components. Thus, installation of BESS calls for need for guidelines for interconnection and development of BESS in Nepal.

As BESS is typically used with inverter-based technology as batteries are DC devices and BESS systems are generally being connected to the AC grid. As such, many of Nepal's existing codes and standards for interconnection of other inverter-based technologies—namely, solar photovoltaic (PV)—apply to the interconnection of BESS. But BESS can provide services in addition to generation. In these use cases, the governance of BESS differs from technologies that are solely generation-based. For example, present interconnection standards for PV include provisions to prevent the unintentional islanding of local grid systems. It is important to prevent unintentional islanding of generation systems to ensure both electrical system protection (both customer and service equipment) and personnel safety; however, energy generation coupled with BESS, designed to act as stand-alone BESS installations when required, may provide additional benefits to the grid and to customers when intentionally islanded from the main grid using coordinated and sophisticated controls and operated as a micro grid to serve local load. The development of standards and codes could help support the deployment of BESS in Nepal. As this study entails the use of BESS in pilot projects at medium voltage levels and low voltage level primarily for peak shaving and backup purposes. Hence, it must be noted, there is need for the development of technical standards and codes to help support streamlined, safe, and reliable deployment of BESS. These will help NEA to carry out revision to grid codes includes considerations for BESS. Developing guidelines, codes, and standards for BESS integration could streamline the process of deploying BESS for various applications as envisioned by policymakers and regulators in Nepal, as well as increase deployment of renewable energy to meet provide energy security as

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[14] This was also recommended by GIZ study of PV integration in India.

well as strengthen the grids in Nepal. Based, on the some of these projects established in USA, Australia and few upcoming projects in India some of the global "Best Practices on BESS Safety and Technical Standards"[15] are highlighted in the table below:

Table 17: Selection of Key Standards and Model Codes Addressing Energy Storage Technology Safety

COMPONENT	STANDARDS
BESS Components	• IEEE P1679.1 Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications • IEEE P1679.2 Guide for the Characterization and Evaluation of Sodium-Beta Batteries in Stationary Applications • IEEE P1679.3 Draft Guide for the Characterization and Evaluation of Flow Batteries in Stationary Applications • UL 1973 Stationary, Vehicle Auxiliary Power and Light Electric Rail Applications • UL 1974 Evaluation for Repurposing Batteries • UL 810A Electrochemical Capacitors

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[15] Adapted from Cole and Conover 2016; Rosewater and Conover 2018; ESA 2019; Searles and Paiss 2020

COMPONENT	STANDARDS
Complete BESS	• IEEE 1679 Recommended Practice for the Characterization and Evaluation of Emerging EnergyStorage Technologies in Stationary Applications • UL 1642 Lithium Batteries • UL 1741 and UL 1741SA Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources • UL 9540 Safety of Energy Storage Systems and Equipment • UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Installation of BESS	• NFPA 111 Standard on Stored Electrical Energy Emergency and Standby Power Systems • NFPA 855 Standard for the Installation of Stationary Energy Storage Systems • NECA 416 Recommended Practice for Installing Energy Storage Systems • FM Global Property Loss Prevention Data Sheet # 5-33 Electrical Energy Storage Systems • DNVGL-RP-0043 Safety, Operation, and Performance of Grid-Connected Energy Storage Systems (GRIDSTOR)

COMPONENT	STANDARDS
Safety of the Built Environment	• NFPA 1 Fire Code • NFPA 70 National Electrical Code [NEC] • NFPA 110 Standard for Emergency and Standby Power Systems • NFPA 5000 Building Construction and Safety Code • IBC International Building Code • IFC International Fire Code • IEEE C2 National Electric Safety Code [NESC] • Local zoning codes • Local building standards and codes
Interconnection Process and Standards	• IEEE 1547-2018 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces • IEEE P1547.9 Guide to Using IEEE Standard 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems • IEEE P2800 Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems (under development)

Note: These are focused only of Li-Ion batteries. For flow and other batteries with different chemistries the guidelines might need to be tweaked.

6 QUALITATIVE AND FINANCIAL ANALYSIS

6.1 Economic and Commercial Impacts of the Renewable Energy Development Plan

Power sector planning process should be undertaken regardless of how the power sector is organised, whether market-based or otherwise. In either case, a long-term energy mix needs to be assessed to guide an appropriate set of policies. In a monopolised market, such a process is used by utilities to guide investments into generation. As the share of VRE increases in power systems, concerns have been raised over the suitability of existing tools and methodologies for long-term energy planning, as they may not be equipped with sufficient detail to capture the techno-economic implications of integrating these sources. While more detailed "grid integration studies" need to be conducted to assess how current power systems need to be reinforced to achieve a higher share of VRE, and their link with long-term planning. Long-term planning, when aiming at a transition to a system with a high share of VRE, needs to be adapted by ensuring clear linkages across studies that address different time horizons. In such a way, policy makers are assured that prescribed long-term renewable energy targets can be achieved without compromising the reliability of the power system, and that the long-term costs of achieving the transition have been assessed appropriately. The integrated planning process can be seen in Figure 108.

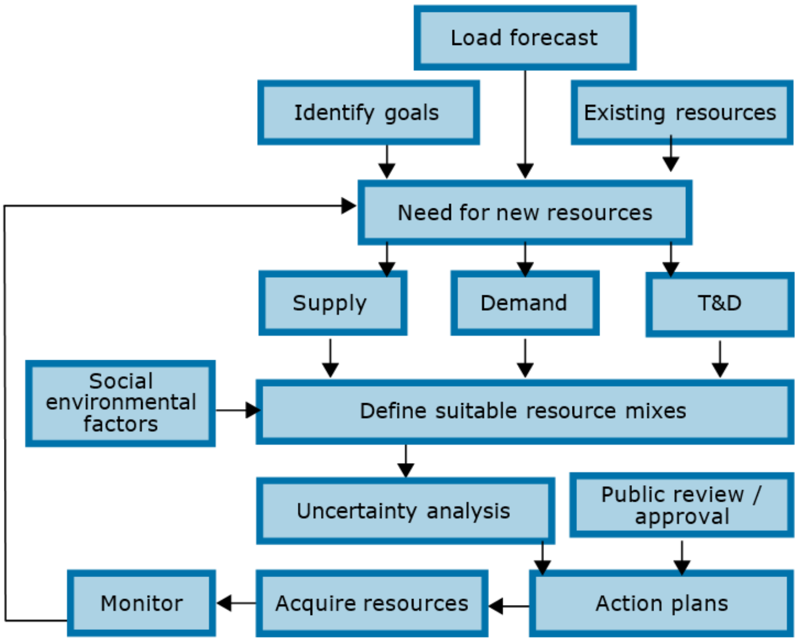
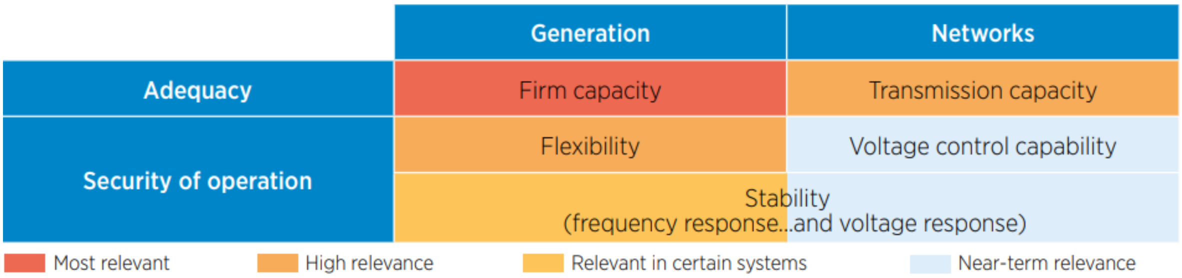


Figure 108: Flow chart for integrated resource planning

Investment in the capacity to provide generation adequacy in a system with a high share of VRE is likely to be the most relevant to long-term planning. This is intuitive, given that significant investment will be required in VRE capacity itself for a large-scale transition.

Investment to ensure sufficient firm capacity is especially important, where rapidly growing electricity demand (sometimes around 5-10% a year) urgently requires capacity expansion. Understanding VRE's contribution to firm capacity over the course of a long term generation expansion plan can have significant investment implications. For example, a temporal match between future demand and VRE supply profiles could substantially improve the contribution of future VRE capacity investments to firm capacity, possibly leading to reducing the need for peak-capacity investment. Although questions about the recovery of investment costs for those plants affected by system transition need to be addressed in the near term, such questions are likely to become less significant as the mix of generation capacity develops over the long term towards greater flexibility as indicated in Figure 109.

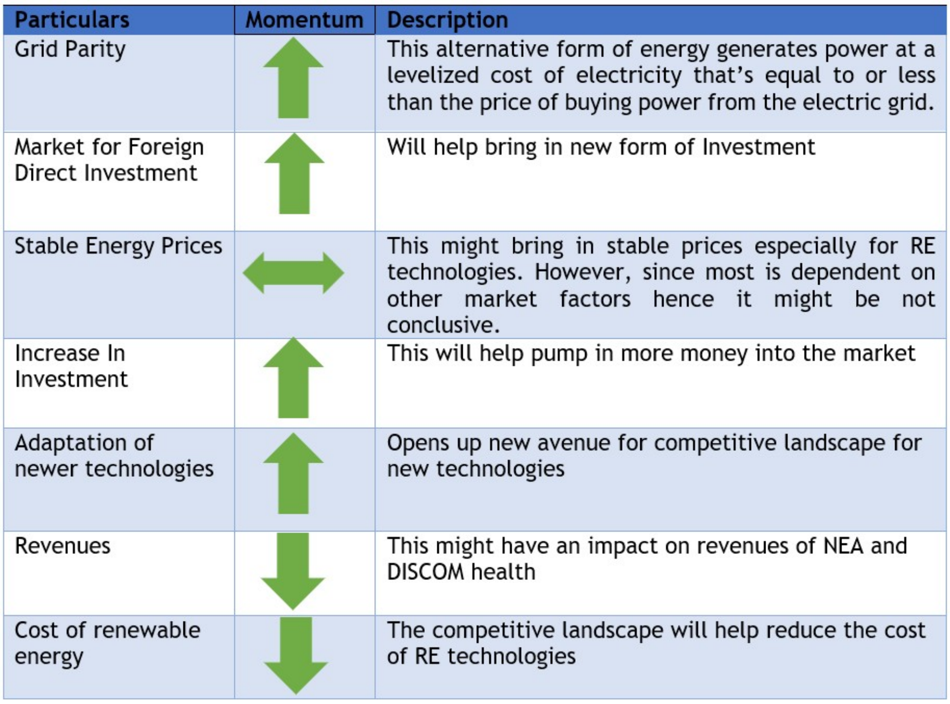


	Generation	Networks
Adequacy	🟥 Firm capacity	🟧 Transmission capacity
Security of operation	🟧 Flexibility	🟦 Voltage control capability
	🟨 Stability (frequency response…	🟦 …and voltage response)

🟥 Most relevant 🟧 High relevance 🟨 Relevant in certain systems 🟦 Near-term relevance

Figure 109: Investment planning

In most cases, if VRE resources are not located near the existing electricity transmission network, increasing the share of VRE ultimately will require additional investments in the grid. Given that investment in generation often has higher absolute cost implications than transmission, a sequential approach of first defining the generation mix, then the optimal transmission capacity for that mix is the most relevant. However, if the site specificity of VRE resources requires additional transmission expansion and corresponding investment – ignoring transmission costs in planning long-term generation expansion helps result in a suboptimal investment strategy. Furthermore, an economic trade-off may exist between transmission capacity investment and resource quality of generation at a given site. There may be times when the cost of new transmission capacity, or increased congestion in existing capacity, outweighs the benefit of a marginally higher-quality VRE resource. Such scenario's will help pump in more investment in control equipment and network enhancements, necessary to ensure voltage-control capability and to maintain a system's secure operation with a high share of VRE. The overall financial impact of the DRE and BESS systems can be seen in Figure 110.



Particulars	Momentum	Description
Grid Parity	↑	This alternative form of energy generates power at a levelized cost of electricity that's equal to or less than the price of buying power from the electric grid.
Market for Foreign Direct Investment	↑	Will help bring in new form of Investment
Stable Energy Prices	↔	This might bring in stable prices especially for RE technologies. However, since most is dependent on other market factors hence it might be not conclusive.
Increase In Investment	↑	This will help pump in more money into the market
Adaptation of newer technologies	↑	Opens up new avenue for competitive landscape for new technologies
Revenues	↓	This might have an impact on revenues of NEA and DISCOM health
Cost of renewable energy	↓	The competitive landscape will help reduce the cost of RE technologies

Figure 110: Commercial Impacts of DRE and BESS

6.2 Market Potential

Market potential help to get insights into though the product is technically sound whether there is market for the product. The first step required when estimating economic market potential is to ascertain the technical market potential. It is the maximum amount (MW) possible given technical constraints. As an upper bound, the technical potential is the peak electric demand. Next, the maximum market potential is established. It is an estimate of the maximum possible demand given constraints that are practical or institutional in nature (e.g., utility regulations and practices). Finally, the addressable market means putting in some constraints to the identified market potential. The market potential for the BESS system is has also been carried out based on the price forecast for storage till 2030.

There are 71 substations especially for HV and MV voltage transmissions. Based on our analysis the average load for these substations is 25-80 MVA. The cost for 4MWh battery storage considered is 300 k USD/MWh. The detailed cost estimates are provided in Table 18.

Table 18: Assumptions for estimating the market potential

NO OF SUBSTATIONS	71	
Load	25	MVA
Battery Storage	4	MWh
Cost	300	USD/kWh

Considering 50% of the market will be met at current market price

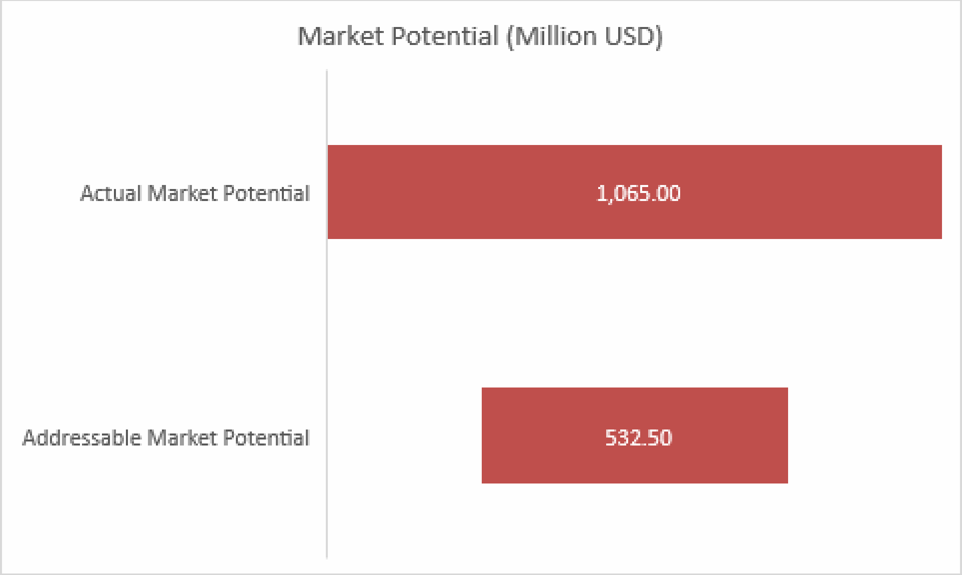


Figure 111: Market Potential

However, as the price of lithium batteries are coming down yearly as the deployment of stationary use of Li ion gets traction especially for utility scale use hence the market forecasting needs to be done based on the future trending prices[16] and increment in loads at the substations and taking an adaptation rate. For carrying out these estimates increase in load of 7% in each substation and adaptation rate of 5.5% for the year 2023. Also, the adaptation rate would increase by 5% there on wards till 2030 reaching 52.5% of the adaptation rate by 2030. The forecasted market potential can be seen in the Figure 112:

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[16] https://www.nrel.gov/docs/fy20osti/75385.pdf

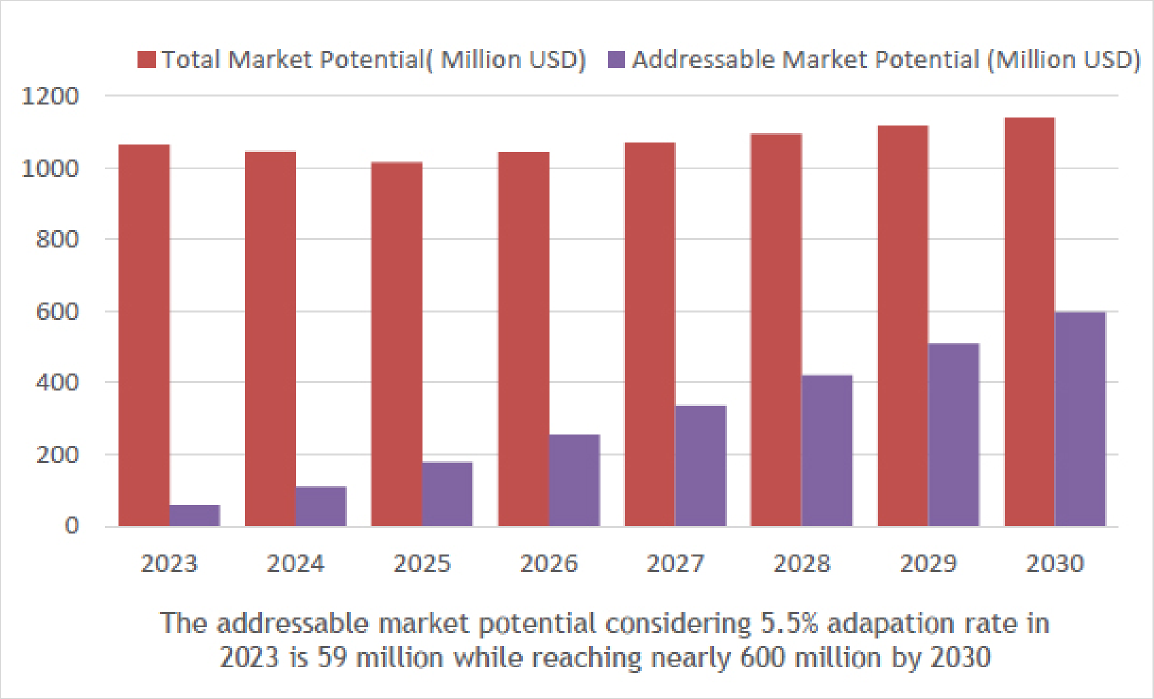

Figure 112: Market Potential

6.3 Economic/Financial Analysis

The market potential of the BESS and solar in Nepal was discussed in earlier section. However, for the adaptation we need to look into the financial returns of such projects to see the market. This is laid out in the economic and financial analysis explained in this section.

Economic and financial analysis refers to evaluating costs and benefits to check the viability of a project, investment opportunity, event, or any other matter. It involves identifying, evaluating, and comparing costs and benefits. The economic analysis is used to document that the project is a net benefit to society as a whole – this is especially interesting in relation to public investments. The financial analysis is used to document a reasonable expected return on investment to prospective investors.

Financial analysis is performed to assess the financial feasibility of a project. This is important for privately owned and operated projects, as an investor wants to know up front whether the investment can be profitable within a reasonable time period. However, this is also important for (largely) grant-funded projects, because payments for connections and electricity services need to be sufficient to sustain the O&M of the system. Therefore, financial analysis is needed to determine the minimum fees that are required for this. Financial analysis considers a variety of financial factors. The typical components of an energy sector related project include:

- Project costs. These include all the equipment, as well as the cost of labour and transport to install the system.
- Financial contributions. These include grants, contributions from the community, and private investment.
- Service fees. These are the fees that users pay for using electricity, either as a fixed fee or per kilowatt-hour.
- Connection fees. These are the fees that customers may need to pay to get connected and receive service.
- Operation and maintenance. These include the salaries of technical and administrative staff, running costs, spare parts, and periodic replacement of major components like batteries.

6.3.1 Cost to Modify the National Grid to Integrate RE to the System

The stochastic nature of DREs demand the development of storage type projects. For a hydropower-based power system like Nepal, the Peaking run-of-river projects are complimentary to the renewable energy projects. In addition to these, the study concludes the requirement of updating the grid code to facilitate integration of Renewable Energy Systems. Other site-specific modifications required to integrate a particular DRE depends widely on the feeder status, age of feeder and current loading. Estimating such cost is beyond the scope of this study. In the field though, the transmission and distribution system of INPS is just shaping. NEA, the government owned utility, is still carrying out construction of transmission lines and the distribution system. Construction of Peaking run-of-river hydropower plants with specific focus to renewable energy integration and implementing wide-area-measurement-system to facilitate renewable energy integration in distribution feeders still seem far. Based on the data collection from Highland the cost estimates for extension of the 132 kV line is shown Table 19.

Table 19: Cost estimated for extension from Kohlapur to Nepalgunj

COST ESTIMATES OF 132 KV LINE EXTENSION FROM KOHALPUR TO NEPALGANJ				
		QTY	**RATE (MILLION RS)**	**AMOUNT (MILLION RS)**
132 kV double circuit line with Panther conductor	km	16	18.87	301.98

COST ESTIMATES OF 132 KV LINE EXTENSION FROM KOHALPUR TO NEPALGANJ				
		QTY	**RATE (MILLION RS)**	**AMOUNT (MILLION RS)**
132 kV line bays	nos.	4	24.56	98.23
132 kV transformer bay	nos.	1	10.56	10.50
132 kV transformer & substation equipment	lot	1	105.65	105.65
				516.37 *[17]

The government of Nepal has set a target of 15000 MW of energy production in 10 years' time. Since the current transmission and distribution systems are nearly fully loaded hence government need to spend substantial amount on revamping the entire transmission and distribution systems. The overall calculation can be seen in Table 20.

Table 20: Cost estimates to integrate RE to the national grid

CATEGORY	UNITS	CAPACITY
Total installed capacity	MW	2190
Total Hydro	MW	2082
Thermal power plant	MW	54
Renewable Energy	MW	55
Nepal Targets	MW	15000
Remaining Capacity	MW	12810
10% from Solar	MW	1281
Cost for 132 kV line considering 63 MVA transformer	Million NPR	757.78
Power transfer Capacity considered for 132 kV line	MW	60
No of 132 and 33 kV extension including bay and others to integrate target RE	No	21
Total Cost	Billion NPR	15.91
Considering BESS capacity	MW	380
Remaining	MW	900
No of 132 and 33 kV extension including bay and others to integrate target RE	No	15

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[17] This is the cost of extending 16 km of 132 kV transmission line considering 31.5 MVA (say 30 MW) 132/33 kV transformer. The corresponding total cost for twice the transformer size of 63 MVA (60 MW) is Rs. 757.78 million.

CATEGORY	UNITS	CAPACITY
Cost for transmission and distribution	Billion NPR	11.36
Cost for BESS (380 MW) with transformer	Billion NPR	9.04

Hence the use of BESS in the system will help save 2.32 billion rupees. Similarly, BESS will further help NEA as well as developers by trimming the cost of equipment like SVAC, Capacitor bank and others to regulate the grid.

6.3.2 PV-Plus-Storage and Standalone Storage Costs Using Bottom-up Analysis

The detailed breakdown of standalone storage capital costs prices helps us to map and group the cost components to the corresponding cost categories in a PV system with BESS. A detailed bottom-up model includes the cost structure of a traditional Li-ion battery, broken into EPC costs (hardware and other costs) and developer costs. They EPC cost was estimated based on the current EPC rates for such BESS projects in India and then the costs of for different battery durations for MW- scale battery systems were based on the National Renewable Energy Laboratory (NREL) cost for 4 hours storage. One of the ways to access the cost for solar and storage cost is look into the Bill of Items comparison for PV standalone system and PV+BESS system.

Table 21: Bill of Components for BESS and Solar PV System

BILL OF ITEMS FOR BESS	BILL OF ITEMS FOR PV
Power conditioning system/bidirectional inverters	Power conditioning units/inverters
Weatherproofing, thermal design for components, heat-removal system, air-handling systems, filters to prevent dust	String combiner box with mounting structures
Step-up transformers	Step-up transformers
Low-tension (LT) and high-tension (HT) switchgear and panels	LT and HT switchgear and panels/ring main unit (RMU)
Performance monitoring and data acquisition/ supervisory control and data acquisition (SCADA)	SCADA
Protection and control	Protection and control
Auxiliary power system	Auxiliary supply system, uninterruptible power supply (UPS)
Bill of Items for BESS	Bill of Items for PV

BILL OF ITEMS FOR BESS	BILL OF ITEMS FOR PV
Wiring/cables - HT/LT/communication	Wiring/cables - HT/LT/communication
Controls and communication	Controls and communication
Auxiliaries and other design requirements: closed-circuit television (CCTV), weather monitoring station (WMS), illumination, fire alarm	Auxiliaries and other design requirements: CCTV, WMS, illumination, fire alarm

The overall cost for the BESS with storage was taken from the Lawrence Berkeley National Laboratory (LBNL) whitepaper on BESS energy storage cost in India.[18] Though the pricing was done in 2018 we have taken the EPC prices as of current market trend whereas the battery price especially was done based on the NREL's estimate.

Table 22: Estimated Cost of Battery Energy Storage System

CATEGORY	COMPONENT	1-HOUR (1 MW/1 MWh) SYSTEM ($/KWh)	4-HOUR (1MW/4MWh) SYSTEM ($/KWh)
Battery pack	Li-ion battery	209	209
BOS hardware	Battery central inverter	70	18
	Structural BOS	19	13
	Electrical BOS	81	36
EPC	Installation labor and equipment	62	23
	EPC overhead	26	12
Soft cost	Tax	33	22
	Developer cost (including EPC and developer net profit)	100	49
	Total	**600**	**382**

Fu et al. build a PV-plus-storage model for several system configurations to determine benchmark costs for grid - scale storage systems. The battery cost accounts for 55% of total system cost in the 4-hour system, but only 35% in the 1-hour system. For the baseline case,

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[18] https://eta-publications.lbl.gov/sites/default/files/lbnl-2001314.pdf

4-hour storage is assumed according to the California Public Utilities Commission's "4-hour rule," which credits storage that can operate for 4 or more consecutive hours with the ability to provide reliable peak capacity. Except, for battery pack costs that stay the same per kWh, other balance of supply (BoS), EPC, and soft costs are spreadover a larger battery capacity - and hence are lower per kWh—for a battery with the same MW rating but higher MWh capacity. Table 23 shows the resulting scaling ratios by cost component.

Table 23: Cost Scaling Ratios between 1- and 4-Hour Battery Systems, Fu et al. (2018)[19]

COMPONENT	1-HOUR (1 MW/1 MWh) SYSTEM ($/kWh)	4-HOUR(1 MW/4 MWh) SYSTEM ($/kWh)	SCALING RATIO BETWEEN 1- AND 4-HOUR SYSTEM
BoS	100	49	-51%
Inverter	70	18	-74%
EPC	88	35	-60%
Soft cost (excluding taxes, land, permitting and interconnection fees)	61	39	-36%

Because many early storage projects are expected to be co-located with PV plants, we estimate storage costs for such a system as well. Denholm et al. (2017) conclude that a direct current (DC) - coupled PV-plus-storage system could save about 40% in BoS costs due to sharing of the inverter, cabling, and so forth. Table 24 combines this factor with our other scaling factors. Current India standalone and co-located system costs are hence estimated to be 31% lower than costs in the United States.

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[19] Fu, R., T. Remo, and R. Margolis. 2018. 2018 U.S. Utility-Scale Photovoltaic-Plus-Energy Storage System Costs Benchmark. Golden, CO: National Renewable Energy Laboratory.

Table 24: Complete Scaling of U.S. to India Battery Cost Components (2018)

	U.S.		INDIA			
COMPONENT	U.S. 1 MW/ 1 MWh SYSTEM (STANDAL-ONE) ($/KWh)	SCALING RATIO (U.S. TO INDIA)	INDIA 1 MW/ 1 MWh SYSTEM (STANDA -LONE) ($/KWh)	SCALING RATIO (1-HOUR TO 4- HOUR SYSTEM)	INDIA 1 MW/4 MWh SYSTEM (STAND-ALONE) ($/KWh)	INDIA 1MW/4M WHh SYSTEM (WITH PV) ($/KWh)
Battery pack	176	0%	176	0%	176	176
BoS	100	-49%	51	-51%	25	15
Inverter	70	0%	70	-74%	18	11
EPC	88	-78%	20	-60%	8	8
Soft cost (excluding taxes, land, permitting and interconnection fees)	61	-60%	25	-36%	16	16
Total	**495**		**341**		**242**	**225**

Since the solar and storage battery is in nascent stage in Nepal hence for the formulation of the benchmark price for Nepal a 30% margin was added to the cost for India's standalone USD price for storage. Hence the price of 1MW/ 4MWh storage is estimated as 300 (US$/kWh).[20]

Table 25: Costs by Component for Large-Scale PV Plant in India and Nepal

COMPONENT	COST IN (INR MILLIONS/MW)	PERCENTAGE OF TOTAL COST	COST IN $/KW*[21]	COST IN (NPR MILLIONS/MW)
PV module	28	67%	308	48
Land cost	2.1	5%	26.9	4.0

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[20] 1USD-130 NPR

*[21] 1USD-78 INR

COMPONENT	COST IN (INR MILLIONS/MW)	PERCENTAGE OF TOTAL COST	COST IN $/KW*[21]	COST IN (NPR MILLIONS/MW)
Civil and general works	2.0	5%	25.6	3.2
Mounting structures	2.5	6%	32.0	4.52
Power-conditioning units	2.3	5.5%	29.4	3.68
Total	**41.6**		**482**	**72.65**

The price for solar+ storage can be seen in the table below:

Table 26: Costs by Component for Large-Scale PV Plant + storage (1 MW +4MWh storage)

COMPONENT	COST IN (NPR MILLIONS/MW INCLUDING 4MWh STORAGE
PV module	48
Land cost	4.0
Civil and general works	3.2
Mounting structures	4.52
Power-conditioning units	3.68
Evacuation cost up to interconnection points (cables and transformers)[22]	4.15
Preliminary and pre- operative expenses including interest during construction and contingency	5.10
BESS including Battery pack, EPC and all BOS	156.0
Total	228.65

Battery pack prices reached US$200-250/kWh in 2019 but are expected to come down to US$100-150/kWh by 2024.[23] A closer look at the price breakdown indicates that while other component costs will balance out each other and reduce slightly, cell costs are expected to go

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[22] This cost includes cost for evacuation up to 10 km

[23] BNEF

up. The cost for BESS for 4 hours energy storage as forecasted by NREL can be seen in Figure 113 below:

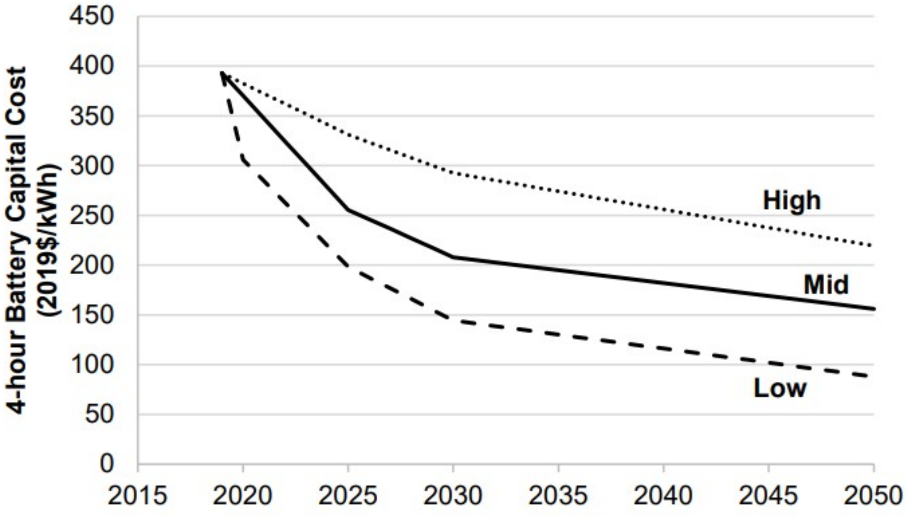

Figure 113: Forecasted Li-Ion prices considering 4 hours storage (Source: NREL)

The drop in battery prices from US$1,220/kWh in 2010 to US$132/kWh in 2021 has been the key driver for adoption of EVs as well as use in stationary storage worldwide. Despite, the intense pressure from rising raw material and component costs, battery prices continued to fall till 2021. The drop in prices led automakers and stationary storage developers to widely adopt LFP in 2021, helping offset the rising material costs. However, going further, BNEF analysis shows that prices increased for the first time to US$135/kWh in 2022 due to the impacts of higher raw material and component prices. Chinese LFP producers increased prices by 10-20%. Based on NREL's estimate the low case the price's for 4 hour storage is 275 US$/kWh but with large manufacturers setting up gigafactories and lowering the unit economics the battery price considered by LBNL estimates are around 172 US$/kWh for the battery pack.

6.3.3 Cost Model

To derive the current costs in 2022 model is developed using the NREL bottom-up BESS and PV+BESS costing tool (Excel-based). BESS storage durations of 2/4/6/8/10 hours are modeled and then a linear cost curve fit to the data. The cost was estimated using the formula

Total BESS cost = Batt_capex_per_kWh x BESS storage capacity (kWh)+ batt_capex_per_kW x BESS power capacity (kW)

There are each three scenarios: Advanced, Moderate, Conservative (cost)

BESS- Cost Projection Assumptions:

- Advanced - applied the NREL 2020 ATB Utility-Scale BESS Advanced scenario,
- normalized to 2020, to both the BESS Energy (kWh) and Power (kW) cost terms in the linear cost curve fit to the data
- Moderate - Applied BNEF 2019 utility-scale BESS cost projections, by component, to the component cost breakdown of the modeled PV+BESS systems
- Conservative - Applied the NREL 2020 ATB commercial & industrial (CI) Scale PV Conservative scenario, normalized to 2020, to both the BESS Energy (kWh) and Power (kW) cost terms in the linear cost curve fit to the data.

The output of the model can be seen in Figure 114.

Results from the NREL Utility-Scale BESS model (current costs) with projections from NREL ATB 2020 Utility-Scale BESS Projections + BNEF battery cost projections
2019 System Costs in 2019 USD. Costs are presented in both $/kW and $/kWh.

	Future 60-MW BESS Costs ($/kW) - MID					Future 60-MW BESS Costs ($/kWh) - MID					
	2-hour	4-hour	6-hour	8-hour	10-hour	2-hour	4-hour	6-hour	8-hour	10-hour	
2018											
2019	902	1,554	2,206	2,858	3,509	451	389	368	357	351	-
2020	866	1,464	2,062	2,660	3,258	433	366	344	333	326	-
2021	829	1,373	1,918	2,462	3,007	414	343	320	308	301	-
2022	792	1,283	1,773	2,264	2,755	396	321	296	283	275	-
2023	755	1,192	1,629	2,066	2,503	377	298	272	258	250	-
2024	718	1,101	1,485	1,868	2,252	359	275	247	234	225	-
2025	681	1,011	1,340	1,670	2,000	340	253	223	209	200	-
2026	666	973	1,280	1,586	1,893	333	243	213	198	189	-
2027	649	935	1,221	1,507	1,793	325	234	204	188	179	-
2028	630	898	1,165	1,433	1,700	315	224	194	179	170	-
2029	610	860	1,111	1,361	1,612	305	215	185	170	161	-
2030	587	823	1,058	1,294	1,529	294	206	176	162	153	-
2031	585	812	1,040	1,267	1,495	292	203	173	158	149	-
2032	586	802	1,018	1,234	1,449	293	200	170	154	145	-
2033	586	792	998	1,203	1,409	293	198	166	150	141	-
2034	584	781	978	1,176	1,373	292	195	163	147	137	-
2035	582	771	961	1,150	1,339	291	193	160	144	134	-
2036	578	761	944	1,126	1,309	289	190	157	141	131	-
2037	574	751	927	1,104	1,280	287	188	155	138	128	-
2038	569	740	911	1,083	1,254	285	185	152	135	125	-
2039	564	730	896	1,062	1,229	282	182	149	133	123	-

	Future 60-MW BESS Costs ($/kW) - LOW					Future 60-MW BESS Costs ($/kWh) - LOW					
	2-hour	4-hour	6-hour	8-hour	10-hour	2-hour	4-hour	6-hour	8-hour	10-hour	
2018											
2019	902	1,554	2,206	2,858	3,509	451	389	368	357	351	-
2020	703	1,210	1,718	2,226	2,733	351	303	286	278	273	-
2021	653	1,125	1,597	2,069	2,541	327	281	266	259	254	-
2022	604	1,040	1,476	1,912	2,349	302	260	246	239	235	-
2023	554	955	1,355	1,756	2,156	277	239	226	219	216	-
2024	505	870	1,234	1,599	1,964	252	217	206	200	196	-
2025	455	784	1,113	1,442	1,771	228	196	186	180	177	-
2026	431	742	1,053	1,364	1,675	215	185	175	170	168	-
2027	406	699	992	1,286	1,579	203	175	165	161	158	-
2028	381	656	932	1,207	1,482	191	164	155	151	148	-
2029	356	614	871	1,129	1,386	178	153	145	141	139	-
2030	332	571	811	1,050	1,290	166	143	135	131	129	-
2031	325	560	795	1,030	1,264	163	140	132	129	126	-
2032	319	549	779	1,009	1,239	159	137	130	126	124	-
2033	312	538	763	989	1,214	156	134	127	124	121	-
2034	306	526	747	968	1,189	153	132	125	121	119	-
2035	299	515	731	947	1,164	150	129	122	118	116	-
2036	293	504	715	927	1,138	146	126	119	116	114	-
2037	286	493	700	906	1,113	143	123	117	113	111	-
2038	280	482	684	886	1,088	140	120	114	111	109	-
2039	273	471	668	865	1,063	137	118	111	108	106	-

	Future 60-MW BESS Costs ($/kW) - HIGH					Future 60-MW BESS Costs ($/kWh) - HIGH				
	2-hour	4-hour	6-hour	8-hour	10-hour	2-hour	4-hour	6-hour	8-hour	10-hour
2018										
2019	902	1,554	2,206	2,858	3,509	451	389	368	357	351
2020	879	1,513	2,148	2,783	3,417	439	378	358	348	342
2021	855	1,473	2,090	2,708	3,326	427	368	348	338	333
2022	831	1,432	2,032	2,633	3,234	416	358	339	329	323
2023	808	1,391	1,975	2,558	3,142	404	348	329	320	314
2024	784	1,350	1,917	2,483	3,050	392	338	319	310	305
2025	760	1,310	1,859	2,408	2,958	380	327	310	301	296
2026	743	1,279	1,816	2,352	2,889	371	320	303	294	289
2027	725	1,249	1,772	2,296	2,820	362	312	295	287	282
2028	707	1,218	1,729	2,240	2,750	354	304	288	280	275
2029	689	1,187	1,685	2,183	2,681	345	297	281	273	268
2030	672	1,157	1,642	2,127	2,612	336	289	274	266	261
2031	663	1,142	1,621	2,101	2,580	332	286	270	263	258
2032	655	1,128	1,601	2,074	2,547	327	282	267	259	255
2033	646	1,113	1,580	2,047	2,514	323	278	263	256	251
2034	638	1,099	1,560	2,021	2,482	319	275	260	253	248
2035	630	1,084	1,539	1,994	2,449	315	271	257	249	245
2036	621	1,070	1,519	1,968	2,416	311	268	253	246	242
2037	613	1,056	1,498	1,941	2,384	306	264	250	243	238
2038	604	1,041	1,478	1,914	2,351	302	260	246	239	235
2039	596	1,027	1,457	1,888	2,318	298	257	243	236	232

Figure 114: Forecasted Li-Ion prices considering 4 hours storage (Source: Highland Analysis)

From the model for 2023 the forecasted price for Li-Ion battery is 239 US$/kWh whereas we have taken cost of 225 US$/kWh. These were forecasted corresponding to India's context. Taking 30% margin in case of Nepal as above it comes out to be around 310 US$/kWh. Thus, we can see that the prices are close in terms of forecasting from model and bottom-up approach considered. Hence, we can consider price of 300 US$/kWh as a safe bet.

6.3.4 Financial Model and Payback

Table 27 lists out the assumptions taken for the financial analysis of the system.

Table 27: Assumptions for Financial Analysis

PARTICULAR	AMOUNT
System Size (kWp)	6500
Price per kWp (NPR)	72,250
System price (NPR)	472,515,000
Battery cost for 1MW/4MWh	156,000,000
Battery storage considered (kWh)	50,000
Total cost for battery storage (50 MWh)	998,400,000[24]
Net Installed cost(NPR)	1,470,915,000
Project Performance and Savings/ Cost Assumptions	
Annual Net Capacity Factor kWp (DC STC)	17.25%
Annual Production Degradation (%)	0.55%
Project Life (Years)	25
Solar Electricity Revenue from NEA (NPR/kWh)	5.94
Storage tariff	12.40
Tariff Escalation	3%/ year up to 8 years
Electricity tariff for battery charging	6.6[25]
% of solar electricity sales	74.4%
% of solar electricity for battery charging	25.6%
Annual Operations and Maintenance Cost Factor (NPR/kWh/year)	612
Annual Operations and Maintenance Cost NPR/Year)	4,002,280
Annual Operations and Maintenance inflation (%)	5%
Inverter Replacement Cost (NRP/kW (DC STC))	2200
Inverter Life	10
Battery Life	15
Battery cycle	12000
Cycles per year	730
Overall efficiency (%) of battery storage	95%

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[24] The battery size was 12.5 times the considered but taking the same scaling ration the cost of1.92 times lower was considered for the battery size.

[25] Average of tariff for ROR dry and wet season as published by NEA. https://www.nea.org.np/admin/assets/uploads/PPA_Rates.pdf

PARTICULAR	AMOUNT
Depth of Discharge (%)	80%
CUF (%)	65%
Financing Assumptions	
% Financed with Cash (%)	20%
% Financed with Loan (%)	30%
% Subsidy	50%
Loan Interest Rate (%)	15%
Loan Period (Year)	10
Depreciation Year (Year)	20
Discount Rate (%)	15.00%
Income tax rate	0% for 10 years,12.5% for 11-15 years and then 25%

6.3.4.1 Financial model and Paybacks

Based on the cost and the assumptions above a financial model was prepared. Based on the model the IRR for the project is 11%. Some of the outputs of the financial model are provided in Table 28.

Table 28: Paybacks and returns from Financial Model

PARTICULAR	AMOUNT
Equity Return Post Financing and Tax	17.16%
ROI (Return on Investment) (Years)	11.29
Project Return Post Financing and Tax	9%
Project ROI (Years)	11.29
NPV (NPR)	107,221,138.7
WACC (Weighted average cost of capital)	10.04%
Average DSCR	1.77

Though the equity IRR is 17% but taking into the consideration the WACC is 10.04% considering the effective tax rate of 14%. Thus, since the WACC is less than the discount rate hence the project is riskier overall. Similarly, the average DSCR is 1.77 which above the returns expected by commercial banks in Nepal of above 1.50. The maximum DSCR is 1.93 in eighth year.

6.3.4.2 Sensitivity Analysis

Sensitivity analysis helps us evaluate the condition in which if changes occur in any of the parameters how will it affect the overall returns of the project. In Table 29 we can see how the change in SECF support will help bring the project will affect the savings and returns of the project. Also, we need to look into the different NEA tariffs for storage for dry and wet seasons and need to evaluate the change in financial returns.

Table 29: Sensitivity Analysis with change in Subsidy

SUBSIDY	EQUITY IRR	EQUITY PAYBACK (YEARS)	PROJECT IRR	PROJECT PAYBACK (YEARS)
0%	1.7%	22.52	1%	22.52
20%	5.2%	17.97	3%	17.97
30%	7.8%	15.36	5%	15.36
40%	11.6%	13.33	7%	13.12
50%	17.6%	11.29	9%	11.60
55%	22.3%	8.05	11%	10.20

Table 30: Sensitivity analysis with change in Feed in tariff

TARIFF	SUBSIDY	EQUITY IRR	PAYBACK
8.55	50%	3.7%	19.62
8.40	50%	3.2%	20.21
9.40	50%	6.4%	16.78
10.55	50%	10.4%	13.85
12.60	50%	18.5%	11.07

Table 31: Sensitivity analysis with change in Feed in tariff and subsidy

TARIFF	SUBSIDY	EQUITY IRR	PAYBACK
8.55	70%	16.2%	11.62
8.55	75%	24.5%	7.03
10.55	60%	17.5%	11.30
10.55	65%	23.6%	7.41
12.40	55%	22.3%	8.05

TARIFF	SUBSIDY	EQUITY IRR	PAYBACK
9.40	70%	22.7%	7.76

Table 32: Sensitivity analysis with change in Feed in Tariff, Interest rate and subsidy

TARIFF	INTEREST RATE	SUBSIDY	EQUITY	PAYBACK
12.40	12%	50%	21.5%	8.21
12.40	10%	40%	16.6%	11.36
10.55	12%	50%	13%	12.60
10.55	10%	50%	15%	11.81
8.55	10%	65%	16.2%	11.41
8.55	12%	70%	19.8%	8.90

Hence from the above sensitivities it can be seen that best case scenario would be a storage tariff of 12.40 which is the current rate for storage offered by NEA for dry seasons but needs to be throughout the year. With this tariff and 50% subsidy by GON the equity IRR is 17.16% which is attractive for the Investor considering the interest rate of 15% as is common now in Nepal. However, with cheaper interest rates for such projects with an interest rate of 10% and 40% subsidy the returns are 16.6% which are ideal considering investors seek at least 15% returns on capital.

6.3.5 Tariff Calculation

In the last couple of year there have seen that there is a growth spurt in storage projects coming up. USA pioneer in RE+ storage has seen a massive spurt in growth of such systems. In last one year there have been lot of RE and solar tender issuance; however, only for a few small tenders, the auctions are successful. In most other tenders, the storage capacity is so high that it leads to infeasible tariffs, and eventually to cancellations of many of these tenders. Keeping this in mind MSEDCL came up with a tender with 100 MW/600MWh storage where the starting price for the tender was 9.65 INR/kWh for peak hours and 2.42 for off- peak tariff. Aayana Renewable Power won the tender with a price of INR 9.0/kWh. The weighted average tariff based on the normative capacity utilization factor of 75% as per the condition of the tender is 5.60 INR. Based on tender issued in India the developer shall make the BESS available for 2 operational cycles per day, i.e. 2 complete charge-discharge cycles per day. The projects are required to demonstrate minimum availability of 95% on an annual basis, a minimum round-trip efficiency of 85% monthly, and suitable liquidated damages stipulated in case of shortfall in meeting the above criteria. The term of the projects will be 12 years, with the scheduled commissioning date being 18 months from the date of signing of the Battery Energy Storage Purchase Agreement (BESPA). Taking this into perspective and using bottom-up analysis the tariffs for different projects to come up in Nepal were evaluated.

Based on the above cost for solar projects in India and Nepal there is roughly around 15-20% difference in the solar project cost. Similarly, the battery storage cost is 30% above that of India. The other external factor is lending rate. In India the current lending rate by IREDA is from around 8.5-9.25%, whereas in Nepal it is around 12-15%. Taking all these in perspective scenarios of different variables the best-case tariff for is shown in Table 33.

Table 33: Case Tariff Scenario for Solar PV with BESS

TARIFF (INR)	VARIABILITY (%)	TARIFF NPR	EQUITY IRR	PAYBACK
5.60	50%	13.46	8.3%	15.13
5.60	60%	14.34	10.1%	14.16
5.60	70%	15.23	11.9%	13.30

(Note: these are scenario based on no subsidy case).

Since this storage is for 6 hours storage and to consider 4 hours storage there will be on the lower side. Based on interaction with developers in India the tariff can be 12-15% lower, making it 4.76 for 4 hours storage. Taking this into context, CUF of 85% and variability of 70% the tariff comes out to be 12.94. With this the tariff and battery charging tariff to be 4.80 the scenario comes out be:

Table 34: Best Case Tariff Scenario for Solar PV with BESS

TARIFF	VARIABILITY	SUBSIDY	TARIFF NPR	EQUITY	PAYBACK
4.76	70%	30%	12.94	17.5%	11.49

Based on the financial calculations and tariff calculation based on bottom-up approach charging tariff of 4.80 and tariff of 12.40 with 3% increment for 8 years and 90% CUF gives equity IRR of 17.0 % considering 30% subsidy which can be an ideal scenario. In UP, India based on the new solar policy for PV+BESS Capital state subsidy of INR 2.50 crore/MW will be provided to utility-scale solar power projects set up with 4-hour battery storage system of 5 MW capacity or above and standalone battery storage system (energized by solar energy only) for sale of power to distribution licensee.

6.3.5.1 PPA Rate for Hydropower Projects

The Ministry of Energy has fixed the rate of Power Purchase Agreement (PPA) for the hydropower projects based on reservoirs and run-off-the-rivers (RoR). PPA rate is fixed at Rs 4.80 to Rs 12.40 depending upon the nature of projects and seasons. PPA rate for storage projects with at least 35% generation in dry season has been fixed at Rs 12.40 per unit from December 1 to May 28 and Rs 7.10 from May 29 to November 30.

Similarly, the PPA rate has been fixed at Rs 4.40 from April to December 15 and Rs 8.40 from December 16 to April 12 per unit for the hydroelectricity generated through the RoR while for RoR-based peaking electricity, the PPA rate has been fixed at Rs 4.40 to 10.55.

The PPA rate is high during dry season that lasts for six months beginning December 1 to May 28 and comparatively low during rainy season starting May 29 to November 30.

The PPA rate shall be escalated at the rate of 3% per year for eight years.

6.3.5.2 PPA Rate for Solar Power

NEA has revised PPA rate to purchase electricity generated from solar power plants from Rs 7.30/unit to Rs 5.94/unit. Recently NEA has invited bids to procure 100 MW of power from solar power plants

6.4 Environmental and Social Aspect

The need for undertaking an Environmental and social aspect is an important part is to minimize the adverse effects from development activities.

The first step of undertaking any Environmental for a development project is to identify if the project will have any adverse effects. The projects are classified under two categories viz. Category 1 and 2.

A project is classified as Category 1 if it is likely to have significant adverse environmental impacts that are sensitive, diverse, or unprecedented, and affects an area broader than the sites or facilities subject to physical works.

A project is classified as Category 2 if its potential adverse environmental impacts on human populations or environmentally sensitive areas (e.g., wetlands, forests, grasslands and other natural habitats) are less adverse than those of Category 1 projects. These impacts are site specific, and few are irreversible.

6.4.1 Physical Environment

- Impacts due to solar energy project are mostly distinct during construction phase

- Access road, office building and transmission lines are likely to have limited environmental impacts on land use, water quality etc.
- The construction of proposed project may bring local changes in the land use pattern of the site but there would be no significant adverse visual impact to the area
- The project will have negligible impact on air emissions and ambient noise levels due to the distant location of receptors

6.4.2 Biological Environment

No significant impacts on biological environment have been foreseen

- Wet lands are not present in or around the project area
- The project will have no impact on the flora and fauna. The identified project will have no negative impacts on the terrestrial environment.

6.4.3 Socio-Economic Environment

The social negative impacts include health and safety of locals and workers during construction phase. The proposed project will have no significant negative impacts on the nearby populations as there will be no displacement of people.

On the other hand, there is high positive impact on the social environment as the level of employment rises tremendously as a result and there will be an economic growth with the establishment of commercial activities in the area and thus would improve the quality of life due to access due to electricity. Table 35 presents the environmental and social risk mitigation matrix for a typical DRE with BESS projects.

Table 35: Environmental and Social risk mitigation

ENVIRONMENTAL PARAMETER	LEVEL OF IMPACT	REASONS	MITIGATION MEASURES
Air Impact	Low	• No atmospheric Emissions from the process.	• Use of PV based solar power technology

ENVIRONMENTAL PARAMETER	LEVEL OF IMPACT	REASONS	MITIGATION MEASURES
Water	Low	• Plant will require a very low amount of water. • No effluent is envisaged to be discharged from the plant that may have impact.	• In the case of wet cleaning, the amount of water needed is insignificant. • There is no need of water if promoter manages to successfully implement dry cleaning of modules. • No effluent should be discharged.
Land	Medium	• Impact of change in land use.	• Site selection has been made in consideration of the local government to develop a solar project.
Noise	Low	• No Sources of Noise within the project area. • As no sensitive locations in the vicinity of the project site.	• Noise barriers will be provided to neutralize the noise. • Noise level of machines shall be below 85 dB (A)
Ecosystem	Low	• As no ecologically sensitive place lies within 10 km radius from the project site	• Although there is no significant vegetation cover within the study area, plantation activities will be carried out.

6.5 Risk and Mitigation Strategies

Table 36: Risks and mitigation measures for BESS+DRE projects

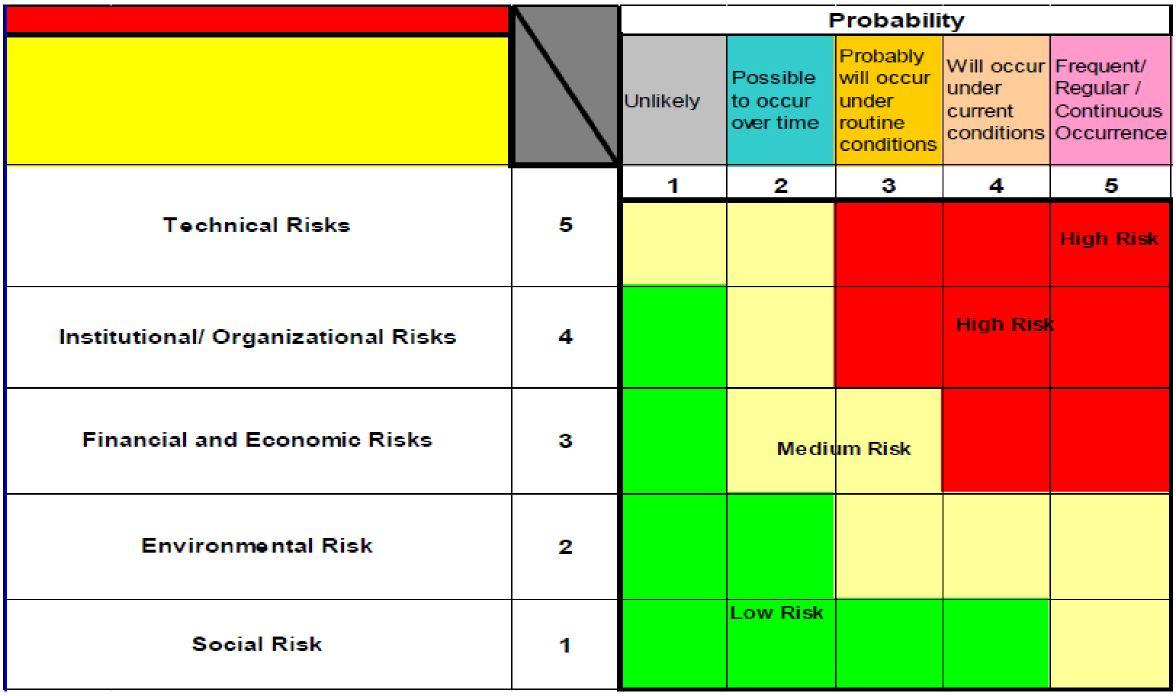
PARAMETER	LEVEL OF IMPACT	REASONS	MITIGATION MEASURES
Battery Safety	Low	• Lithium secondary batteries contain both oxidizers (negative) and fuel (positive) within the enclosed battery space, and therefore also carry the risk of fire and explosion in case of overcharging over-discharging, excess current, or short circuits.	• Safety design is essential at the cell, module, pack, and final product level. • Battery protection circuit.
Grid Tariff Applications and Licensing Issues	High	• The overall capex for BESS is on the higher than RE generators.	• Different tariffs for BESS. • Easy process of handing over licenses to such projects.
Challenges of reducing carbon emissions	Medium	• Since for most of such systems the share of RE charging in the batteries may be low due to cost optimization, hence there will be risk of lower reduction in the CO_2 reductions.	• Cheaper tariff for charging with electricity generated from RE. • Use of BESS with RE based source where at least 50% of the charging is done from RE source.

PARAMETER	LEVEL OF IMPACT	REASONS	MITIGATION MEASURES
Battery recycling and reuse risk	Medium	• Once the battery reach end of life they generally gets disposed. • The batteries contain harmful chemicals which may incur negative impacts on the environment and health of the wellbeing.	• Need to have strict guidelines and policy on the dumping of batteries rather than recycling. • Some of the vendors like CATL and CALB has a provision of battery replacement and recycling concept hence need to select vendors wisely.
Economic Risks	Medium	• Plant operation costs. • Corrective maintenance costs. • Prevention maintenance costs. • Performance losses Revenue estimation. • Costs of connection to electric grid. • Obtaining of the construction license.	• Proper assessment of all the parameters while carrying out the detailed feasibility studies.

PARAMETER	LEVEL OF IMPACT	REASONS	MITIGATION MEASURES
Technical Risks	High	• Technological adequacy to climate change • Associated with technology. • Development of new systems. • Possibility of alternative power generation systems.	• Be up to date with the current. • Market trends in terms of technology. • The technology use should have a cost and technological benefit for the entire project life.
Macroeconomic	Medium	• Obtaining of bank financing. • Changes in power demand. • Changes in the price of money. • Changes in energy prices.	• In most of projects which are dependent on supply chain from the outside its better to sign a hedging binding contract with the bank.

PARAMETER	LEVEL OF IMPACT	REASONS	MITIGATION MEASURES
Time Delay risks	Medium	• Connection to Electric grid. • Delays in the construction of the power connection line. • Delays in the obtaining of the administration approval for the construction of the line. • Delays in the signature of the agreement with the Electricity supply Firm.	• Policy level intervention for fast-tracking and processing such projects.

The overall different risks can be categorized in the risk matrix as presented in figure below:



		Probability				
		Unlikely	Possible to occur over time	Probably will occur under routine conditions	Will occur under current conditions	Frequent/ Regular / Continuous Occurrence
		1	2	3	4	5
Technical Risks	**5**	🟨	🟨	🟥	🟥	🟥 **High Risk**
Institutional/ Organizational Risks	**4**	🟩	🟨	🟥	🟥 **High Risk**	🟥
Financial and Economic Risks	**3**	🟩	🟨 **Medium Risk**	🟨	🟥	🟥
Environmental Risk	**2**	🟩	🟩	🟨	🟨	🟨
Social Risk	**1**	🟩	🟩 Low Risk	🟩	🟩	🟨

Figure 115: Risk Matrix

7 CONCLUSION

Electricity generation in Nepal is predominantly hydro based. There is excess power in the system during wet season and deficit during dry season. This is due to lack of adequate capacity of storage power plants. Electricity is imported from India during the dry period to meet the demand. Electricity demand is constantly rising and expansion and reinforcement of transmission and distribution system is required to cater the ever-increasing demand. Hydro power plants are concentrated in eastern and central Nepal.

In the western region, west of Butwal, occasionally during summer, system voltage was recorded lower than the permissible limit in some substations. Capacitor banks installed in various substations helped to some extent in maintaining voltage but it is not sufficient enough. The voltage could not be maintained at the desired level despite the continuous effort of Load Dispatch Centre which is the NEA's center for grid operation. Also, many links in the INPS grid system are heavily loaded resulting in poor voltages as low as 0.8 p.u. Overall transmission losses on in 2021/22 was 4.49% while the corresponding figure for west of Butwal was 3.62%. The transmission line Hetauda-Bharatpur 132 kV, Damauli - Bharatpur 132kV, Bharatpur – Kawasoti - Bardghat132 kV, Lekhnath – Syanga - Kaligandaki A, Marsyangdi - Bharatpur 132 kV, Duhabi - Anarmani 132 kV were being operated almost in full capacity continuously which might have originated the power cut in some areas. In recent year, difficulty in the smooth power supply to the western part of the country (west from Butwal) has been realized due to the unavailability of sufficient generation in the western part of the country to cater the growing demand. Due to the transmission line's inadequate capacity, surplus generation of the eastern part of the country cannot be transmitted to the west thus Butwal west is partly supplied from the imported power from Tanakpur (India). Despite Nepal being a generation surplus country in the wet season, still imported power is playing a vital role in the supply of power in the western part which has triggered the issues of energy security and is leading to outflow monetary reserves from Nepal.

Also on the distribution side frequent tripping of power lines and unreliable power supply along with a poorly regulated voltage in many locations have raised some question about the reliability of Nepalese power systems. Due to poor planning and system design voltage can go down to as much as 17 - 20% or more which is unacceptable for many electrical equipment. Unprecedented and unscientific length of distribution feeders sometimes up to 30 km has led to end user of the feeder has a poorly regulated voltage supply. This is one of the many issues responsible for the poor voltage regulation in many places of Nepal. Because of poorly maintained transformers, substations and transmission line, significant energy is lost yearly resulting in loss of revenue amounting to millions of rupees.

Analysis of the current loading shows most of the substations towards west of Butwal have the capacity just sufficient to cater to the current peak demand. Mainihawa, Motipur, Sandhikhark and Ghorahi (Jhigni) substations are exceptions as they are relatively new substations. Some of the substation's transformers are loaded at full capacity and most of the sites where forecasting has been carried out, the substation loading is more than 75% where up-gradation is required to cater the future energy demands.

Load flow analysis showed the voltages at the 132 kV substations are towards the lower side but within the permissible limit set forth by the grid code i.e., ±10%. However, in substations namely Kohalpur and Hapure the voltage level is below the permissible limits in few situations. In case of 33 kV system, the voltage has dropped beyond 20 kV compared to lower limit of 29.7 kV. Such extreme conditions are seen for the substation which are far from 132 kV grid substations and are connected by extremely long 33 kV lines or are heavily loaded without reactive power compensation. The voltage situations of 33 kV substations in Butwal, Bhairahawa, Kapilvastu and Sandhikharka area has improved with the commissioning of new 132 kV substations. Voltage drop still exists in Taulihawa, Bhairahawa and Palpa 33 kV substations.

The loading of the 132 kV transmission line west of Butwal is within the permissible limit. In case of 33kV lines it is found that two out of 17 major line sections are overloaded in Karnali Province. The 11.49 km Kohalpur Grid - Nepalgunj Medical College have the maximum loading of 132.80%. Similarly, the section from Nepalgunj Medical College and Bheri Diversion Tapping with sectional length of 10.28km have 125.62% loading (LRMP, 2021/22). The situation will not improve before commissioning of Kohalpur-Surkhet 132 kV transmission line and Surkhet 132 kV substation under construction. In Sudurpaschim Province, Attariya – Dhangadhi 33 kV line section is loaded at 109.38% of the maximum loading capacity while loading of remaining line sections are below maximum loading capacity. To overcome the situation, it is planned to construct another 33 kV line between Attariya and Dhangadhi.

Impact analysis of solar PV power plant on frequency deviation and voltage indicated stable behavior of the system and the voltage and frequency deviations are within the prescribed limit. However, when the solar power plant is far from the hydro power plant site, the frequency oscillations are sustained for longer time. This is the case for the locations west of

Butwal where few small capacity hydro power plants are located at far off distances. Adaptation of DRE with BESS would help improve the situation. With BESS, if there is outage of the solar power plant, battery storage system will take over the load and the supply will remain intact.

Detailed analysis is required before deciding level of penetration of DREs or BESS at 11 kV or low voltage system, otherwise it may lead over or under voltages depending upon the size and location of the DREs or BESS.

Modelling and analysis of 3 selected sites namely, Nepalgunj, Chanuta and Surkhet at 33kV voltages of selected substations at 1 pm on a typical day, showed that the injection of solar PV plant serves in improving the voltage profile. BESS has a big role to play technically for strengthening the grid. Since BESS adaption in Nepal is in nascent stage but is a billion-dollar market, hence this is an enticing opportunity for developers and investors to tap into. However financial analysis shows there is a need of higher storage tariffs throughout the year with certain amount of subsidy to market the offering more lucrative to these investors and developers.

For the peak shaving two sites one 33kV catering to the industries in Chanauta and similarly another in Nepalgunj catering to the industries was selected. The sites were selected as they will be able to cater to the industries where the import from India or supply from NEA will be lower. The system will be able to supply the peak to the industries using batteries. For the weak grid Islanding 33kV substation in Surkhet was considered as due to the long distance of around 54 km passing through the forest area there is frequent tripping in the line. A total of 94 hours in 2021/22 there was frequent line tripping and power outages. Thus, it serves as a suitable case for observing the weak grid islanding. Similarly in case of Belauri solar and battery integration can help in managing the flexibility that will align peak solar generation in the middle of the day with evening peak demand. This will help NEA in adding the loads without much upgrading the transmission network and adding new generation as battery can help balance the load. Hence it is recommended that 4 sites namely Nepalgunj, Chanauta, Surkhet and Belauri DC be considered initially for BESS and DRE integration. Thus, NEA needs to bring these sites on the planning process and will help add 210 MW of BESS storage and 20 MW of solar capacity to the national grid.

For the detailed analysis for integration of DRE in medium voltage line, Bageshwori Feeder and Khajura Feeder emanating from Nepalgunj New substation could be considered.

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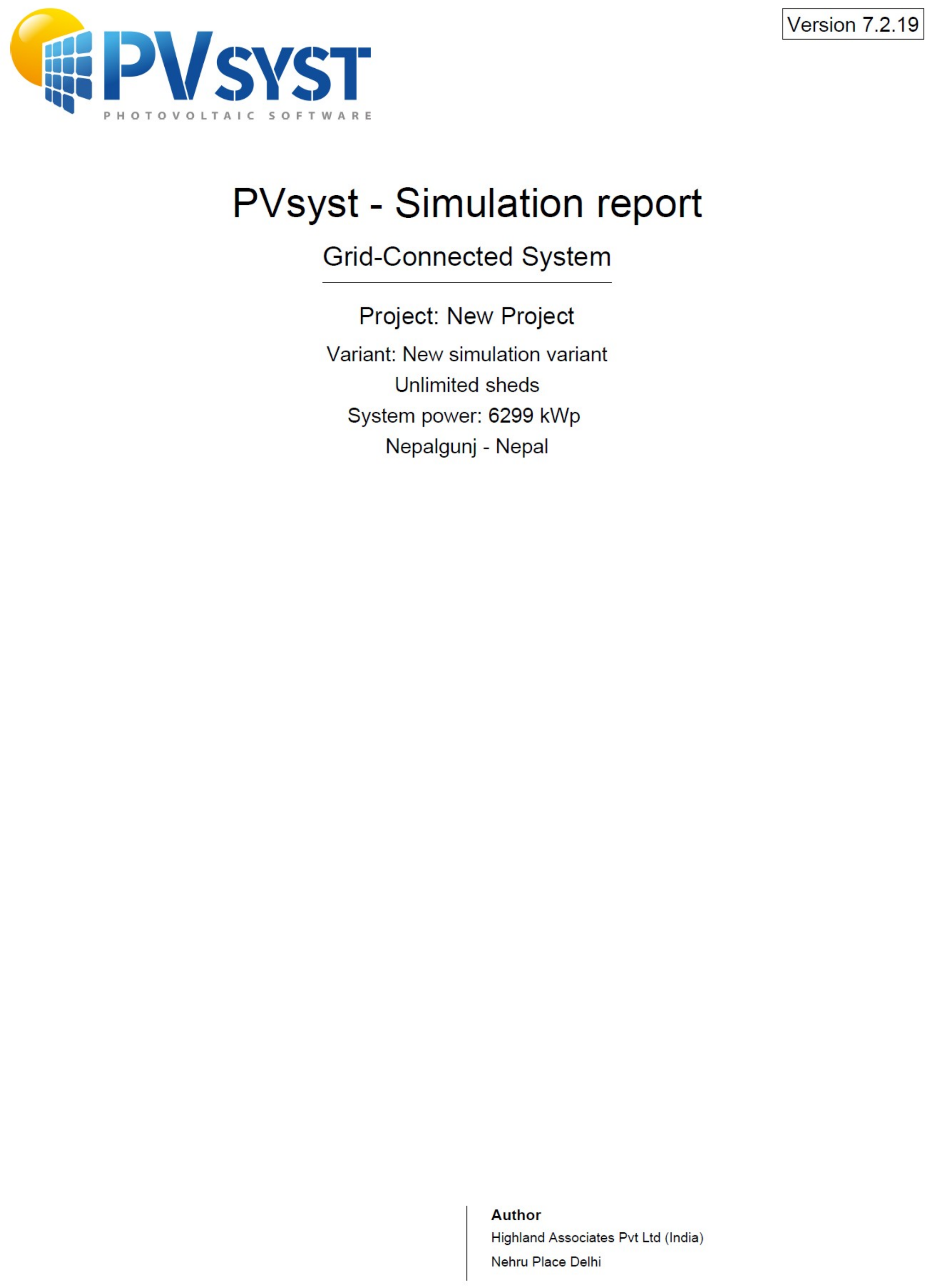
9 ANNEXURE

9.1 Annexure 1

Weak Grid Islanding Model



PVSYST PHOTOVOLTAIC SOFTWARE

Version 7.2.19

PVsyst - Simulation report

Grid-Connected System

Project: New Project

Variant: New simulation variant
Unlimited sheds
System power: 6299 kWp
Nepalgunj - Nepal

Author
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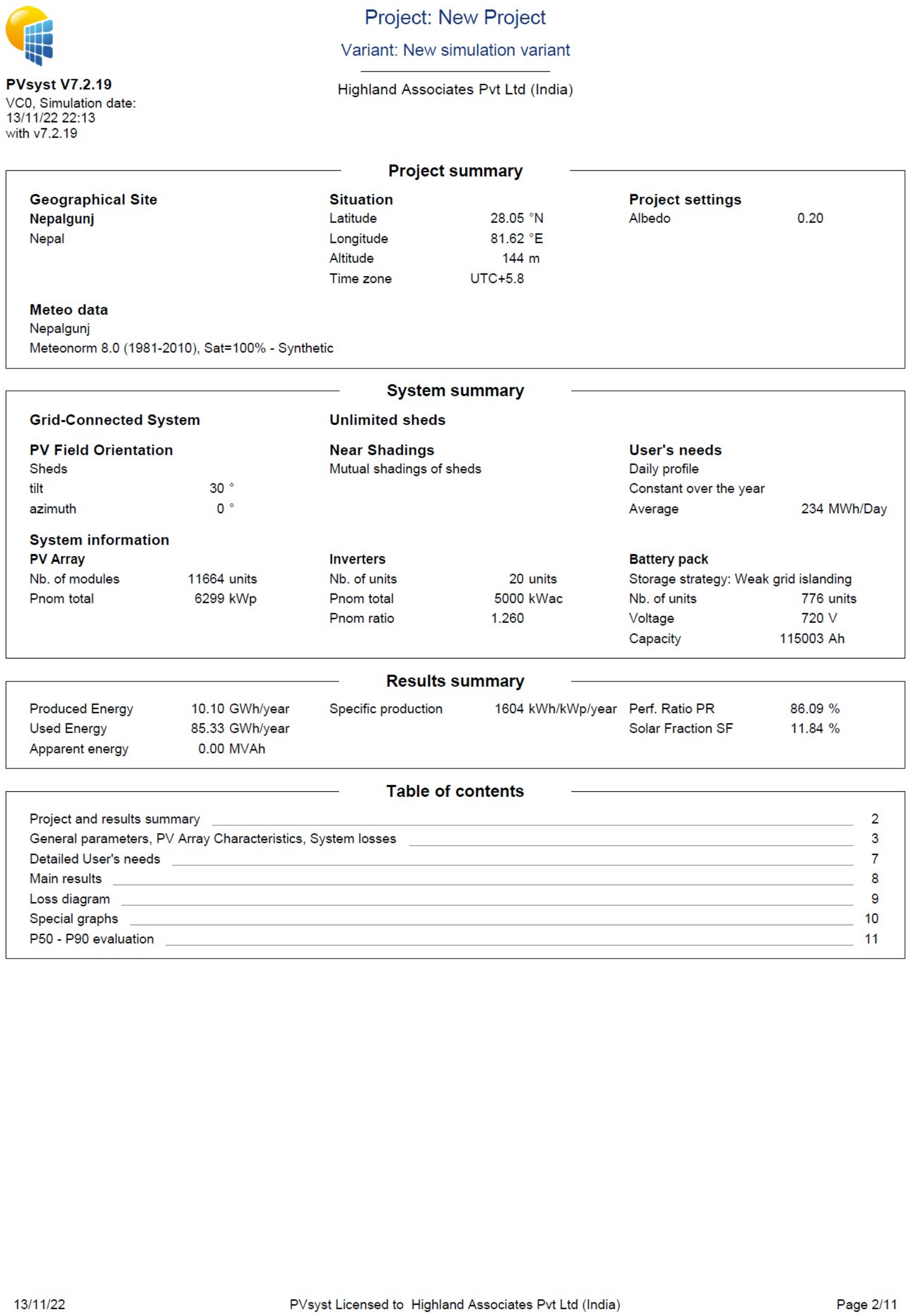

PVsyst V7.2.19
VC0, Simulation date:
13/11/22 22:13
with v7.2.19

Project: New Project

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

Project summary

Geographical Site	Situation		Project settings	
Nepalgunj	Latitude	28.05 °N	Albedo	0.20
Nepal	Longitude	81.62 °E		
	Altitude	144 m		
	Time zone	UTC+5.8		

Meteo data
Nepalgunj
Meteonorm 8.0 (1981-2010), Sat=100% - Synthetic

System summary

Grid-Connected System | **Unlimited sheds**

PV Field Orientation		Near Shadings	User's needs	
Sheds		Mutual shadings of sheds	Daily profile	
tilt	30 °		Constant over the year	
azimuth	0 °		Average	234 MWh/Day

System information

PV Array		Inverters		Battery pack	
Nb. of modules	11664 units	Nb. of units	20 units	Storage strategy: Weak grid islanding	
Pnom total	6299 kWp	Pnom total	5000 kWac	Nb. of units	776 units
		Pnom ratio	1.260	Voltage	720 V
				Capacity	115003 Ah

Results summary

Produced Energy	10.10 GWh/year	Specific production	1604 kWh/kWp/year	Perf. Ratio PR	86.09 %
Used Energy	85.33 GWh/year			Solar Fraction SF	11.84 %
Apparent energy	0.00 MVAh				

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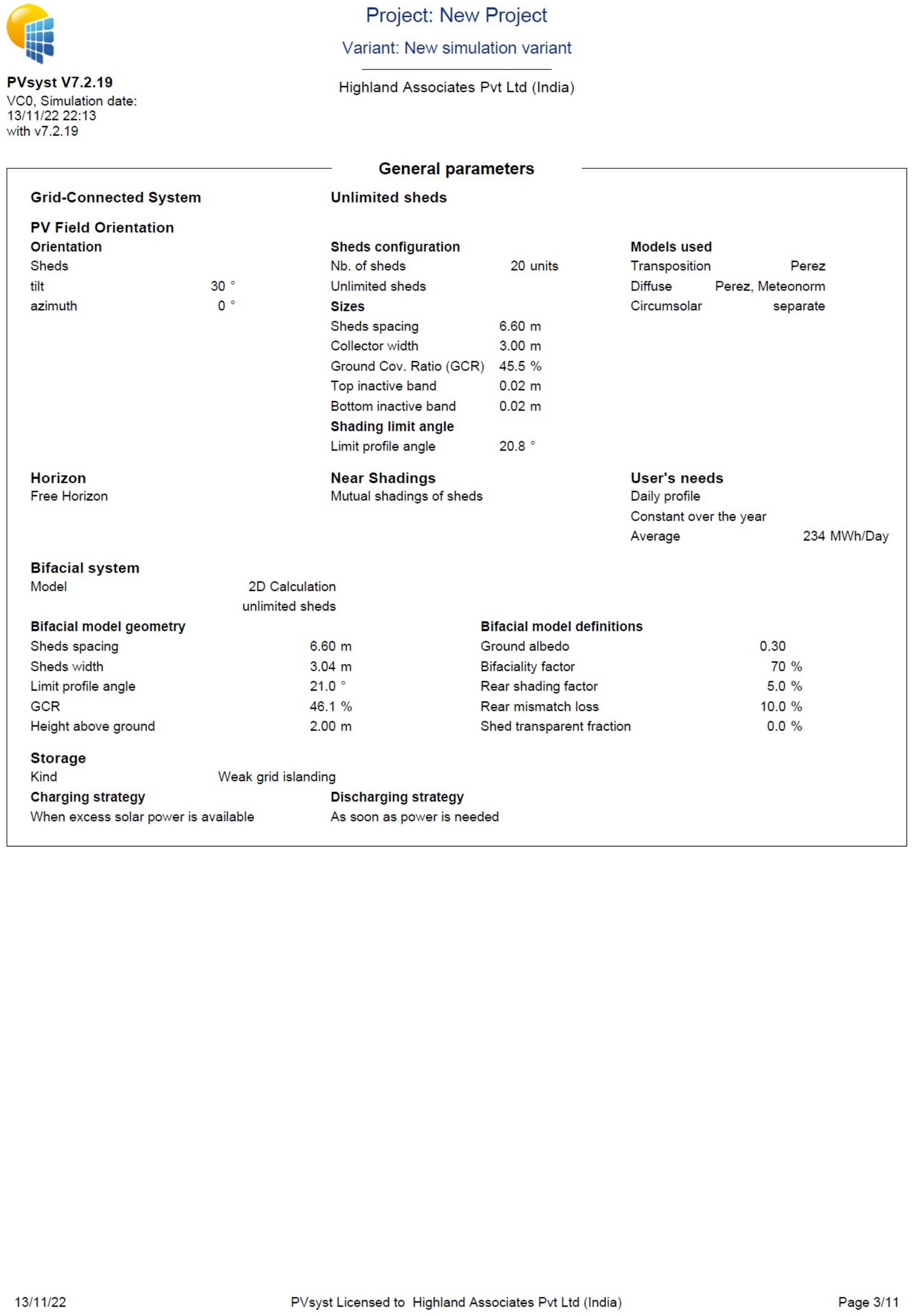


PVsyst V7.2.19
VC0, Simulation date:
13/11/22 22:13
with v7.2.19

Project: New Project

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

General parameters

Grid-Connected System

Unlimited sheds

PV Field Orientation

Orientation	
Sheds	
tilt	30 °
azimuth	0 °

Sheds configuration	
Nb. of sheds	20 units
Unlimited sheds	
Sizes	
Sheds spacing	6.60 m
Collector width	3.00 m
Ground Cov. Ratio (GCR)	45.5 %
Top inactive band	0.02 m
Bottom inactive band	0.02 m
Shading limit angle	
Limit profile angle	20.8 °

Models used	
Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon
Free Horizon

Near Shadings
Mutual shadings of sheds

User's needs	
Daily profile	
Constant over the year	
Average	234 MWh/Day

Bifacial system

Model	2D Calculation unlimited sheds

Bifacial model geometry	
Sheds spacing	6.60 m
Sheds width	3.04 m
Limit profile angle	21.0 °
GCR	46.1 %
Height above ground	2.00 m

Bifacial model definitions	
Ground albedo	0.30
Bifaciality factor	70 %
Rear shading factor	5.0 %
Rear mismatch loss	10.0 %
Shed transparent fraction	0.0 %

Storage

Kind	Weak grid islanding

Charging strategy
When excess solar power is available

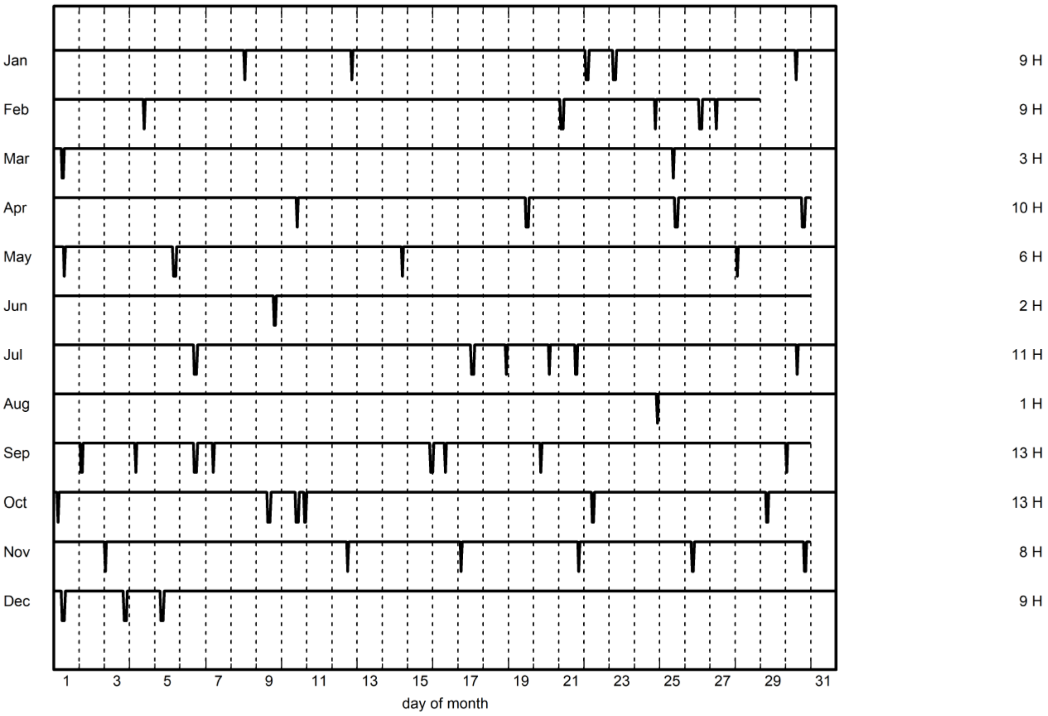
Discharging strategy
As soon as power is needed

13/11/22 PVsyst Licensed to Highland Associates Pvt Ltd (India) Page 3/11

General parameters

Storage
Kind Weak grid islanding
Grid unavailability
52 periods
94 hours
1.1 % of time

Grid unavailability



Hourly load	0 h	1 h	2 h	3 h	4 h	5 h	6 h	7 h	8 h	9 h	10 h	11 h	
	8915	8340	8000	7890	7666	8230	8290	9720	8970	8170	8860	8740	kW
	12 h	13 h	14 h	15 h	16 h	17 h	18 h	19 h	20 h	21 h	22 h	23 h	
	9770	9600	9550	10400	10460	10920	11030	14920	13720	11770	10350	9490	kW

Grid injection point
Power factor
Cos(phi) (lagging) 1.000

PV Array Characteristics

PV module

Manufacturer	Jinkosolar
Model	JKM-540M-72HL4-BDVP
(Original PVsyst database)	
Unit Nom. Power	540 Wp
Number of PV modules	11664 units
Nominal (STC)	6299 kWp
Modules	486 Strings x 24 In series
At operating cond. (50°C)	
Pmpp	5745 kWp
U mpp	896 V
I mpp	6415 A

Inverter

Manufacturer		Sungrow
Model		SG250-HX
(Original PVsyst database)		
Unit Nom. Power		250 kWac
Number of inverters	240 * MPPT 8%	20 units
Total power		5000 kWac
Operating voltage		500-1450 V
Pnom ratio (DC:AC)		1.26

Total PV power

Nominal (STC)	6299 kWp
Total	11664 modules
Module area	30078 m²

Total inverter power

Total power	5000 kWac
Number of inverters	20 units
Pnom ratio	1.26

Battery Storage

Battery

Manufacturer	LG Chem
Model	Rack JH4 SR19_2P

Battery pack

Nb. of units	776 in parallel
Discharging min. SOC	20.0 %
Stored energy	66691.6 kWh

Battery Pack Characteristics

Voltage	720 V
Nominal Capacity	115003 Ah (C10)
Temperature	Fixed 20 °C

Battery input charger

Model	Generic
Max. charg. power	5600.0 kWdc
Max./Euro effic.	97.0/95.0 %

Battery to Grid inverter

Model	Generic
Max. disch. power	15.0 MWac
Max./Euro effic.	97.0/95.0 %

Array losses

Array Soiling Losses

Loss Fraction	2.0 %

Thermal Loss factor

Module temperature according to irradiance

Uc (const)	29.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	2.3 mΩ
Loss Fraction	1.5 % at STC

LID - Light Induced Degradation

Loss Fraction	2.0 %

Module Quality Loss

Loss Fraction	-0.8 %

Module mismatch losses

Loss Fraction	0.3 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

IAM loss factor

Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Array losses

Spectral correction
FirstSolar model
Precipitable water estimated from relative humidity

Coefficient Set	C0	C1	C2	C3	C4	C5
Monocrystalline Si	0.85914	-0.02088	-0.0058853	0.12029	0.026814	-0.001781

System losses

Unavailability of the system

Time fraction	2.0 % 7.3 days, 3 periods

Auxiliaries loss

AC wiring losses

Inv. output line up to MV transfo

Inverter voltage	800 Vac tri
Loss Fraction	1.66 % at STC
Inverter: SG250-HX	
Wire section (20 Inv.)	Alu 20 x 3 x 185 mm²
Average wires length	200 m

MV line up to Injection

MV Voltage	33 kV
Wires	Alu 3 x 120 mm²
Length	5000 m
Loss Fraction	0.75 % at STC

AC losses in transformers

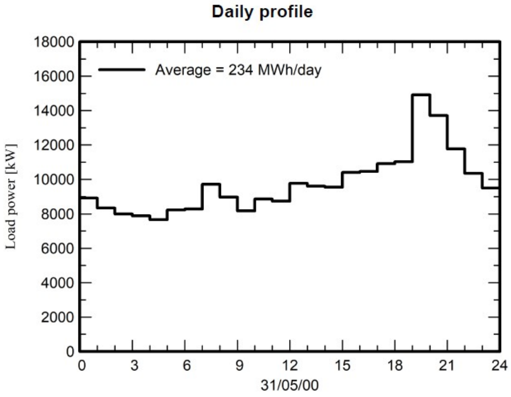
MV transfo

Grid voltage	33 kV
Operating losses at STC	
Nominal power at STC	6236 kVA
Iron loss (24/24 Connexion)	5.00 kW
Loss Fraction	0.08 % at STC
Coils equivalent resistance	3 x 1.28 mΩ
Loss Fraction	1.25 % at STC

Detailed User's needs

Daily profile, Constant over the year, average = 234 MWh/day

Hourly load	0 h	1 h	2 h	3 h	4 h	5 h	6 h	7 h	8 h	9 h	10 h	11 h	
	8915	8340	8000	7890	7666	8230	8290	9720	8970	8170	8860	8740	kW
	12 h	13 h	14 h	15 h	16 h	17 h	18 h	19 h	20 h	21 h	22 h	23 h	
	9770	9600	9550	10400	10460	10920	11030	14920	13720	11770	10350	9490	kW



Main results

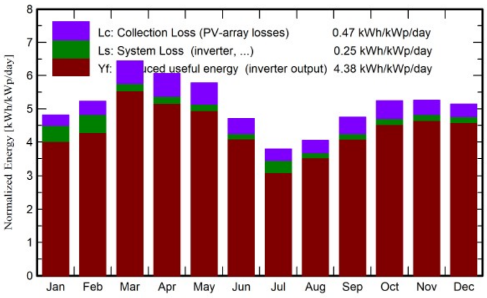
System Production

Produced Energy (P50)	10.10 GWh/year	Specific production (P50)	1604 kWh/kWp/year	Performance Ratio PR	86.09 %
Produced Energy (P90)	9.32 GWh/year	Specific production (P90)	1480 kWh/kWp/year	Solar Fraction SF	11.84 %
Produced Energy (P75)	9.68 GWh/year	Specific production (P75)	1536 kWh/kWp/year		
Apparent energy	0.00 MVAh				

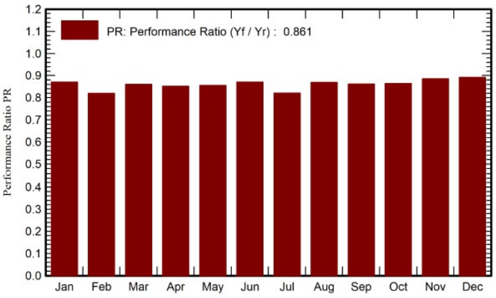
Battery aging (State of Wear)

Cycles SOW	100.0 %
Static SOW	90.0 %

Normalized productions (per installed kWp)



Performance Ratio PR



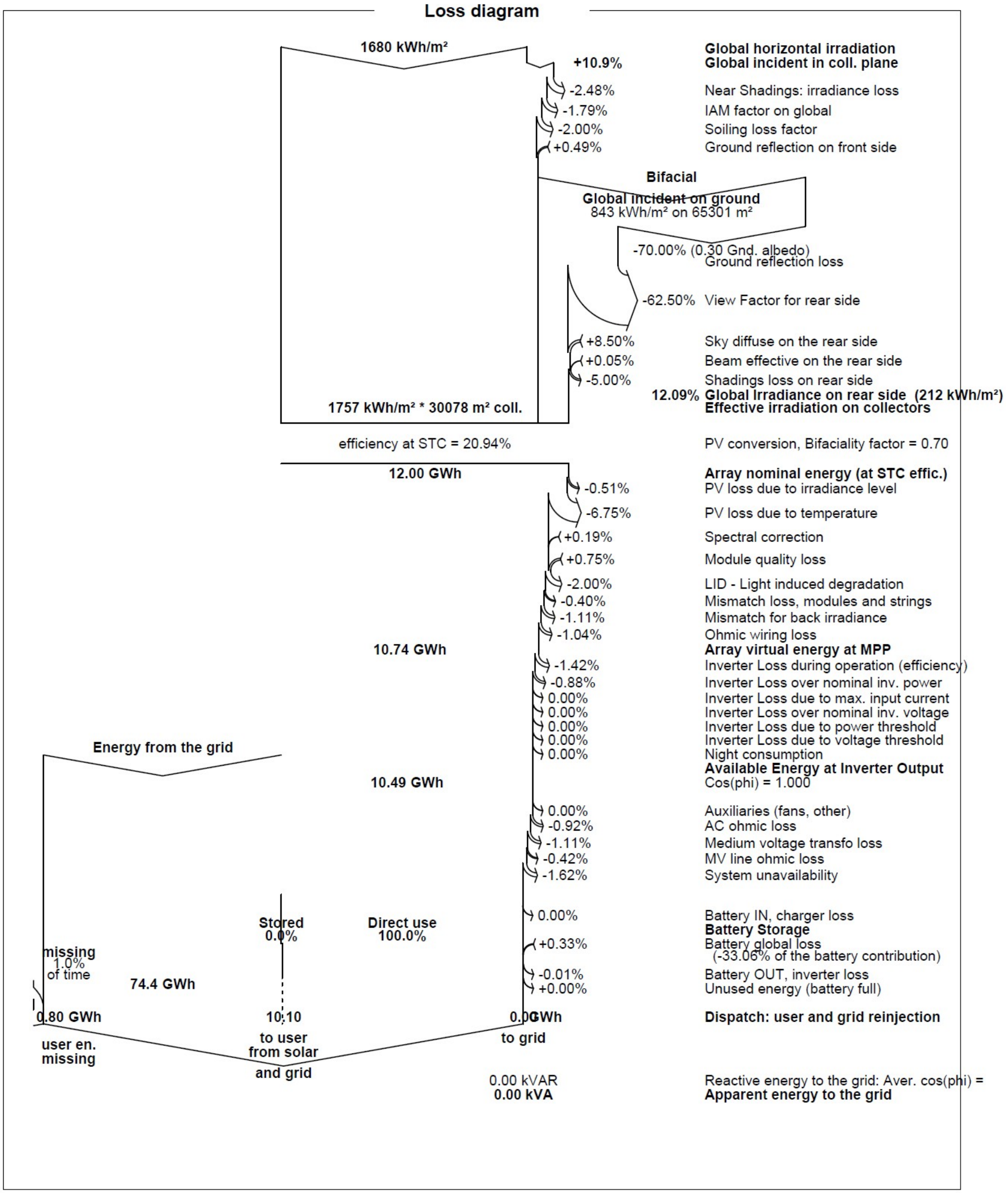
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_User GWh	E_Grid GWh	EFrGrid GWh	E_Miss GWh
January	106.3	42.5	13.77	149.2	142.3	0.879	7.247	0.000	6.374	0.055
February	116.5	54.8	18.38	146.4	138.8	0.853	6.546	0.000	5.717	0.073
March	174.0	67.4	24.24	199.6	189.5	1.126	7.247	0.000	6.147	0.017
April	179.9	85.9	29.83	182.0	171.7	1.016	7.013	0.000	5.935	0.100
May	193.0	100.7	32.61	179.3	168.1	1.004	7.247	0.000	6.213	0.067
June	156.6	103.8	32.06	141.2	131.2	0.805	7.013	0.000	6.218	0.021
July	129.4	83.2	29.89	117.3	108.6	0.673	7.247	0.000	6.549	0.091
August	130.9	83.1	29.49	125.7	117.1	0.718	7.247	0.000	6.548	0.010
September	134.6	74.1	28.50	142.5	133.8	0.805	7.013	0.000	6.129	0.111
October	135.9	62.5	26.27	162.6	154.3	0.920	7.247	0.000	6.271	0.091
November	115.3	48.6	20.53	157.7	149.9	0.913	7.013	0.000	6.053	0.081
December	107.8	39.2	15.54	159.4	151.8	0.931	7.247	0.000	6.270	0.081
Year	1680.2	845.8	25.12	1862.9	1757.1	10.643	85.326	0.000	74.425	0.800

Legends

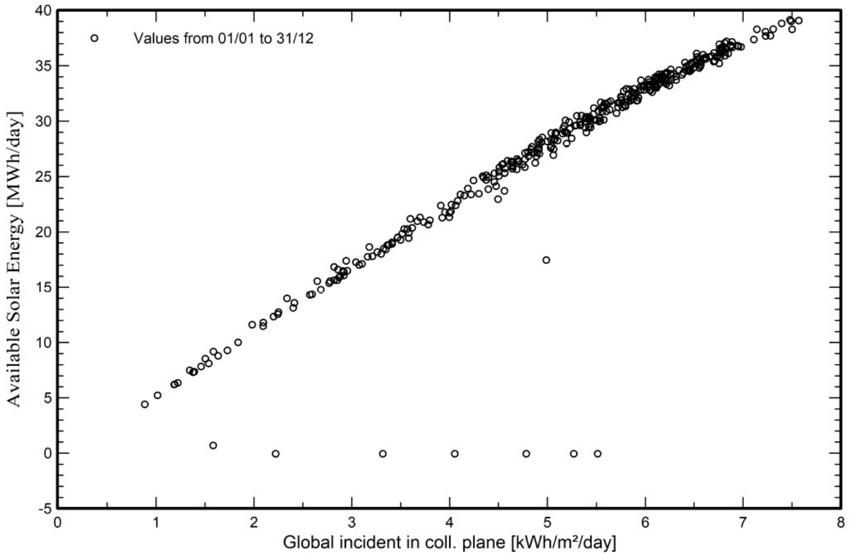
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EFrGrid	Energy from the grid
GlobEff	Effective Global, corr. for IAM and shadings	E_Miss	Missing energy

Loss diagram

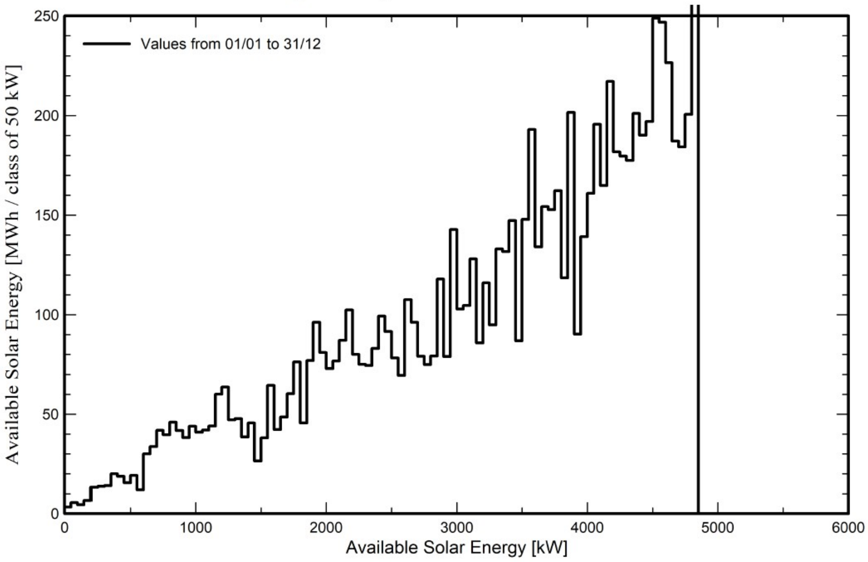


Special graphs

Daily Input/Output diagram



System Output Power Distribution



P50 - P90 evaluation

Meteo data

Source	Meteonorm 8.0 (1981-2010), Sat=100%
Kind	TMY, multi-year
Year-to-year variability(Variance)	5.5 %

Specified Deviation

Climate change	0.0 %

Global variability (meteo + system)

Variability (Quadratic sum)	5.8 %

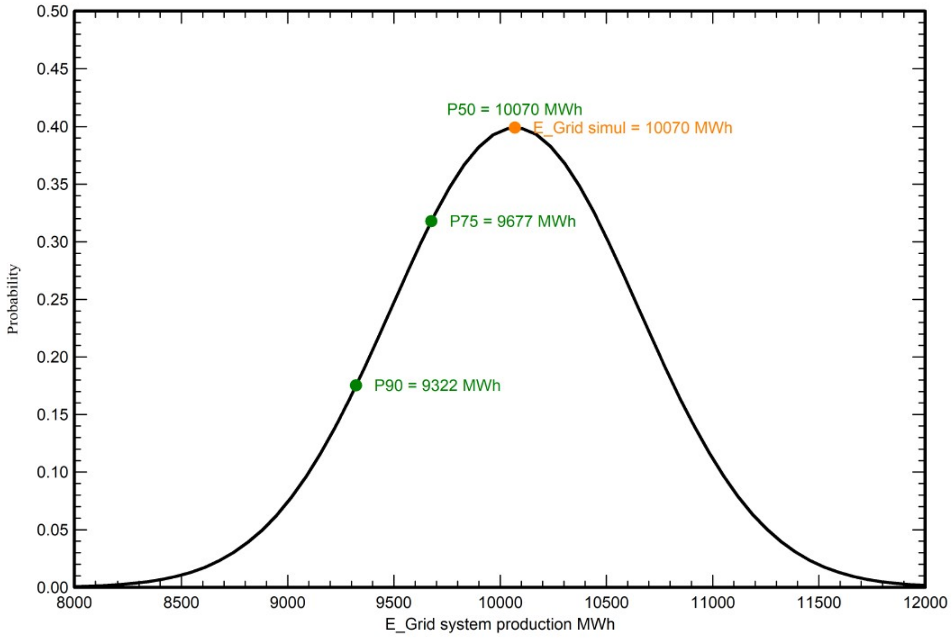
Simulation and parameters uncertainties

PV module modelling/parameters	1.0 %
Inverter efficiency uncertainty	0.5 %
Soiling and mismatch uncertainties	1.0 %
Degradation uncertainty	1.0 %

Annual production probability

Variability	583 MWh
P50	10070 MWh
P90	9322 MWh
P75	9677 MWh

Probability distribution



Version 7.2.19

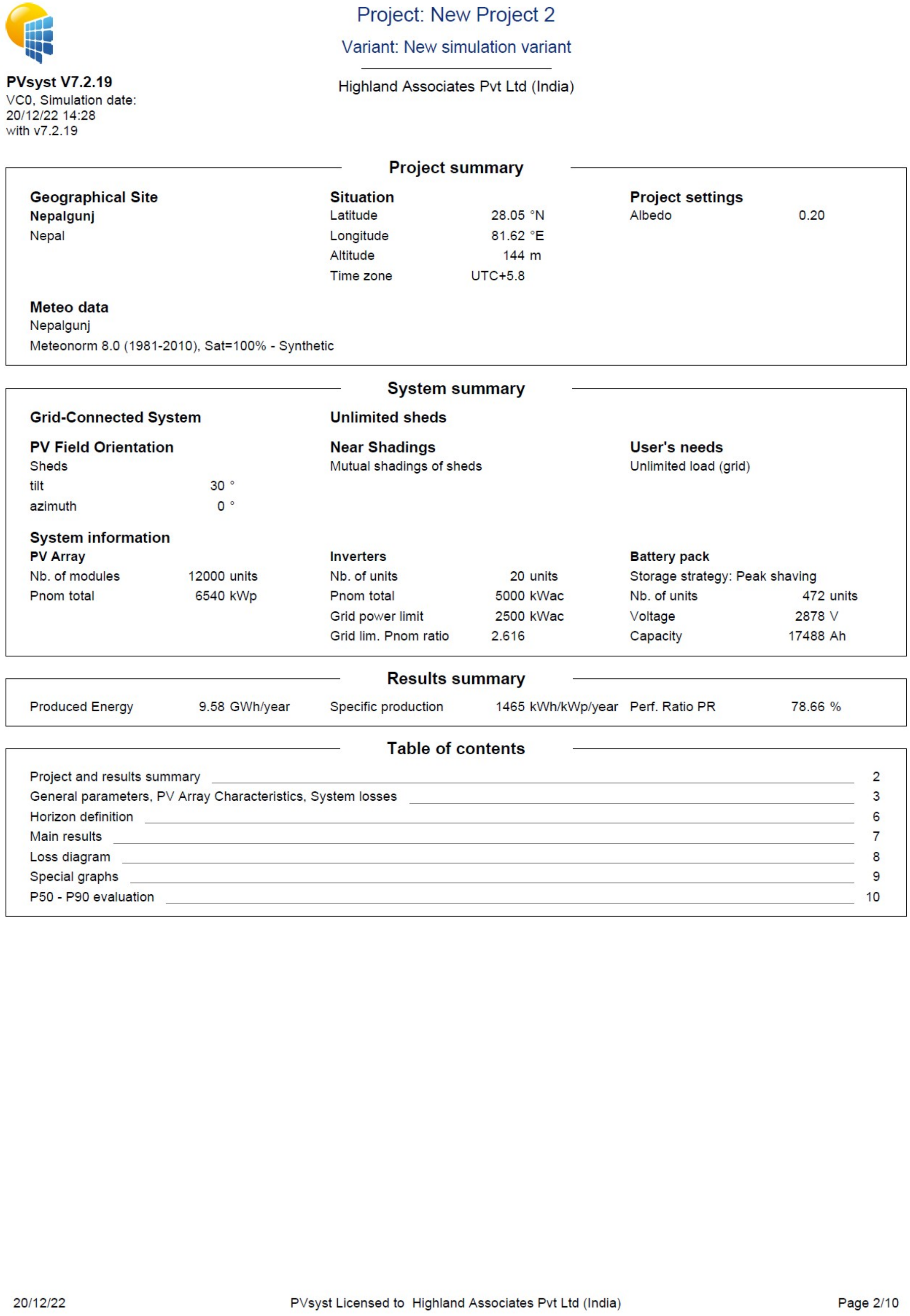
PVsyst - Simulation report

Grid-Connected System

Project: New Project 2

Variant: New simulation variant
Unlimited sheds
System power: 6540 kWp
Nepalgunj - Nepal

Author
Highland Associates Pvt Ltd (India)
Nehru Place Delhi



PVsyst V7.2.19
VC0, Simulation date:
20/12/22 14:28
with v7.2.19

Project: New Project 2

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

Project summary

Geographical Site
Nepalgunj
Nepal

Situation

Latitude	28.05 °N
Longitude	81.62 °E
Altitude	144 m
Time zone	UTC+5.8

Project settings

Albedo	0.20

Meteo data
Nepalgunj
Meteonorm 8.0 (1981-2010), Sat=100% - Synthetic

System summary

Grid-Connected System

Unlimited sheds

PV Field Orientation
Sheds

tilt	30 °
azimuth	0 °

Near Shadings
Mutual shadings of sheds

User's needs
Unlimited load (grid)

System information

PV Array

Nb. of modules	12000 units
Pnom total	6540 kWp

Inverters

Nb. of units	20 units
Pnom total	5000 kWac
Grid power limit	2500 kWac
Grid lim. Pnom ratio	2.616

Battery pack
Storage strategy: Peak shaving

Nb. of units	472 units
Voltage	2878 V
Capacity	17488 Ah

Results summary

Produced Energy	9.58 GWh/year	Specific production	1465 kWh/kWp/year	Perf. Ratio PR	78.66 %

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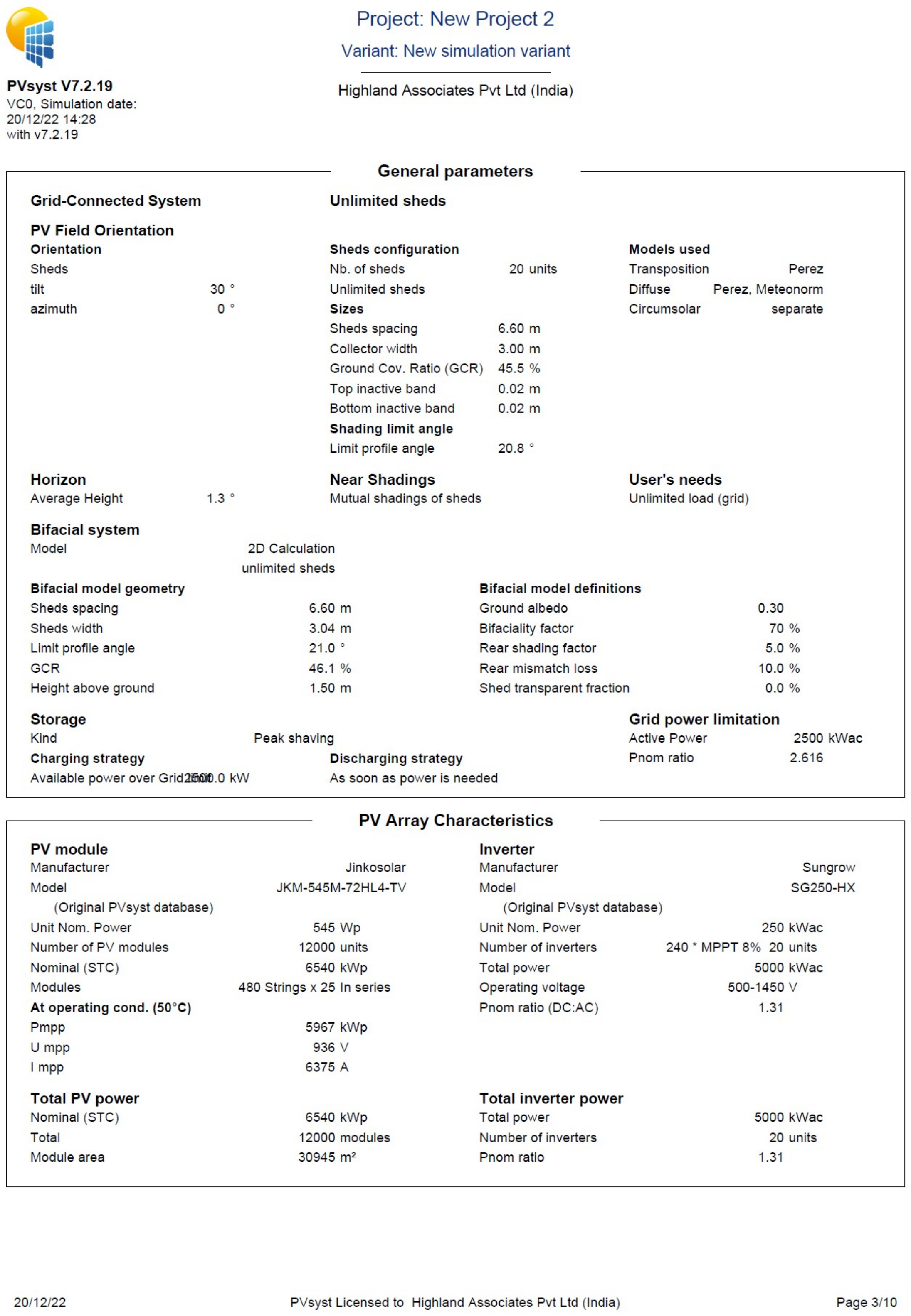


Project: New Project 2

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

PVsyst V7.2.19
VC0, Simulation date:
20/12/22 14:28
with v7.2.19

General parameters

Grid-Connected System

Unlimited sheds

PV Field Orientation

Orientation	
Sheds	
tilt	30 °
azimuth	0 °

Sheds configuration	
Nb. of sheds	20 units
Unlimited sheds	
Sizes	
Sheds spacing	6.60 m
Collector width	3.00 m
Ground Cov. Ratio (GCR)	45.5 %
Top inactive band	0.02 m
Bottom inactive band	0.02 m
Shading limit angle	
Limit profile angle	20.8 °

Models used	
Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon
Average Height 1.3 °

Near Shadings
Mutual shadings of sheds

User's needs
Unlimited load (grid)

Bifacial system
Model 2D Calculation
unlimited sheds

Bifacial model geometry	
Sheds spacing	6.60 m
Sheds width	3.04 m
Limit profile angle	21.0 °
GCR	46.1 %
Height above ground	1.50 m

Bifacial model definitions	
Ground albedo	0.30
Bifaciality factor	70 %
Rear shading factor	5.0 %
Rear mismatch loss	10.0 %
Shed transparent fraction	0.0 %

Storage
Kind Peak shaving
Charging strategy
Available power over Grid2500.0 kW
Discharging strategy
As soon as power is needed

Grid power limitation	
Active Power	2500 kWac
Pnom ratio	2.616

PV Array Characteristics

PV module	
Manufacturer	Jinkosolar
Model	JKM-545M-72HL4-TV
(Original PVsyst database)	
Unit Nom. Power	545 Wp
Number of PV modules	12000 units
Nominal (STC)	6540 kWp
Modules	480 Strings x 25 In series
At operating cond. (50°C)	
Pmpp	5967 kWp
U mpp	936 V
I mpp	6375 A

Inverter	
Manufacturer	Sungrow
Model	SG250-HX
(Original PVsyst database)	
Unit Nom. Power	250 kWac
Number of inverters	240 * MPPT 8% 20 units
Total power	5000 kWac
Operating voltage	500-1450 V
Pnom ratio (DC:AC)	1.31

Total PV power	
Nominal (STC)	6540 kWp
Total	12000 modules
Module area	30945 m²

Total inverter power	
Total power	5000 kWac
Number of inverters	20 units
Pnom ratio	1.31

PV Array Characteristics

Battery Storage

Battery

Manufacturer	LG Chem
Model	Rack JH4 SR19_2P

Battery pack		**Battery Pack Characteristics**	
Nb. of units	4 in series	Voltage	2878 V
	x 118 in parallel	Nominal Capacity	17488 Ah (C10)
Discharging min. SOC	20.0 %	Temperature	Fixed 20 °C
Stored energy	40565.0 kWh		

Battery input charger

Model	Generic
Max. charg. power	6800.0 kWdc
Max./Euro effic.	97.0/95.0 %

Battery to Grid inverter

Model	Generic
Max. disch. power	20.0 MWac
Max./Euro effic.	97.0/95.0 %

Array losses

Thermal Loss factor

Module temperature according to irradiance

Uc (const)	20.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	2.4 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-0.8 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

IAM loss factor

Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

AC wiring losses

Inv. output line up to MV transfo

Inverter voltage	800 Vac tri
Loss Fraction	5.31 % at STC

Inverter: SG250-HX

Wire section (20 Inv.)	Alu 20 x 3 x 150 mm²
Average wires length	500 m

MV line up to Injection

MV Voltage	33 kV
Wires	Alu 3 x 70 mm²
Length	10000 m
Loss Fraction	2.68 % at STC

AC losses in transformers

MV transfo

Grid voltage	33 kV
Operating losses at STC	
Nominal power at STC	6475 kVA
Iron loss (24/24 Connexion)	4.99 kW
Loss Fraction	0.08 % at STC
Coils equivalent resistance	3 x 1.28 mΩ
Loss Fraction	1.29 % at STC

Horizon definition

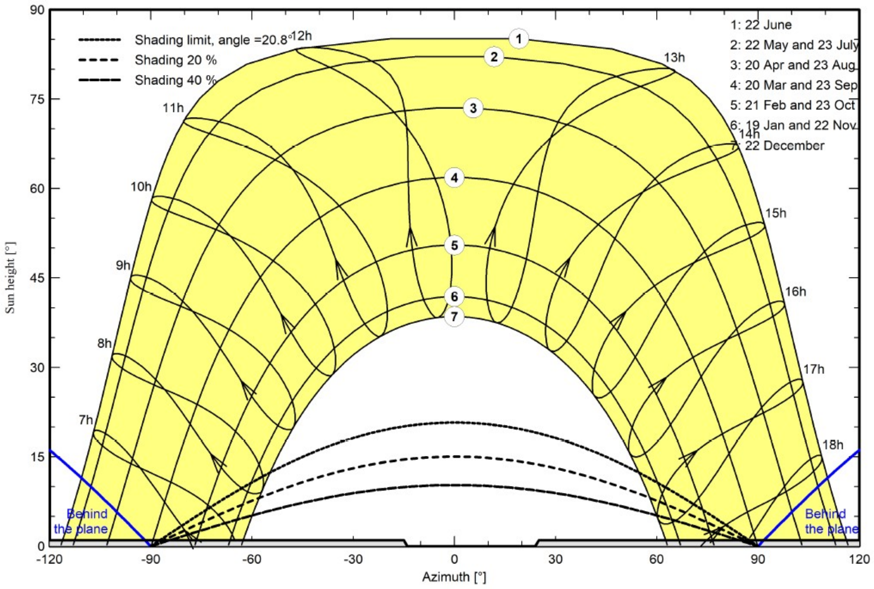
Horizon from Meteonorm web service, lat=27.62, lon=82.98

Average Height	1.3 °	Albedo Factor	0.97
Diffuse Factor	1.00	Albedo Fraction	100 %

Horizon profile

Azimuth [°]	-180	-160	-159	-152	-151	-145	-144	-134	-133	-15	-14	24
Height [°]	3.0	3.0	2.0	2.0	3.0	3.0	2.0	2.0	1.0	1.0	0.0	0.0
Azimuth [°]	25	121	122	123	126	127	134	135	139	140	155	156
Height [°]	1.0	1.0	2.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	3.0
Azimuth [°]	157	160	161	162	163	164	165	166	168	169	179	
Height [°]	2.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	3.0	3.0	

Sun Paths (Height / Azimuth diagram)



Main results

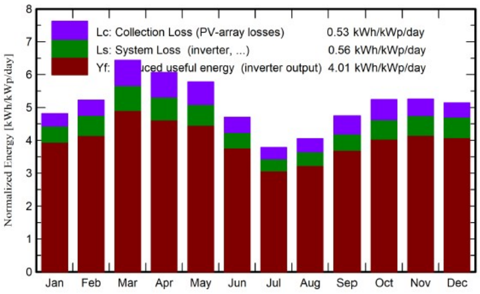
System Production

Produced Energy (P50)	9.58 GWh/year	Specific production (P50)	1465 kWh/kWp/year	Performance Ratio PR	78.66 %
Produced Energy (P90)	9.44 GWh/year	Specific production (P90)	1444 kWh/kWp/year		
Produced Energy (P75)	9.79 GWh/year	Specific production (P75)	1497 kWh/kWp/year		

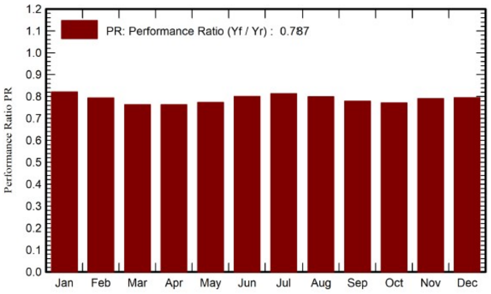
Battery aging (State of Wear)

Cycles SOW	99.0 %
Static SOW	90.0 %

Normalized productions (per installed kWp)



Performance Ratio PR



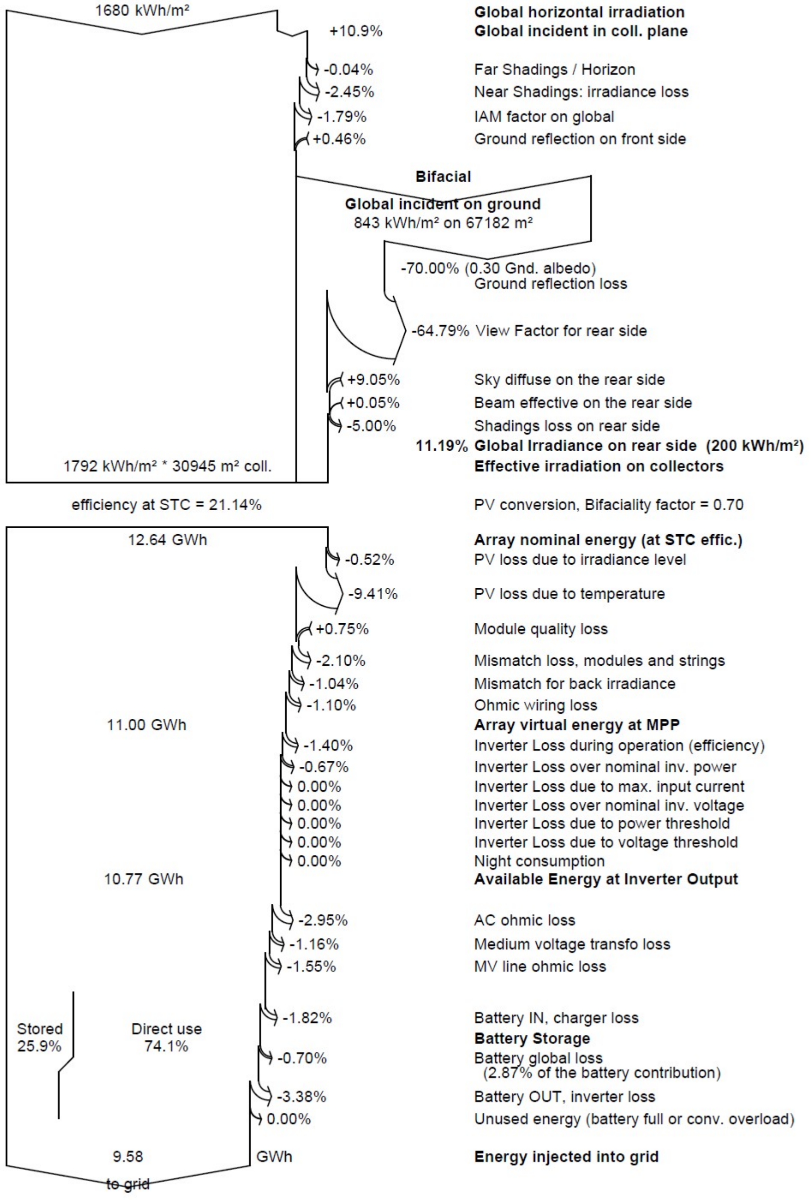
Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	EBatDis	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	GWh	GWh	GWh	ratio
January	106.3	42.5	13.77	149.2	145.2	0.900	0.801	0.240	0.821
February	116.5	54.8	18.38	146.4	141.6	0.874	0.761	0.208	0.794
March	174.0	67.4	24.24	199.6	193.3	1.150	0.996	0.311	0.763
April	179.9	85.9	29.83	182.0	175.1	1.044	0.908	0.248	0.763
May	193.0	100.7	32.61	179.3	171.4	1.035	0.906	0.212	0.773
June	156.6	103.8	32.06	141.2	133.8	0.833	0.740	0.116	0.801
July	129.4	83.2	29.89	117.3	110.8	0.697	0.623	0.091	0.813
August	130.9	83.1	29.49	125.7	119.4	0.741	0.657	0.117	0.800
September	134.6	74.1	28.50	142.5	136.5	0.825	0.726	0.157	0.779
October	135.9	62.5	26.27	162.6	157.4	0.939	0.820	0.217	0.771
November	115.3	48.6	20.53	157.7	152.9	0.935	0.816	0.219	0.791
December	107.8	39.2	15.54	159.4	154.9	0.955	0.829	0.241	0.795
Year	1680.2	845.8	25.12	1862.9	1792.4	10.926	9.583	2.377	0.787

Legends

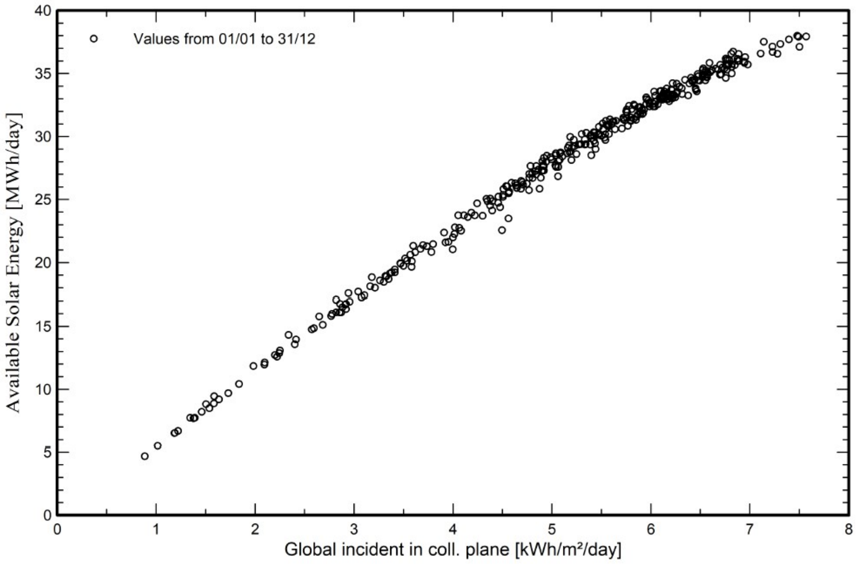
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	EBatDis	Battery Discharging Energy
GlobInc	Global incident in coll. plane	PR	Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

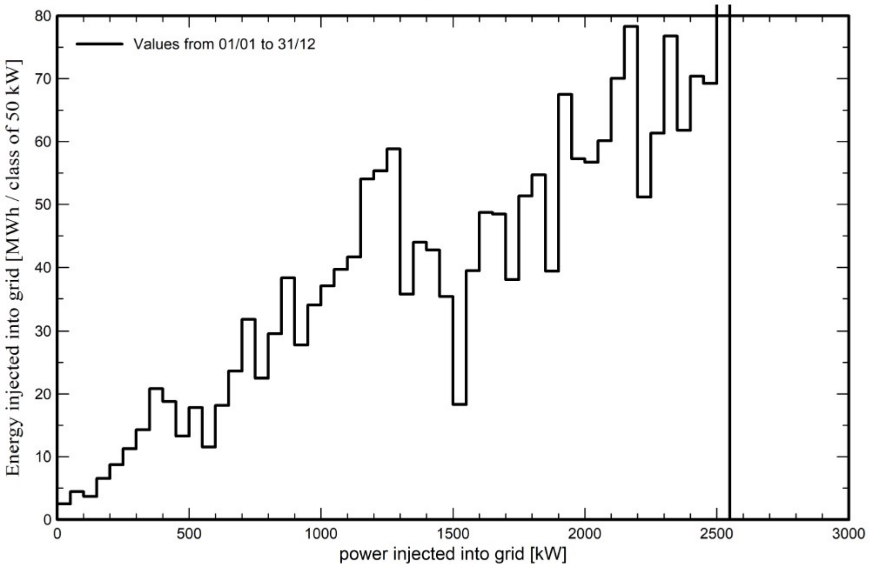


Special graphs

Daily Input/Output diagram



System Output Power Distribution



P50 - P90 evaluation

Meteo data

Source	Meteonorm 8.0 (1981-2010), Sat=100%
Kind	TMY, multi-year
Year-to-year variability(Variance)	5.3 %

Specified Deviation

Climate change	0.0 %

Global variability (meteo + system)

Variability (Quadratic sum)	5.6 %

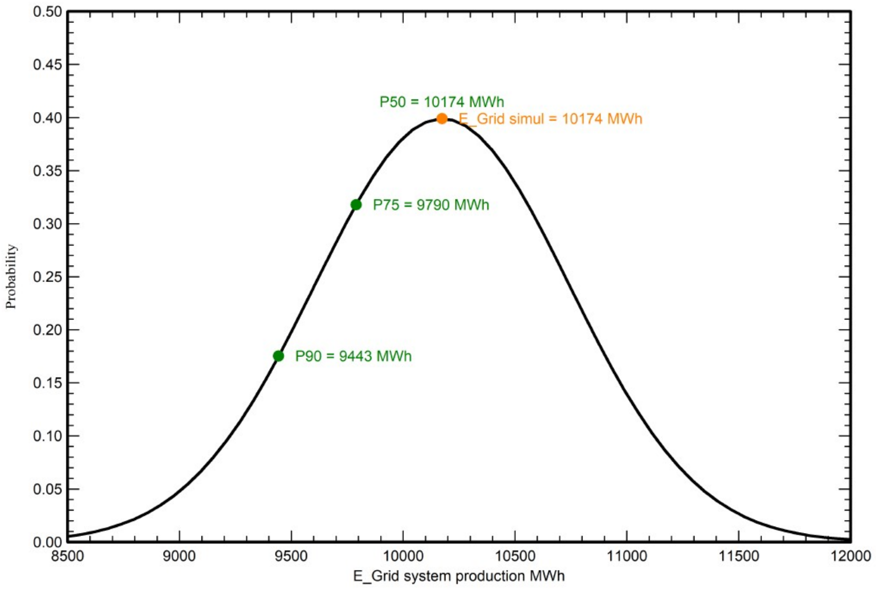
Simulation and parameters uncertainties

PV module modelling/parameters	1.0 %
Inverter efficiency uncertainty	0.5 %
Soiling and mismatch uncertainties	1.0 %
Degradation uncertainty	1.0 %

Annual production probability

Variability	570 MWh
P50	10174 MWh
P90	9443 MWh
P75	9790 MWh

Probability distribution



Version 7.3.1

PVsyst - Simulation report

Grid-Connected System

Project: New Project 2

Variant: New simulation variant
Unlimited sheds
System power: 6540 kWp
Chanauta - Nepal

Author
Highland Associates Pvt Ltd (India)
Nehru Place Delhi

PVsyst V7.3.1
VC0, Simulation date:
13/01/23 10:35
with v7.3.1

Project: New Project 2

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

Project summary

Geographical Site	**Situation**		**Project settings**	
Chanauta	Latitude	27.65 °N	Albedo	0.20
Nepal	Longitude	82.87 °E		
	Altitude	119 m		
	Time zone	UTC+5.8		

Meteo data
Chanauta
Meteonorm 8.1 (1996-2015), Sat=100% - Synthetic

System summary

Grid-Connected System

Unlimited sheds

PV Field Orientation		**Near Shadings**	**User's needs**
Sheds		Mutual shadings of sheds	Unlimited load (grid)
Tilt	30 °		
Azimuth	0 °		

System information

PV Array		**Inverters**		**Battery pack**	
Nb. of modules	12000 units	Nb. of units	20 units	Storage strategy: Peak shaving	
Pnom total	6540 kWp	Pnom total	5000 kWac	Nb. of units	752 units
		Grid power limit	2450 kWac	Voltage	2878 V
		Grid lim. Pnom ratio	2.669	Capacity	27862 Ah

Results summary

Produced Energy	9011 MWh/year	Specific production	1378 kWh/kWp/year	Perf. Ratio PR	82.17 %

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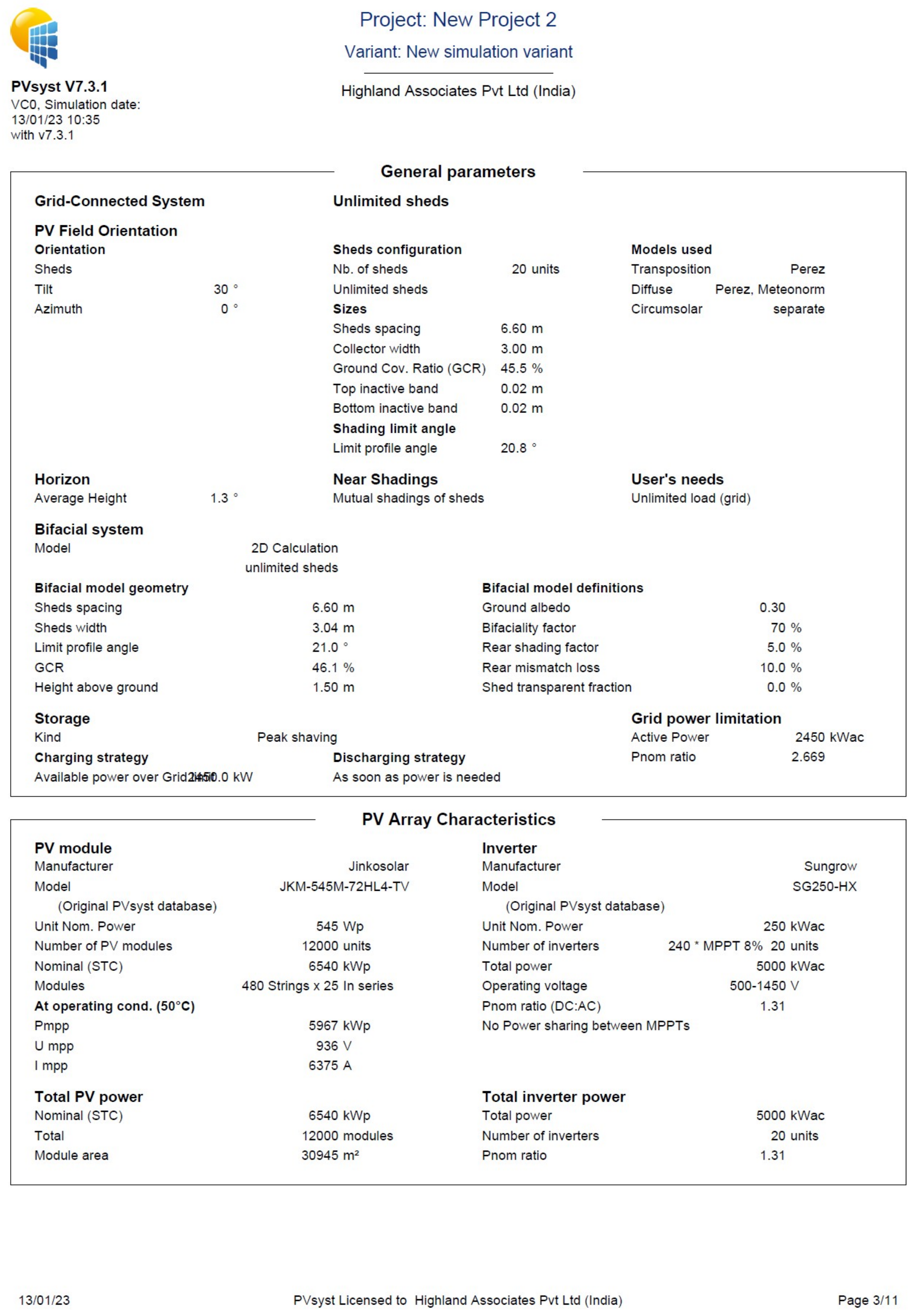


PVsyst V7.3.1
VC0, Simulation date:
13/01/23 10:35
with v7.3.1

Project: New Project 2

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

General parameters

Grid-Connected System

Unlimited sheds

PV Field Orientation

Orientation	
Sheds	
Tilt	30 °
Azimuth	0 °

Sheds configuration	
Nb. of sheds	20 units
Unlimited sheds	
Sizes	
Sheds spacing	6.60 m
Collector width	3.00 m
Ground Cov. Ratio (GCR)	45.5 %
Top inactive band	0.02 m
Bottom inactive band	0.02 m
Shading limit angle	
Limit profile angle	20.8 °

Models used	
Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon
Average Height 1.3 °

Near Shadings
Mutual shadings of sheds

User's needs
Unlimited load (grid)

Bifacial system

Model 2D Calculation
unlimited sheds

Bifacial model geometry	
Sheds spacing	6.60 m
Sheds width	3.04 m
Limit profile angle	21.0 °
GCR	46.1 %
Height above ground	1.50 m

Bifacial model definitions	
Ground albedo	0.30
Bifaciality factor	70 %
Rear shading factor	5.0 %
Rear mismatch loss	10.0 %
Shed transparent fraction	0.0 %

Storage

Kind Peak shaving

Charging strategy
Available power over Grid 2450.0 kW

Discharging strategy
As soon as power is needed

Grid power limitation

Active Power	2450 kWac
Pnom ratio	2.669

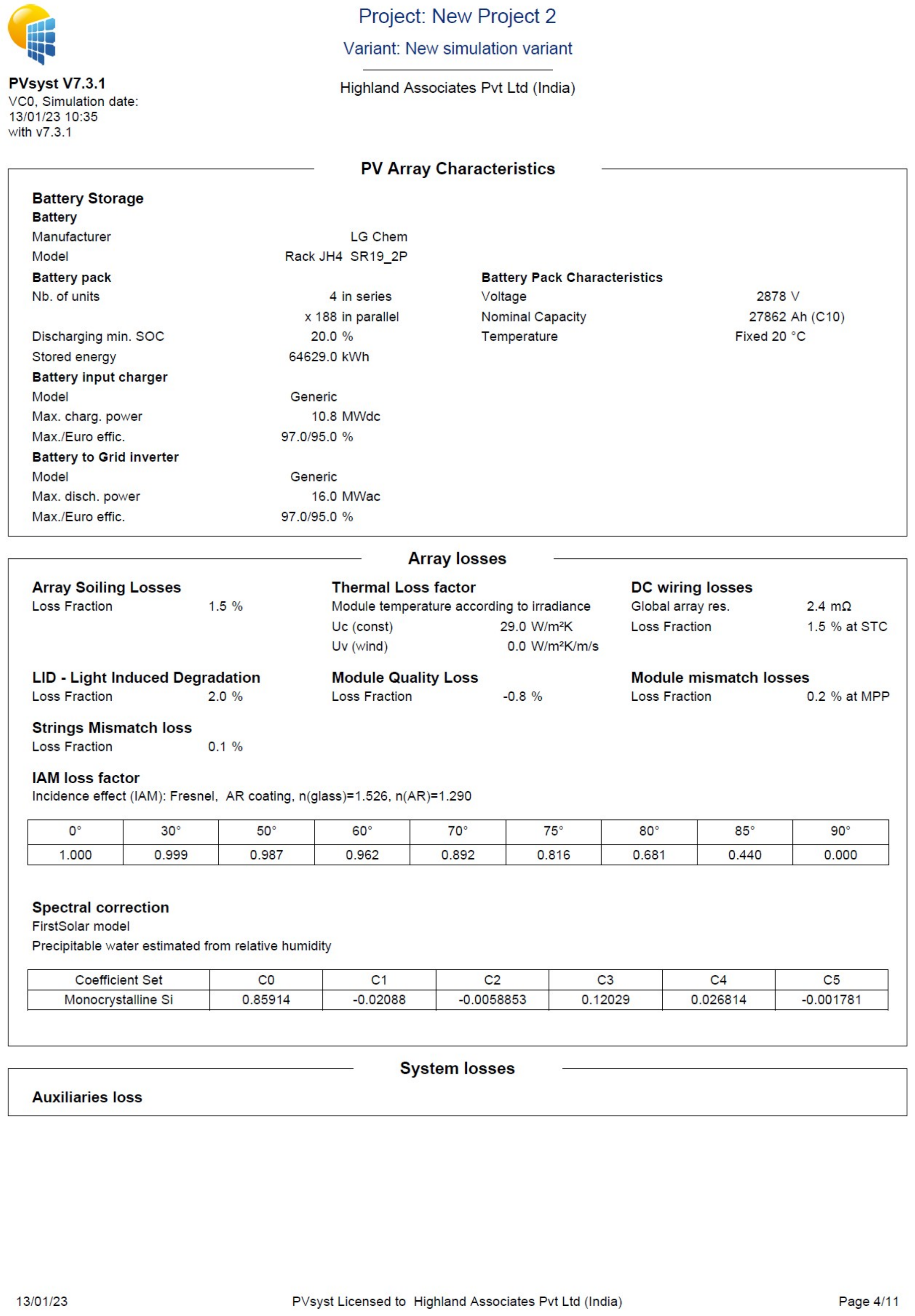
PV Array Characteristics

PV module	
Manufacturer	Jinkosolar
Model	JKM-545M-72HL4-TV
(Original PVsyst database)	
Unit Nom. Power	545 Wp
Number of PV modules	12000 units
Nominal (STC)	6540 kWp
Modules	480 Strings x 25 In series
At operating cond. (50°C)	
Pmpp	5967 kWp
U mpp	936 V
I mpp	6375 A

Inverter	
Manufacturer	Sungrow
Model	SG250-HX
(Original PVsyst database)	
Unit Nom. Power	250 kWac
Number of inverters	240 * MPPT 8% 20 units
Total power	5000 kWac
Operating voltage	500-1450 V
Pnom ratio (DC:AC)	1.31
No Power sharing between MPPTs	

Total PV power	
Nominal (STC)	6540 kWp
Total	12000 modules
Module area	30945 m²

Total inverter power	
Total power	5000 kWac
Number of inverters	20 units
Pnom ratio	1.31



PV Array Characteristics

Battery Storage

Battery

Manufacturer	LG Chem
Model	Rack JH4 SR19_2P

Battery pack

Nb. of units	4 in series	**Battery Pack Characteristics**	
	x 188 in parallel	Voltage	2878 V
Discharging min. SOC	20.0 %	Nominal Capacity	27862 Ah (C10)
Stored energy	64629.0 kWh	Temperature	Fixed 20 °C

Battery input charger

Model	Generic
Max. charg. power	10.8 MWdc
Max./Euro effic.	97.0/95.0 %

Battery to Grid inverter

Model	Generic
Max. disch. power	16.0 MWac
Max./Euro effic.	97.0/95.0 %

Array losses

Array Soiling Losses
Loss Fraction 1.5 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 2.4 mΩ
Loss Fraction 1.5 % at STC

LID - Light Induced Degradation
Loss Fraction 2.0 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 0.2 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

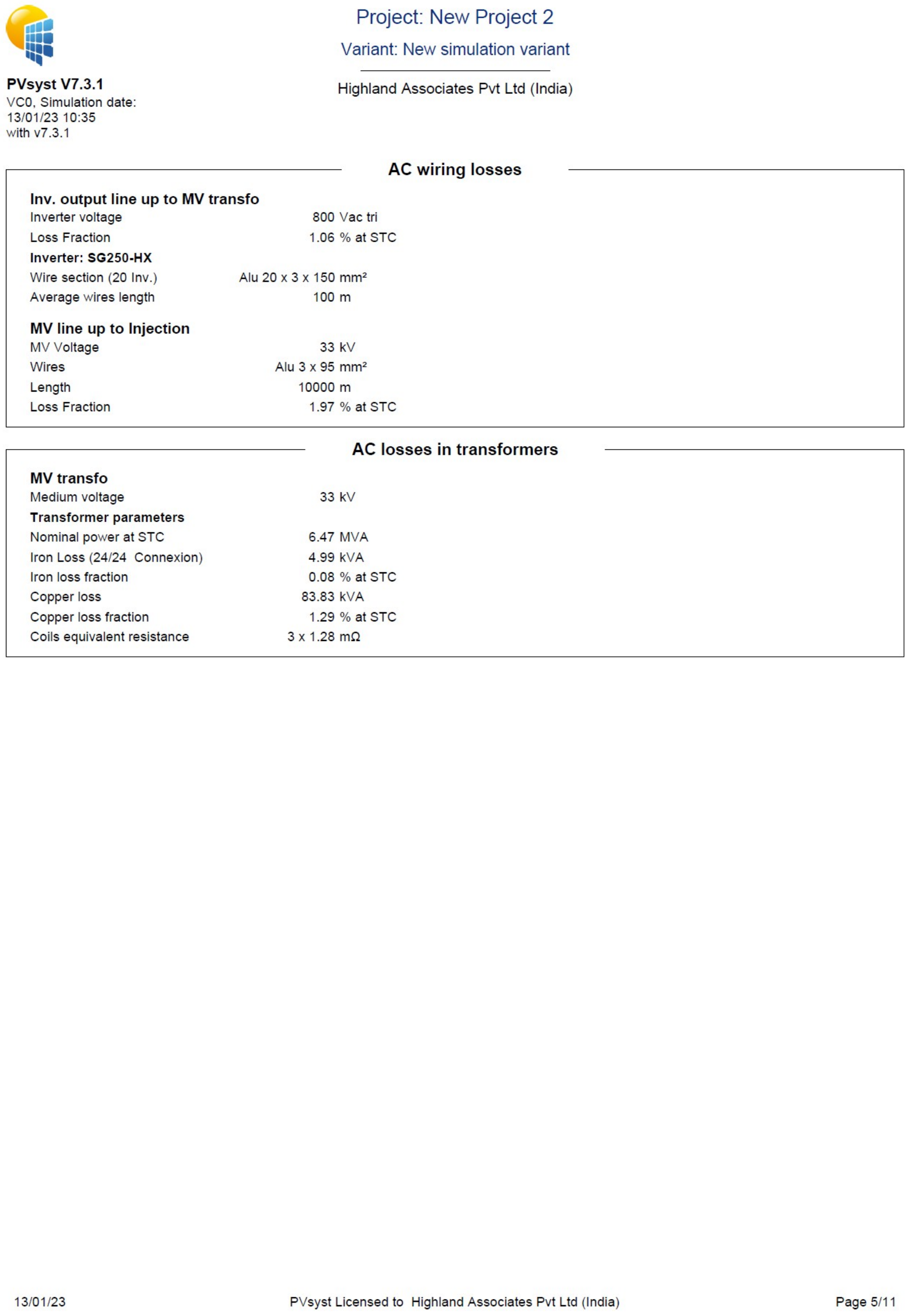
0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Spectral correction
FirstSolar model
Precipitable water estimated from relative humidity

Coefficient Set	C0	C1	C2	C3	C4	C5
Monocrystalline Si	0.85914	-0.02088	-0.0058853	0.12029	0.026814	-0.001781

System losses

Auxiliaries loss



AC wiring losses

Inv. output line up to MV transfo

Inverter voltage	800 Vac tri
Loss Fraction	1.06 % at STC
Inverter: SG250-HX	
Wire section (20 Inv.)	Alu 20 x 3 x 150 mm²
Average wires length	100 m

MV line up to Injection

MV Voltage	33 kV
Wires	Alu 3 x 95 mm²
Length	10000 m
Loss Fraction	1.97 % at STC

AC losses in transformers

MV transfo

Medium voltage	33 kV
Transformer parameters	
Nominal power at STC	6.47 MVA
Iron Loss (24/24 Connexion)	4.99 kVA
Iron loss fraction	0.08 % at STC
Copper loss	83.83 kVA
Copper loss fraction	1.29 % at STC
Coils equivalent resistance	3 x 1.28 mΩ

Horizon definition

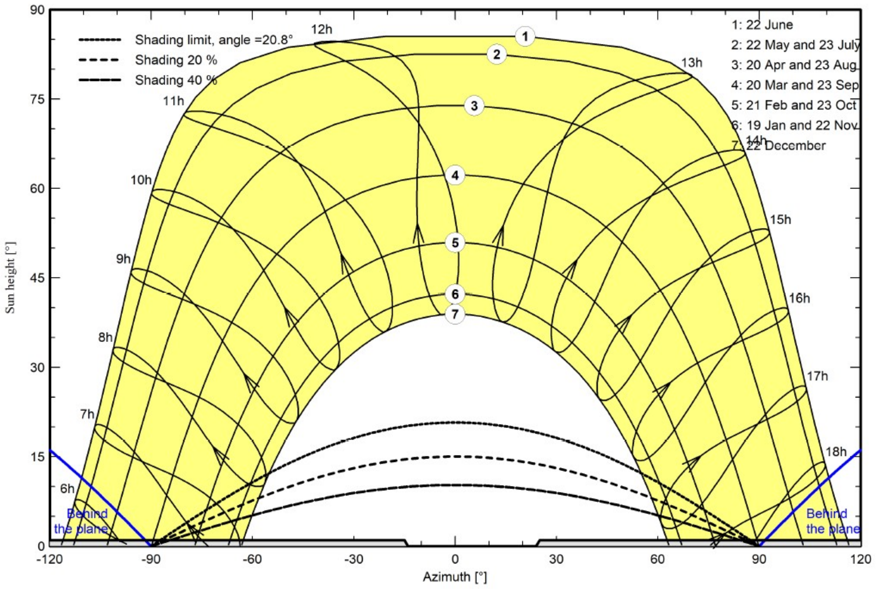
Horizon from Meteonorm web service, lat=27.62, lon=82.98

Average Height	1.3 °	Albedo Factor	0.97
Diffuse Factor	1.00	Albedo Fraction	100 %

Horizon profile

Azimuth [°]	-180	-160	-159	-152	-151	-145	-144	-134	-133	-15	-14	24
Height [°]	3.0	3.0	2.0	2.0	3.0	3.0	2.0	2.0	1.0	1.0	0.0	0.0
Azimuth [°]	25	121	122	123	126	127	134	135	139	140	155	156
Height [°]	1.0	1.0	2.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	3.0
Azimuth [°]	157	160	161	162	163	164	165	166	168	169	179	
Height [°]	2.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	3.0	3.0	

Sun Paths (Height / Azimuth diagram)



Main results

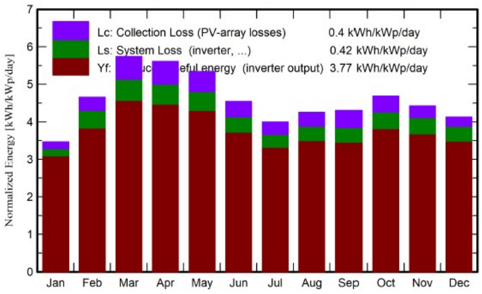
System Production

Produced Energy (P50)	9011.11 MWh/year	Specific production (P50)	1378 kWh/kWp/year	Performance Ratio PR	82.17 %
Produced Energy (P90)	8908.89 MWh/year	Produced Energy (P90)	1362 kWh/kWp/year		
Produced Energy (P75)	9235.64 MWh/year	Produced Energy (P75)	1412 kWh/kWp/year		

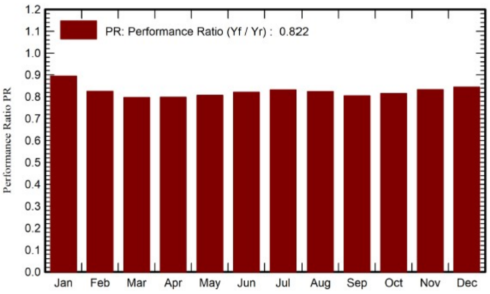
Battery aging (State of Wear)

Cycles SOW	99.5 %
Static SOW	90.0 %

Normalized productions (per installed kWp)



Performance Ratio PR



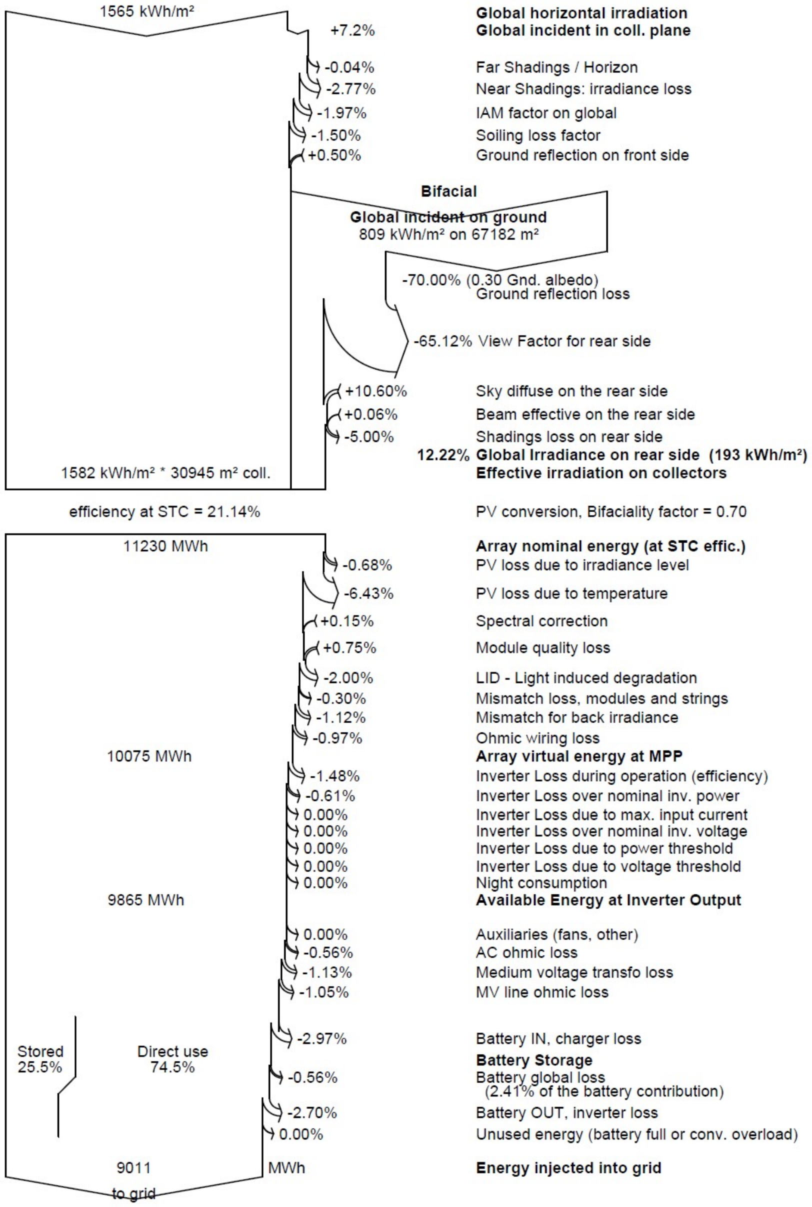
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EBatDis MWh	PR ratio
January	83.5	48.4	14.03	107.4	101.9	667	628.3	163.1	0.895
February	105.8	54.1	19.05	130.3	123.9	789	703.2	193.0	0.825
March	159.2	75.0	24.76	178.0	169.1	1042	927.4	278.4	0.797
April	167.7	89.7	29.53	168.3	158.9	982	878.2	233.5	0.798
May	178.3	101.2	31.33	165.5	155.5	975	872.9	208.0	0.806
June	151.7	98.4	30.91	136.2	127.1	812	731.6	128.3	0.821
July	137.2	91.0	29.69	124.0	115.2	744	673.9	102.6	0.831
August	138.1	93.4	29.48	131.8	123.0	788	710.4	115.7	0.824
September	124.2	72.4	28.52	129.1	121.3	756	679.6	142.5	0.805
October	124.8	67.9	26.37	145.4	138.0	865	775.2	193.1	0.815
November	101.6	53.2	20.96	132.7	126.2	808	723.1	181.5	0.833
December	92.9	47.4	16.08	128.1	121.4	788	707.2	169.8	0.844
Year	1564.9	892.2	25.08	1676.9	1581.6	10015	9011.1	2109.6	0.822

Legends

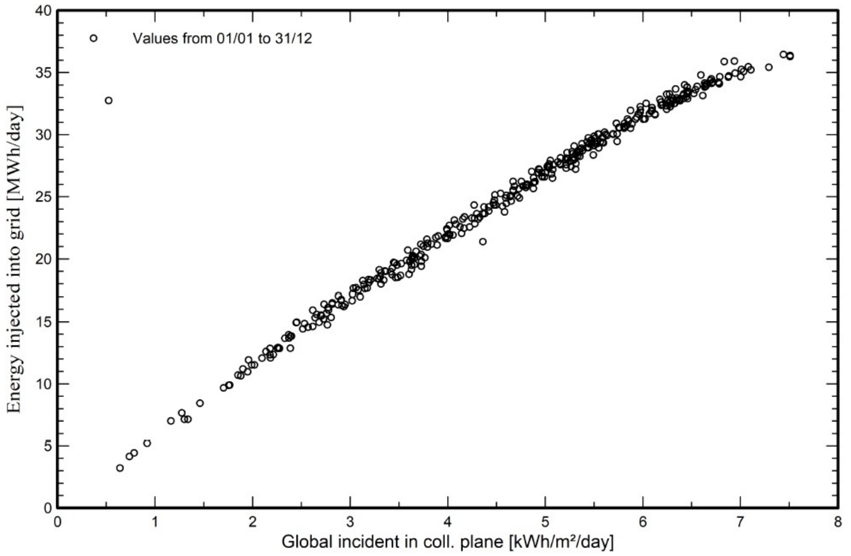
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	EBatDis	Battery Discharging Energy
GlobInc	Global incident in coll. plane	PR	Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

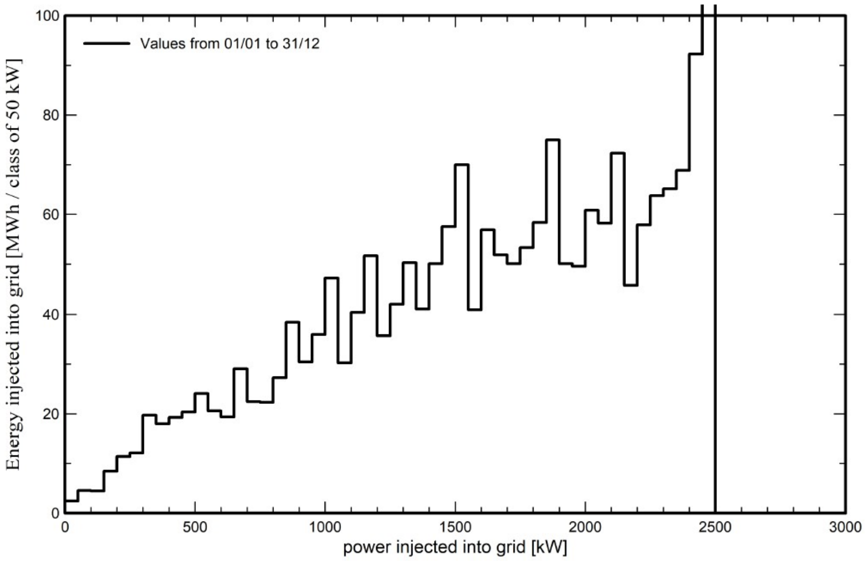


Predef. graphs

Daily Input/Output diagram



System Output Power Distribution



P50 - P90 evaluation

Meteo data

Source	Meteonorm 8.1 (1996-2015), Sat=100%
Kind	TMY, multi-year
Year-to-year variability(Variance)	5.3 %
Specified Deviation	
Climate change	0.0 %

Global variability (meteo + system)

Variability (Quadratic sum)	5.6 %

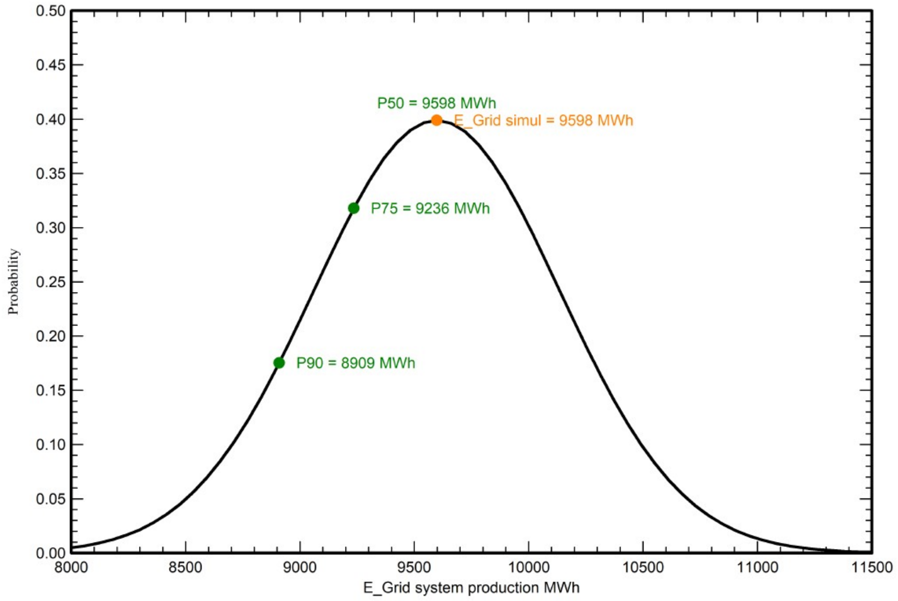
Simulation and parameters uncertainties

PV module modelling/parameters	1.0 %
Inverter efficiency uncertainty	0.5 %
Soiling and mismatch uncertainties	1.0 %
Degradation uncertainty	1.0 %

Annual production probability

Variability	537 MWh
P50	9598 MWh
P90	8909 MWh
P75	9236 MWh

Probability distribution



Single-line diagram

PVsyst V7.3.1
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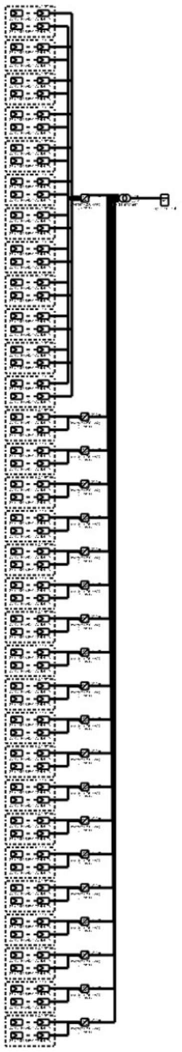
with v7.3.1



PV module	JKM-545M-72HL4-TV
Inverter	SG250-HX
String	25 x JKM-545M-72HL4-TV

New Project 2	Highland Associate
VC0 : New simulation variant	13/01/23

BESS and solar model in Belauri DC to accommodate high DRE

Version 7.3.1

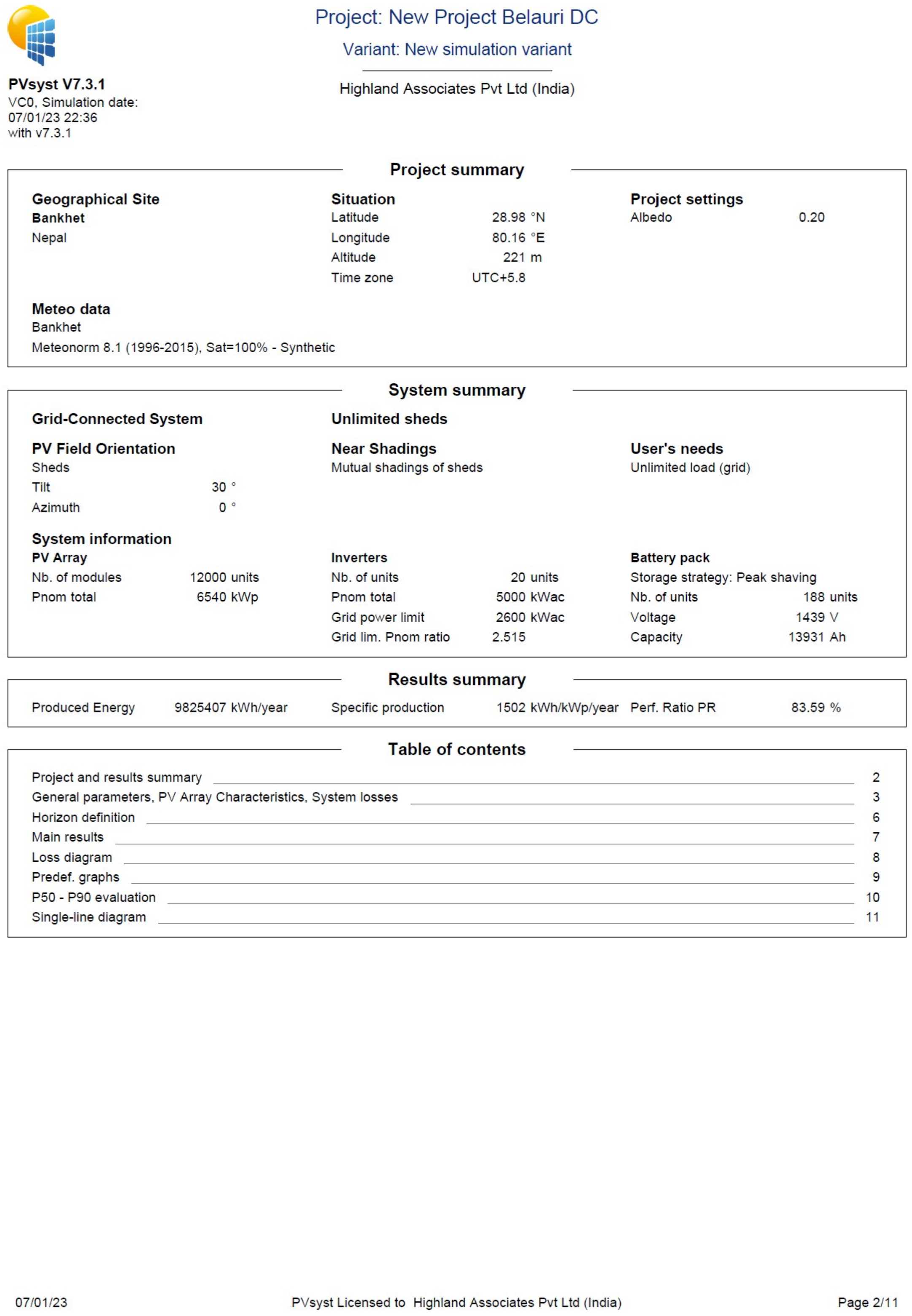
PVsyst - Simulation report

Grid-Connected System

Project: New Project Belauri DC

Variant: New simulation variant
Unlimited sheds
System power: 6540 kWp
Bankhet - Nepal

Author
Highland Associates Pvt Ltd (India)
Nehru Place Delhi



PVsyst V7.3.1
VC0, Simulation date:
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with v7.3.1

Project: New Project Belauri DC

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

Project summary

Geographical Site		Situation		Project settings	
Bankhet		Latitude	28.98 °N	Albedo	0.20
Nepal		Longitude	80.16 °E		
		Altitude	221 m		
		Time zone	UTC+5.8		

Meteo data
Bankhet
Meteonorm 8.1 (1996-2015), Sat=100% - Synthetic

System summary

Grid-Connected System | **Unlimited sheds**

PV Field Orientation		Near Shadings	User's needs
Sheds		Mutual shadings of sheds	Unlimited load (grid)
Tilt	30 °		
Azimuth	0 °		

System information

PV Array		Inverters		Battery pack	
				Storage strategy: Peak shaving	
Nb. of modules	12000 units	Nb. of units	20 units	Nb. of units	188 units
Pnom total	6540 kWp	Pnom total	5000 kWac	Voltage	1439 V
		Grid power limit	2600 kWac	Capacity	13931 Ah
		Grid lim. Pnom ratio	2.515		

Results summary

Produced Energy	9825407 kWh/year	Specific production	1502 kWh/kWp/year	Perf. Ratio PR	83.59 %

Table of contents

General parameters

Grid-Connected System | **Unlimited sheds**

PV Field Orientation

Orientation		**Sheds configuration**		**Models used**	
Sheds		Nb. of sheds	20 units	Transposition	Perez
Tilt	30 °	Unlimited sheds		Diffuse	Perez, Meteonorm
Azimuth	0 °	**Sizes**		Circumsolar	separate
		Sheds spacing	6.60 m		
		Collector width	3.00 m		
		Ground Cov. Ratio (GCR)	45.5 %		
		Top inactive band	0.02 m		
		Bottom inactive band	0.02 m		
		Shading limit angle			
		Limit profile angle	20.8 °		

Horizon		**Near Shadings**	**User's needs**
Average Height	1.3 °	Mutual shadings of sheds	Unlimited load (grid)

Bifacial system

Model: 2D Calculation unlimited sheds

Bifacial model geometry		**Bifacial model definitions**	
Sheds spacing	6.60 m	Ground albedo	0.30
Sheds width	3.04 m	Bifaciality factor	70 %
Limit profile angle	21.0 °	Rear shading factor	5.0 %
GCR	46.1 %	Rear mismatch loss	10.0 %
Height above ground	1.50 m	Shed transparent fraction	0.0 %

Storage		**Grid power limitation**	
Kind	Peak shaving	Active Power	2600 kWac
Charging strategy	**Discharging strategy**	Pnom ratio	2.515
Available power over Grid 2600.0 kW	As soon as power is needed		

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Jinkosolar	Manufacturer	Sungrow
Model	JKM-545M-72HL4-TV	Model	SG250-HX
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	545 Wp	Unit Nom. Power	250 kWac
Number of PV modules	12000 units	Number of inverters	240 * MPPT 8% 20 units
Nominal (STC)	6540 kWp	Total power	5000 kWac
Modules	480 Strings x 25 In series	Operating voltage	500-1450 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.31
Pmpp	5967 kWp	No Power sharing between MPPTs	
U mpp	936 V		
I mpp	6375 A		

Total PV power		**Total inverter power**	
Nominal (STC)	6540 kWp	Total power	5000 kWac
Total	12000 modules	Number of inverters	20 units
Module area	30945 m²	Pnom ratio	1.31

PV Array Characteristics

Battery Storage

Battery

Manufacturer	LG Chem
Model	Rack JH4 SR19_2P

Battery pack

Nb. of units	2 in series x 94 in parallel
Discharging min. SOC	20.0 %
Stored energy	16157.2 kWh

Battery Pack Characteristics

Voltage	1439 V
Nominal Capacity	13931 Ah (C10)
Temperature	Fixed 20 °C

Battery input charger

Model	Generic
Max. charg. power	2675.0 kWdc
Max./Euro effic.	97.0/95.0 %

Battery to Grid inverter

Model	Generic
Max. disch. power	4000.0 kWac
Max./Euro effic.	97.0/95.0 %

Array losses

Thermal Loss factor

Module temperature according to irradiance

Uc (const)	29.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	2.4 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-0.8 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

IAM loss factor

Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

AC wiring losses

Inv. output line up to MV transfo

Inverter voltage	800 Vac tri
Loss Fraction	5.31 % at STC

Inverter: SG250-HX

Wire section (20 Inv.)	Alu 20 x 3 x 150 mm²
Average wires length	500 m

MV line up to Injection

MV Voltage	33 kV
Wires	Alu 3 x 95 mm²
Length	10000 m
Loss Fraction	1.97 % at STC

AC losses in transformers

MV transfo

Medium voltage	33 kV
Transformer parameters	
Nominal power at STC	6.47 MVA
Iron Loss (24/24 Connexion)	4.99 kVA
Iron loss fraction	0.08 % at STC
Copper loss	83.83 kVA
Copper loss fraction	1.29 % at STC
Coils equivalent resistance	3 x 1.28 mΩ

Horizon definition

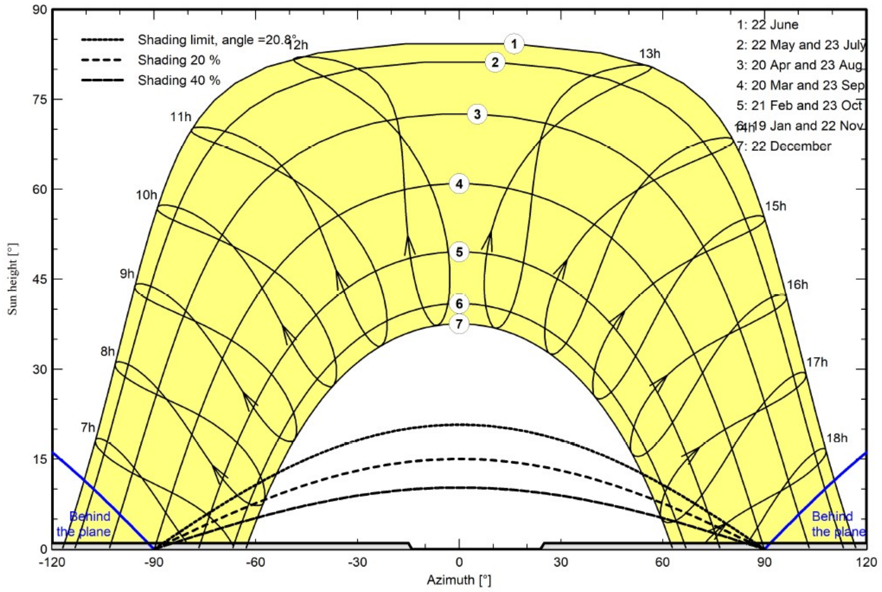
Horizon from Meteonorm web service, lat=27.62, lon=82.98

Average Height	1.3 °	Albedo Factor	0.97
Diffuse Factor	1.00	Albedo Fraction	100 %

Horizon profile

Azimuth [°]	-180	-160	-159	-152	-151	-145	-144	-134	-133	-15	-14	24
Height [°]	3.0	3.0	2.0	2.0	3.0	3.0	2.0	2.0	1.0	1.0	0.0	0.0
Azimuth [°]	25	121	122	123	126	127	134	135	139	140	155	156
Height [°]	1.0	1.0	2.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	3.0
Azimuth [°]	157	160	161	162	163	164	165	166	168	169	179	
Height [°]	2.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	3.0	3.0	

Sun Paths (Height / Azimuth diagram)



PVsyst V7.3.1
VC0, Simulation date:
07/01/23 22:36
with v7.3.1

Project: New Project Belauri DC

Variant: New simulation variant

Highland Associates Pvt Ltd (India)

Main results

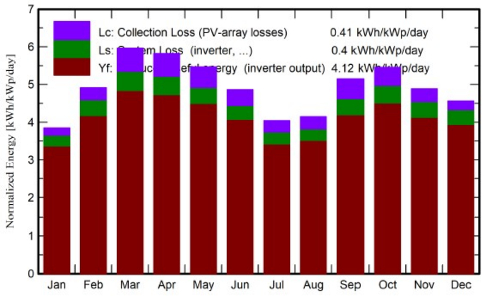
System Production

Produced Energy (P50)	9825407 kWh/year	Specific production (P50)	1502 kWh/kWp/year	Performance Ratio PR	83.59 %
Produced Energy (P90)	9358303 kWh/year	Produced Energy (P90)	1431 kWh/kWp/year		
Produced Energy (P75)	9701535 kWh/year	Produced Energy (P75)	1483 kWh/kWp/year		

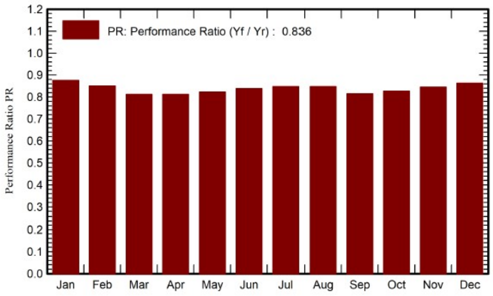
Battery aging (State of Wear)

Cycles SOW	97.7 %
Static SOW	90.0 %
Battery lifetime	10.0 years

Normalized productions (per installed kWp)



Performance Ratio PR



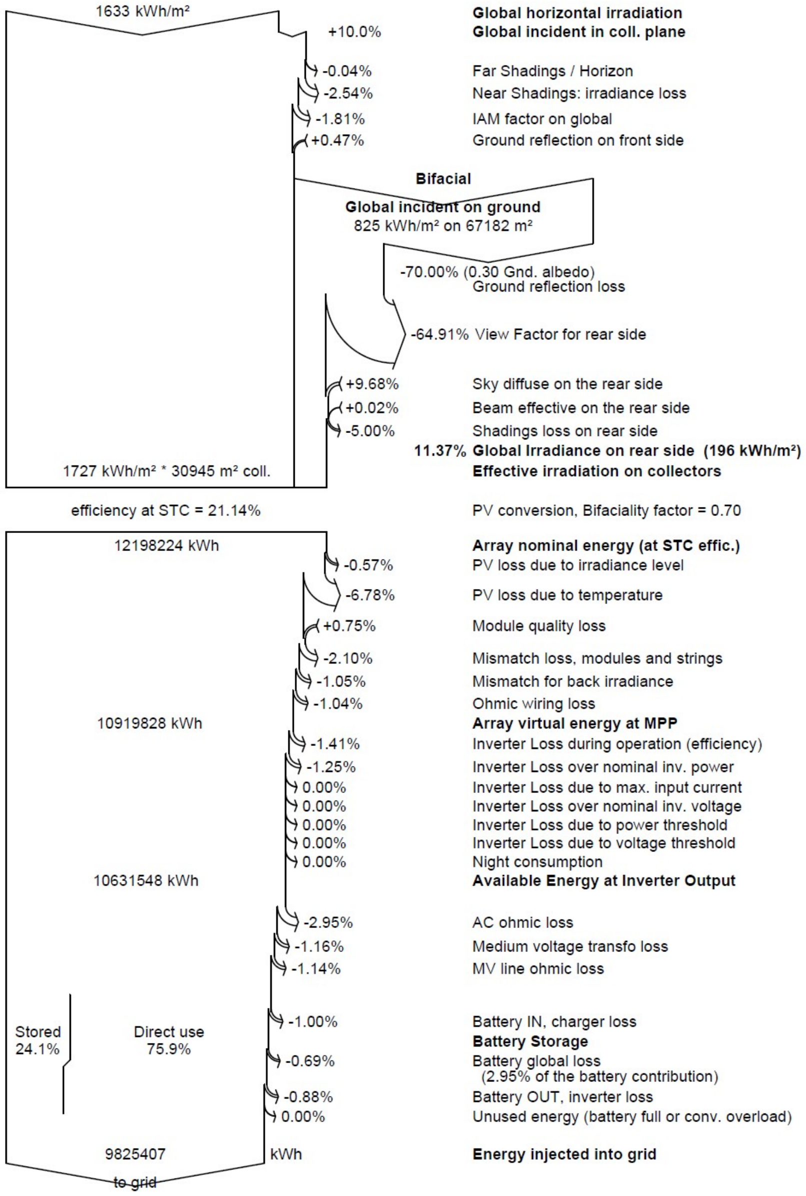
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EBatDis kWh	PR ratio
January	89.2	45.5	13.58	119.2	115.3	741401	682495	158088	0.876
February	109.8	54.3	17.68	137.6	132.9	842814	765254	187751	0.850
March	162.1	71.1	23.68	184.9	178.6	1085966	982225	270892	0.812
April	171.3	82.9	29.49	174.8	168.1	1024172	928084	240469	0.812
May	181.3	100.6	33.47	169.4	161.8	998978	912198	198350	0.823
June	161.1	101.3	32.99	145.8	138.5	871394	799934	141462	0.839
July	136.0	89.0	31.31	125.3	118.9	757630	694427	116669	0.847
August	133.3	90.0	30.26	128.6	121.9	774684	713083	108575	0.848
September	144.5	70.4	28.96	154.5	148.5	907992	823993	200089	0.815
October	139.5	66.4	26.40	169.1	163.6	1008458	914517	237947	0.827
November	107.5	48.7	20.17	146.6	141.9	893190	810618	202995	0.846
December	97.9	43.4	15.07	141.5	137.2	878519	798578	193929	0.863
Year	1633.5	863.9	25.29	1797.3	1727.3	10785199	9825407	2257216	0.836

Legends

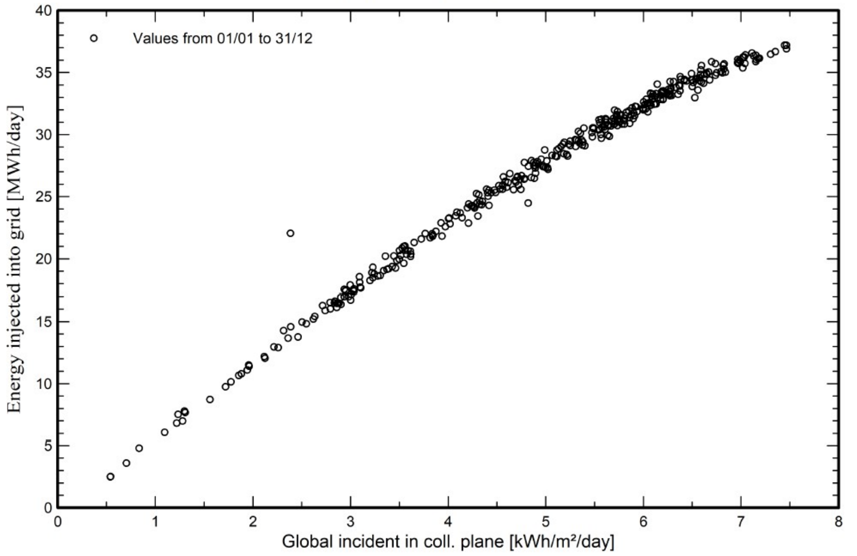
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	EBatDis	Battery Discharging Energy
GlobInc	Global incident in coll. plane	PR	Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

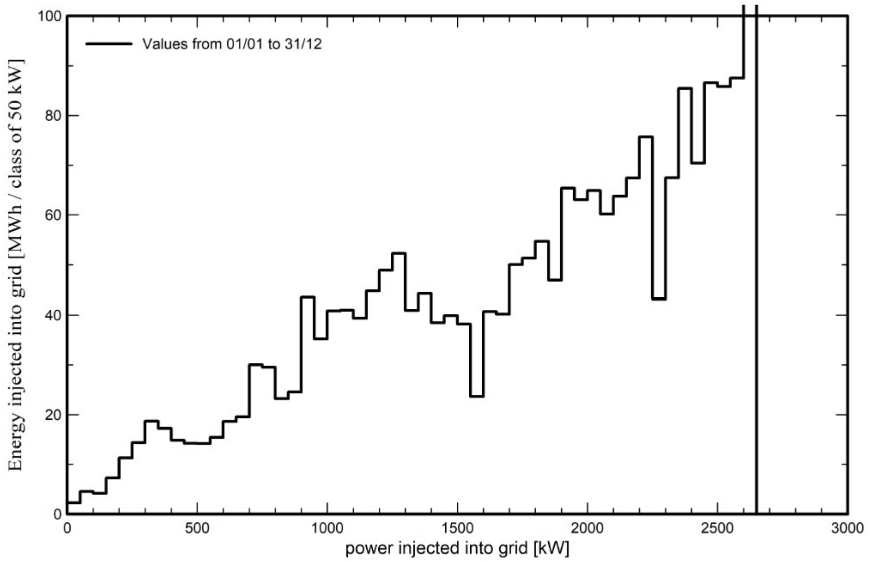


Predef. graphs

Daily Input/Output diagram



System Output Power Distribution



P50 - P90 evaluation

Meteo data

Source	Meteonorm 8.1 (1996-2015), Sat=100%
Kind	TMY, multi-year
Year-to-year variability(Variance)	5.3 %
Specified Deviation	
Climate change	0.0 %

Global variability (meteo + system)

Variability (Quadratic sum)	5.6 %

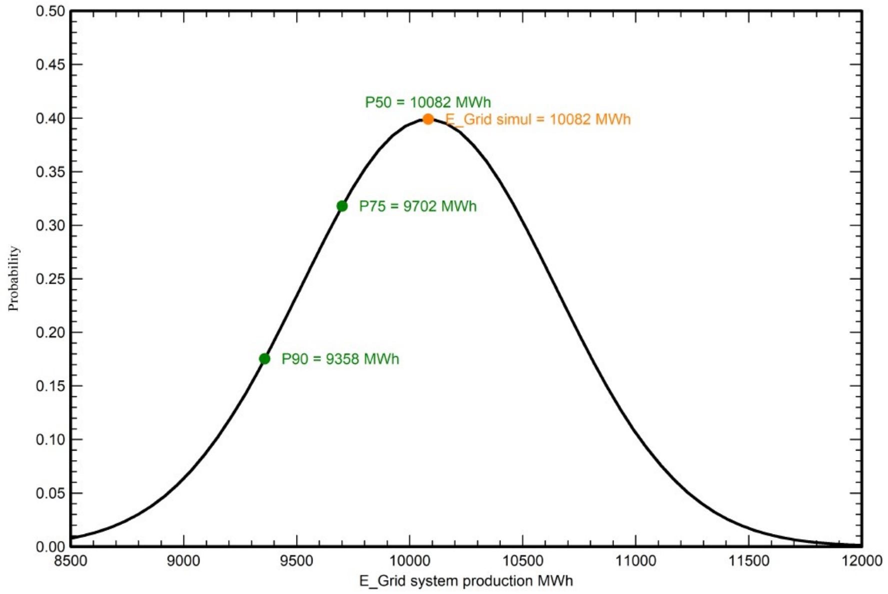
Simulation and parameters uncertainties

PV module modelling/parameters	1.0 %
Inverter efficiency uncertainty	0.5 %
Soiling and mismatch uncertainties	1.0 %
Degradation uncertainty	1.0 %

Annual production probability

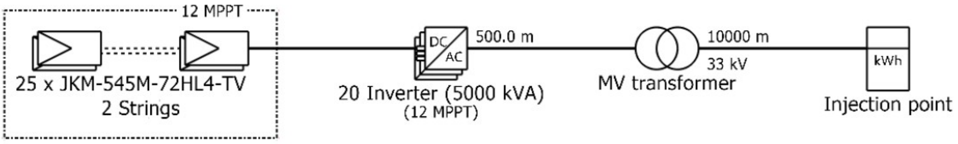
Variability	564 MWh
P50	10082 MWh
P90	9358 MWh
P75	9702 MWh

Probability distribution



Single-line diagram

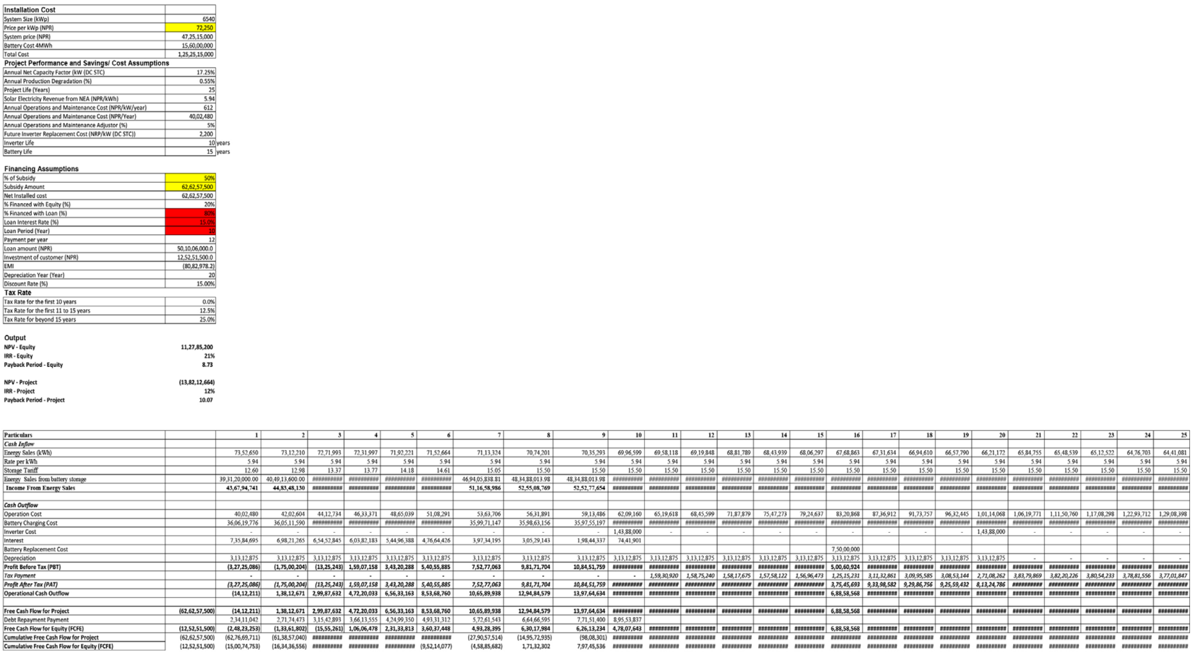
PVsyst V7.3.1
VC0, Simulation date:
07/01/23 22:36
with v7.3.1



PV module	JKM-545M-72HL4-TV
Inverter	SG250-HX
String	25 x JKM-545M-72HL4-TV

	New Project Belauri DC	Highland Associate
	VC0 : New simulation variant	07/01/23

9.2 Annexure 2: Financial Model



Installation Cost	
System Size (kWp)	6540
Price per kWp (NPR)	72,250
System price (NPR)	47,25,15,000
Battery Cost 4MWh	15,60,00,000
Total Cost	1,25,25,15,000

Project Performance and Savings/ Cost Assumptions

Annual Net Capacity Factor (kW (DC STC)	17.25%	
Annual Production Degradation (%)	0.55%	
Project Life (Years)	25	
Solar Electricity Revenue from NEA (NPR/kWh)	5.94	
Annual Operations and Maintenance Cost (NPR/kW/year)	612	
Annual Operations and Maintenance Cost (NPR/Year)	40,02,480	
Annual Operations and Maintenance Adjustor (%)	5%	
Future Inverter Replacement Cost (NRP/kW (DC STC))	2,200	
Inverter Life	10	years
Battery Life	15	years

Financing Assumptions

% of Subsidy	50%
Subsidy Amount	62,62,57,500
Net Installed cost	62,62,57,500
% Financed with Equity (%)	20%
% Financed with Loan (%)	80%
Loan Interest Rate (%)	15.0%
Loan Period (Year)	10
Payment per year	12
Loan amount (NPR)	50,10,06,000.0
Investment of customer (NPR)	12,52,51,500.0
EMI	(80,82,978.2)
Depreciation Year (Year)	20
Discount Rate (%)	15.00%

Tax Rate

Tax Rate for the first 10 years	0.0%
Tax Rate for the first 11 to 15 years	12.5%
Tax Rate for beyond 15 years	25.0%

Output

NPV - Equity	**11,27,85,200**
IRR - Equity	**21%**
Payback Period - Equity	**8.73**
NPV - Project	**(13,82,12,664)**
IRR - Project	**12%**
Payback Period - Project	**10.07**

Particulars		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Cash Inflow																										
Energy Sales (kWh)		73,52,650	73,12,210	72,71,993	72,31,997	71,92,221	71,52,664	71,13,324	70,74,201	70,35,293	69,96,599	69,58,118	69,19,848	68,81,789	68,43,939	68,06,297	67,68,863	67,31,634	66,94,610	66,57,790	66,21,172	65,84,755	65,48,539	65,12,522	64,76,703	64,41,081
Rate per kWh		5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94	5.94
Storage Tariff		12.60	12.98	13.37	13.77	14.18	14.61	15.05	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50
Energy Sales from battery storage		39,31,20,000.00	40,49,13,600.00	##########	##########	##########	##########	46,94,05,838.81	48,34,88,013.98	48,34,88,013.98	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Income From Energy Sales		**43,67,94,741**	**44,83,48,130**	##########	##########	##########	##########	**51,16,58,986**	**52,55,08,769**	**52,52,77,654**	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Cash Outflow																										
Operation Cost		40,02,480	42,02,604	44,12,734	46,33,371	48,65,039	51,08,291	53,63,706	56,31,891	59,13,486	62,09,160	65,19,618	68,45,599	71,87,879	75,47,273	79,24,637	83,20,868	87,36,912	91,73,757	96,32,445	1,01,14,068	1,06,19,771	1,11,50,760	1,17,08,298	1,22,93,712	1,29,08,398
Battery Charging Cost		36,06,19,776	36,05,11,590	##########	##########	##########	##########	35,99,71,147	35,98,63,156	35,97,55,197	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Inverter Cost		-	-	-	-	-	-	-	-	-	1,43,88,000	-	-	-	-	-	-	-	-	-	1,43,88,000	-	-	-	-	-
Interest		7,35,84,695	6,98,21,265	6,54,52,845	6,03,82,183	5,44,96,388	4,76,64,426	3,97,34,195	3,05,29,143	1,98,44,337	74,41,901															
Battery Replacement Cost																	7,50,00,000									
Depreciation		3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	3,13,12,875	-	-	-	-	-
Profit Before Tax (PBT)		**(3,27,25,086)**	**(1,75,00,204)**	**(13,25,243)**	**1,59,07,158**	**3,43,20,288**	**5,40,55,885**	**7,52,77,063**	**9,81,71,704**	**10,84,51,759**	##########	##########	##########	##########	##########	##########	**5,00,60,924**	##########	##########	##########	##########	##########	##########	##########	##########	##########
Tax Payment		-	-	-	-	-	-	-	-	-	-	*1,59,30,920*	*1,58,75,240*	*1,58,17,675*	*1,57,58,122*	*1,56,96,473*	*1,25,15,231*	*3,11,32,861*	*3,09,95,585*	*3,08,53,144*	*2,71,08,262*	*3,83,79,869*	*3,82,20,226*	*3,80,54,233*	*3,78,81,556*	*3,77,01,847*
Profit After Tax (PAT)		***(3,27,25,086)***	***(1,75,00,204)***	***(13,25,243)***	***1,59,07,158***	***3,43,20,288***	***5,40,55,885***	***7,52,77,063***	***9,81,71,704***	***10,84,51,759***	##########	##########	##########	##########	##########	##########	***3,75,45,693***	***9,33,98,582***	***9,29,86,756***	***9,25,59,432***	***8,13,24,786***	##########	##########	##########	##########	##########
Operational Cash Outflow		**(14,12,211)**	**1,38,12,671**	**2,99,87,632**	**4,72,20,033**	**6,56,33,163**	**8,53,68,760**	**10,65,89,938**	**12,94,84,579**	**13,97,64,634**	##########	##########	##########	##########	##########	##########	**6,88,58,568**	##########	##########	##########	##########	##########	##########	##########	##########	##########
Free Cash Flow for Project	**(62,62,57,500)**	**(14,12,211)**	**1,38,12,671**	**2,99,87,632**	**4,72,20,033**	**6,56,33,163**	**8,53,68,760**	**10,65,89,938**	**12,94,84,579**	**13,97,64,634**	##########	##########	##########	##########	##########	##########	**6,88,58,568**	##########	##########	##########	##########	##########	##########	##########	##########	##########
Debt Repayment Payment		2,34,11,042	2,71,74,473	3,15,42,893	3,66,13,555	4,24,99,350	4,93,31,312	5,72,61,543	6,64,66,595	7,71,51,400	8,95,53,837															
Free Cash Flow for Equity (FCFE)	**(12,52,51,500)**	**(2,48,23,253)**	**(1,33,61,802)**	**(15,55,261)**	**1,06,06,478**	**2,31,33,813**	**3,60,37,448**	**4,93,28,395**	**6,30,17,984**	**6,26,13,234**	**4,78,07,643**	##########	##########	##########	##########	##########	**6,88,58,568**	##########	##########	##########	##########	##########	##########	##########	##########	##########
Cumulative Free Cash Flow for Project	(62,62,57,500)	(62,76,69,711)	(61,38,57,040)	##########	##########	##########	##########	(27,90,57,514)	(14,95,72,935)	(98,08,301)	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Cumulative Free Cash Flow for Equity (FCFE)	(12,52,51,500)	(15,00,74,753)	(16,34,36,556)	##########	##########	##########	(9,52,14,077)	(4,58,85,682)	1,71,32,302	7,97,45,536	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########