TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO:

Determination of Solar Hosting Capacity: A Case Study in 33 kV Distribution Network of Province No. 1, Nepal

by

Ashish Nepal

A THESIS SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULLFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

LALITPUR, NEPAL

NOVEMBER 2019

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled Determination of Solar Hosting Capacity: A Case Study in 33 kV Distribution Network of Province No. 1, Nepal submitted by Ashish Nepal in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

____

Supervisor, Dr. Nawraj Bhattarai

Head of Department,

Department of Mechanical Engineering

____

External, Dr. Shailendra Kumar Jha

Acting Head of Department,

Department of Electrical and Electronics Engineering

Kathmandu University.

____

Committee Chairperson, Dr. Nawraj Bhattarai

Head of Department,

Department of Mechanical Engineering

Date:_________________________

ABSTRACT

The case of utilities supplying energy to the consumers from centralized grid is shifting towards decentralized generation where, power production is supplemented by local distributed generations. With increase in attraction towards clean energy, such generations are usually renewable energy sources. However, integrating renewable energy sources to the power system often become troublesome due to unpredictable output of such sources. It is essential to study the capability of the grid to withstand the variations of these source before interconnecting them to the power system. Integration of large amount of renewable energy is restricted by the system reserve margin and operational characteristics of the system. The availability of Solar Insolation all around the year makes Nepal suitable location for installation of Solar Photo Voltaic (PV) Plant. This study is focused to determine the PV hosting capacity in power system network of Province No. 1, Nepal which is dominated by 33 kV lines. Steady state load flow has been carried out with step increment in size of PV installed at two buses namely Inaruwa and Duhabi at 33 kV. Time domain load flow of wet and dry season, signifying excess and scarce generation in the power system has been performed. Typical data of March is used for System parameters for dry season and of June for Wet Season. Voltages at different weak buses improved after the integration of PV into the system during wet and dry season. System loss increased after injection of PV beyond 30MWp.The line loading limit and system reserve margin were not violated for this size. The financial analysis of the Grid tied Photo voltaic plant was carried out with power purchase rate of NPR 7.30 per kilowatt- hour which gave internal rate of return of 8.46%. To assess the effect of change in major variables upon the IRR of the project, sensitivity analysis was performed by varying the investment, power purchase rate and energy generation. The maximum value of IRR was found to be 11.50%, when the capital investment was set to 0.85 times of actual value as well as minimum value of IRR was found to be 5.63% when the energy generation was 0.85 times of actual value.

ACKNOWLEDGEMENT

I take this opportunity to extend sincere thanks and indebtedness to all those persons who helped me during the entire period of thesis work. First of all, I would like to express my gratitude to my project supervisor Dr. Nawraj Bhattarai for his continuous guidance and support during the entire period.

I would like to express my deep sense of gratitude to Institute of Engineering - Pulchowk Campus, Department of Mechanical Engineering for including thesis work in our master's degree. I would also like to thank MSREE Coordinator Dr. Ajay Kumar Jha for providing us guidelines and teaching us Research Methodology which helped me in shaping up the research work. I would also like to thank all the esteemed faculty members of Department of Mechanical Engineering for guiding and encouraging us throughout period of my study.

I also acknowledge indebtedness to my family members, my roommates, colleagues for their continuous help, support and inspiration throughout my study period.

TABLE OF CONTENTS

COPYRIGHT....2
ABSTRACT....4
ACKNOWLEDGEMENT....5
TABLE OF CONTENTS....6
LIST OF TABLES....9
LIST OF FIGURES....10
LIST OF ABBREVIATIONS....11
INTRODUCTION....12
1.1 Background....12
1.1.1 Hosting Capacity....14
1.2 Problem Statement....15
1.3 Objectives....15
1.3.1 Main Objective....15
1.3.2 Specific Objective....15
1.3.3 Assumption and Limitations....16
LITERATURE REVIEW....17
1.4 Solar Output Characteristics....21
1.4.1 Un-controllable Variability....21
1.4.2 Partial Unpredictability....21
1.4.3 Location Dependency....22
1.5 Solar PV Integration Challenge....22
1.5.1 Technical Challenges of PV Hosting Capacity....22
1.6 Grid Impact Study....23
1.6.1 Static Load Flow....24

1.6.2 Effect of Variation of PV on Load Curve. 24
1.6.3 Short Circuit and Transient Analysis 25
1.7 Interconnection Guideline/standards and Criteria (PV less than 10MVA) 26
RESEARCH METHODOLOGY 28
1.8 Description of Methodology 28
1.9 Modelling of Province 1 Network in ETAP 28
1.9.1 Modeling of Existing network of Province 1 in ETAP 28
1.10 Base Case Load Flow Analysis 31
1.11 Load Flow with Step Incremental of PV Farm. 32
1.12 Solar Power Generation 33
1.12.1 Solar Insolation study in selected site region 34
1.13 Solar Site Selection 36
1.14 ETAP 36
1.14.1 Steady State Simulation 36
RESULTS AND DISCUSSION 38
1.15 Load Flow of Dry Season 38
1.16 Load Flow of Wet Season 43
1.17 Financial Analysis of the 30MWp Solar PV Plant 47
CONCLUSION AND RECOMMENDATIONS 50
1.18 Conclusion 50
1.19 Recommendations 51
REFERENCES 52
APPENDIX A: Single Line Diagram of the Power Grid Modelled in ETAP 55
APPENDIX B: Generations in Dry Season 56
APPENDIX C: Generations in Wet Season 58
APPENDIX D: Loading in Dry Season 60

APPENDIX E: Loading in Wet Season..64

APPENDIX F: Financial Analysis of Solar PV Plant 68

LIST OF TABLES

Table 2-1: Interconnection Standards for Transmission- Connected Systems [IEEE]. 26

Table 2-2: Frequency range versus time [IEEE]... 27

Table 3-1: The clear sky situation in Nepal 34

Table 4.1: Economic Parameters for Solar PV Plant 47

LIST OF FIGURES

Figure 2-1: Typical Components of Solar PV System..18

Figure 2-2: Typical Solar output of a cloudy and rainy day.......................................21

Figure 2-3: Changes in demand as PV penetration increases. 25

Figure 3-1: Block Diagram for Methodology of the work carried out in the Study....30

Figure 3-2: Percentage of loading in the model throughout the day............................32

Figure 3-3: Diurnal Variation of Total Solar Radiation at Biratnagar 35

Figure 3-4: Daily Variation of Solar Energy at the site in January 2010 35

Figure 4-1:System Losses in Dry Season, with and without PV Injection at 15:00 hour 39

Figure 4-2: Voltage Profile of Duhabi, Inaruwa and PV Buses, for base case and with PV Injection in Dry Season...39

Figure 4-3: Voltage Profile of Weak Buses, with and without PV Injection in Dry Season 40

Figure 4-4: Power Flow in MW from PV and Swing Bus in the system during Dry Season 41

Figure 4-5: Percentage Line Loading of Transmission Lines in Province 1, Nepal during Dry Season 42

Figure 4-6: Power Flow in MW from PV and Swing Bus in the system during Wet Season 43

Figure 4-7: Voltage Profile of Duhabi, Inaruwa and PV Buses, for base case and with PV Injection in Wet Season 44

Figure 4-8: Voltage Profile of Weak Buses, with and without PV Injection in Wet Season 45

Figure 4-9: Percentage Line Loading of Transmission Lines in Province 1, Nepal during Wet Season...46

Figure 4-10: Sensitivity Analysis for change in Investment cost, Power Purchase Rate, Energy Generation and Debt to Equity Ratio for Solar PV Plant................................48

LIST OF ABBREVIATIONS

B/C	Benefit to Cost Ratio
DG	Distributed Generation
ETAP	Electrical Power Systems Analysis Software
FACTS	Flexible AC Transmission System
GW	Giga Watt
HC	Hosting Capacity
HEP	Hydro Electric Project
INPS	Integrated Nepal Power System
IRR	Internal Rate of Return
kVA	Kilo Volt Ampere
kW	Kilo Watt
LDC	Load Dispatch Centre
MATLAB	Matrix Laboratory, Software
MW	Mega Watt
MWp	Mega Watt peak
NEA	Nepal Electricity Authority
NPV	Net Present Value
PSO	Particle Swarm Optimization
pu	Per Unit
PV	Photo-Voltaic
SLD	Single Line Diagram

INTRODUCTION

1.1 Background

Nepal is enriched with water resources having theoretically reported potential of about 83 GW and techno-economically viable potential of about 42 GW in hydropower (Shrestha, 2017). For a country with area of 147,181 sq. km, electrical power generation from hydro resource should have been abundant with electricity consumers having shifted to electricity from other fast depleting energy resources like coal and petroleum oil. The development of hydropower potential to meet the domestic electricity demand and to export surplus power to neighboring countries seems to be quite reasonable. Contrary to this, hydropower development in the country has not been going in quick pace, ensuing deficit of electrical power and energy in this South Asian nation.

The demand for power and energy has been consistently increasing for last few years in the country (Nepal Electricity Authority, 2019). There was consistent power cuts and unreliable power supply hours crippling every aspect of lives of people and their economic activities since the year 2006 (Nepal Electricity Authority, 2012). This has been omitted in the present scenario (Nepal Electricity Authority, 2019). Now, the question has risen for the power quality. The mainstream hydropower is delayed due to multiple reasons, with few like Kulekhani III, Trishuli 3A, connecting to grid this year after long delays (Nepal Electricity Authority, 2019). To fulfill the gap of delaying mainstream hydropower plants and alleviate the country from power shedding, development of alternative power generation schemes, like wind and solar PV technologies, is essential. The alternative power generation can serve two purposes in the context of Nepal. It provides immediate relief from long hours of power cuts and interrupted power supply with shorter construction period. It also helps utilizing locally available resources for electricity generation and reduces reliance of electricity and energy from other places/regions.

Renewable source of energy is clean and environmentally friendly. They can provide many immediate environmental benefits by avoiding the emission of greenhouse gases and can help conserve fossil resources as electricity supply for future generation. One of the technologies used to generate electricity in a renewable way is to use solar cells to convert the energy delivered by the solar irradiance into electricity. PV generation is the current subject of much commercial and academic interest. Large scale PV generation is commercially so attractive that large scale PV is implemented in many parts of the developed world. As of December 2017, 402.5 GW of PV are now globally installed with the number being at least 70% higher than 2006. (International Energy Agency, 2019)

Over last two decade there have been unparalleled development in renewable energy sector all over the world. Several countries have adopted support schemes as feed-in tariff, green subside, micro grids, roof top solar and tax exemption as well. Compiling to all these scenarios electricity utilities are forced to respond to the excessive demand to provide their networks for DG connection and at the same time ensuring that interconnection doesn't violate technical standards of existing network. When the local DG interconnection exceeds the capacity of line and substation especially during lightly loaded condition traditional one-way power flow from substation to feeders to low voltage distribution lines are supplemented by reverse power flow and power fed into upstream networks. Such conditions sources various other problems including low power factor in medium voltage and high voltage substations, voltage regulations and high short circuit capacity. Thus, utilities should determine first in fast simplified and reliable manner the hosting capacity of the particular feeder and distribution network. There have been several works in the field of determining Hosting Capacity in a power system. (Al-Alamata & Faza, 2017) (S. KoohiKamali, et al., 2010)

Renewable energy interconnection arises in different form in a network sometime as rooftop solar, as a PV module directly to distribution feeders as a wind turbine and sometime even as hybrid network. Distributed Generation might be of any type but before approving interconnection in the network utilities must go through screening process to determine potential adverse effect of such connection which can often be time consuming and requires attention of the regulators. With high demand of interconnection awaiting it has become essential for utilities to promptly analyze the entire feeder and determine its Hosting Capacity (HC) analyzing risk before normal operation of the distribution system are violated and power quality remains within normal standards. The maximum amount of Distributed Generation that can be added to the distribution feeder, at certain location on the feeder, to the medium voltage substation, at some part or whole of the integrated power system is most basically know as hosting capacity. Determining HC is not a straight forward process as it may varies according to location or point of interconnection, to the type of DG added to the system.

The value of HC once calculated for certain feeder's changes even when the configuration of feeder is changed and power system equipment upstream and downstream changes.

In correlation with around the world Nepal is also expecting potential amount of DG interconnection as an isolated system mini grid and to Integrated Nepalese Power Systems (INPS), so it is wise to investigate potential amount of Distributed Generation before real works of installation begins. Although many studies have been carried out to determine Hosting capacity in in a single 11kV feeders originating from certain substation this thesis highlights and attempts to calculate solar hosting capacity of the entire province No 1 of Nepal. This work gets its value added as Nepal is in elementary phase of implementing federalism and government has just began the process of deregulation.

Nepal Electricity Authority (NEA) is currently working in construction of 25MWp Grid connected in Nuwakot and has plans in developing more in future in different parts of Nepal (Nepal Electricity Authority, 2019). In this research study one of such site Province No. 1 of Nepal will be chosen to determine the solar hosting capacity of a 33-kV network in that area.

1.1.1 Hosting Capacity

The PV hosting capacity of distribution systems refers to the maximum installed PV power that can be incorporated within the distribution system without violating any performance indicators. These performance indicators are satisfied as long as certain technical constraints, such as bus voltages and transformer power ratings, are not exceeded (Al-Alamata & Faza, 2017).

The performance indicators considered in this study are the line loading and system losses for the power system network. It is expected that the system losses shall decrease after the PV injection into the system without violating the line loading constraints and voltage constraints. A standard practice in Nepal is to load line less than 100% and in case of emergency up to 120% for a shorter period of time. NEA has developed NEA Grid Code which speaks for the line loading capability and as well as the voltage constraints. For a Medium Voltage of 33 kV, NEA Grid code allows voltage variation of up to ±5%. In reality, the voltage drop is much higher during peak hours in several locations in the country.

Recently, Nepal Electricity Regulatory Commission has been formed which is the apex body in Nepal and shall be regulating the electricity sector that includes developing the grid code for Nepal. (The Himalayan Times, 2018)

1.2 Problem Statement

The demand for power and energy has been consistently increasing for the last few decades. Nepal has just recovered from hour's long power cuts and there still exist question on reliability of electricity supply crippling every aspect of lives of people and their economic activities. Currently, the major source of electrical energy is hydropower and despite of heavy investment on infrastructure development, construction of the generating facility takes years to complete. The present generating capacity of Nepal is unable to meet its demand hence to fulfil the deficit, electrical energy is being imported from India. In order to fulfill the gap of generation and load on our own, development of alternative power generation scheme, like wind and solar technologies is essential. Among the renewable resources, Nepal has excellent solar insolation across the country. Thus, large scale solar PV generation is possible which help in decrease the gap of supply-demand and increase the availability of power supply. Due to unpredictable nature of output of PV, the system may experience many consequences that effect the power system parameters of some part or whole part of power system. In this study, solar hosting capacity of a 33-kV network is analyzed.

1.3 Objectives

1.3.1 Main Objective

The main objective of this thesis is to determine the hosting capacity of PV in a 33 kV dominated Medium Voltage network in Province No.1, Nepal.

1.3.2 Specific Objective

1. To study the impact on voltage profile, line loss, line loading after injection in PV by performing Time domain load flow.
2. To determine active power flow in the system before and after PV Injection to the System.
3. To carry out financial analysis of the PV plant to be connected to the system.

1.3.3 Assumption and Limitations

Integrated Nepal Power System (INPS) in Province 1 is dominated by 33 kV network. The network of Province 1 is modelled in ETAP with swing bus in Dhalkebar. The network to the west of Dhalkebar in INPS has not been modelled. The designed model in software does not include contact and other losses which may arise in real field. Transmission lines to be constructed in near future has been taken into account to accommodate load flow analysis. Similarly, modelling of solar PV is done only as a generating source and only active power flow in the system from the PV plant is considered. The reactive power that PV inverters could supply during the night time has not been considered in this study. Loading of transmission in some cases has been adjusted for the load flow to converge. For dry season load flow 40% of generation from the hydro power plant is considered and in the same manner for the load flow of the wet season 60% of generation is considered.

LITERATURE REVIEW

Utilization of renewable energy appear attractive from the perspective of environmental conservation and fossil fuel shortage. Recent studies suggest that, in medium and long terms photovoltaic (PV) generator will become commercially so attractive that large-scale implementation of this type can be seen in many parts of the world. (International Energy Agency, 2019) A large-scale PV generation system includes photovoltaic array, maximum power point tracking (MPPT), DC/AC converter and the associated controllers. It is a multivariable and non-linear system, and its performance depends on environmental conditions. It was discovered that cloud cover has a huge impact on large scale PV power plant output and that the variability of cloud causes variable output of the power from the generating PV plant. Therefore, it is very important to consider the variability of cloud cover an important parameter on the power production when studying the effect or impact of integrating large PV power to the grid in transmission voltage level. Recently, the increasing penetration levels of PV plants are raising concerns to utilities due to possible negative impacts on power system stability as speculated by a number of studies. Thus, the thorough investigation of power system stability with large-scale PV is emerging as attractive area of research.

The impact of a grid-connected PV system on the steady-state operation of a Malaysian grid is presented in (Shah, 2012). The main object of the research was to investigate the voltage profile and power losses of a grid connected solar PV system for residential, commercial and industrial load pattern categories at Peninsular Malaysia. After data collection, the study modeled the photovoltaic generator as a negative load connected to the distribution generation bus. The single line diagram voltages were 132 kV/11 kV. For commercial load category (>1MW) it was discovered that the voltage increases from 6:00am to 6:00pm, but the voltage rise did not cause over-voltage when compared with the standard permissible voltage of 1.05 p.u. in Malaysia. The study also concluded that there was some substantial reduction in power losses when the solar PV was injected into the grid.

The influence of large-scale PV on voltage stability of sub-transmission systems has been reported by (Weidong, 2010) (Chyou-Jong Lin, 2011). The study used the IEEE-14 bus test system to report the result of static voltage stability with large-scale PV penetrations on sub-transmission system for realistic load composition. A study on the impact of Large Scale and High Voltage Level Photovoltaic Penetration on the Security and Stability of Power Systems (Weidong, 2010), discussed new requirements that might be brought to network simulation and calculation technology by grid connected photovoltaic systems. The technical ramifications of the grid integration of large-scale solar PV were reported to be effects on electricity quality, power flow control, new requirements for simulation technologies and power system test environment, voltage and frequency stability, codes and standards revising or supplementing of grid operation and dispatching.

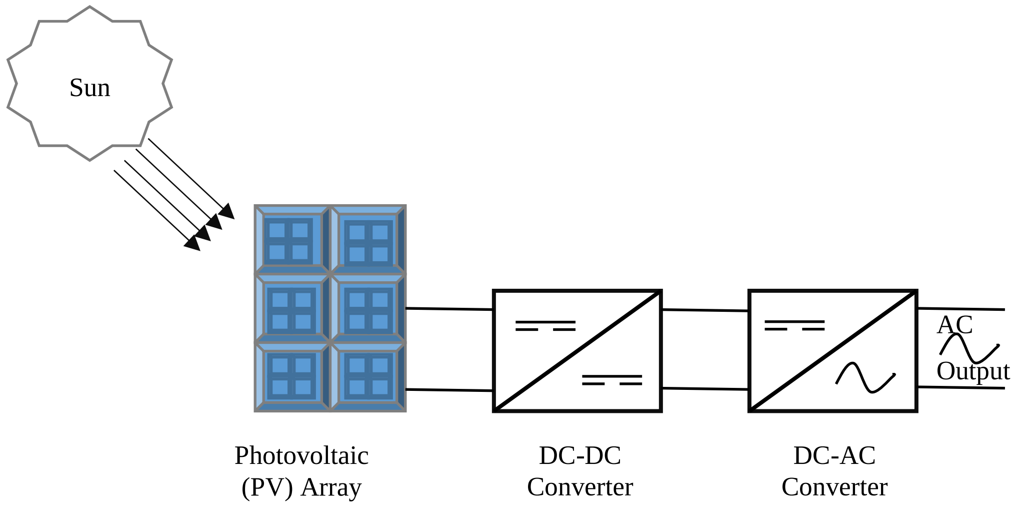


Figure 0-1: Typical Components of Solar PV System

A study conducted by California ISO (CAISO) assessed different types of solar PV generator interconnections (Hardcastle & Stacey, 2009). The study analyzed and reported several transient stability and voltage phenomena related to solar PV generator interconnections. The queue-base methodology, which requires generation developers to submit interconnected requests, was used in the research. It was reported that the interaction between the solar PV generators and the system amplifies the oscillation and causes unstable conditions. The research concluded that Solar PV generator interconnection may cause oscillation problems following faults, high voltage problems in sub-transmission and distribution systems under normal conditions, and the transient over-voltage problem in the grid following faults.

Access to reliable energy supply, climate change and the high price of fossil fuel have all underpinned the need for the development and generation of renewable energy . (2012) The growth trend of Solar Photovoltaic (PV) electricity generation in 2011 was very remarkable. The grid integration for 2011 was 29.7 GW as compare to 16.8 GW in 2010 making it the third most important renewable energy source in terms of global installation capacity, (2012). Recent trend shows that integration of renewable energy into grid is increase day by day, thus can reduce stability limit of existing grid system and make more vulnerable to disturbance. Thus, with the increase in PV penetration challenge also increases. Understanding these distinctive characteristics is very necessary for the integration of large-capacity RE power in the grid. (Widen & Wackelgard, 2010).

According to Rao and Obulesh (Rao & Obulesh, 2013), the introduction of Distributed Generation (DG) will effectively improve the active power and loss reduction. They represented a technique by which power losses can be minimized in a distribution feeder by optimizing distributed generation DG model in terms of size, location and operating point of DG. A typical Distributed Generation size is of the ranges from less than a kilowatt to few megawatts of Power Generation. FACTs devices provide passive element except for DG units placement that provides an active element to improve the power system network. Installation of DG units in a given power system network will rapidly improve the voltage profile twice or thrice that of passive injection of reactive power through capacitors bank to reduce power losses. In their work, a sensitivity analysis was carried out to minimize the power losses, optimal sizing of the DG and its operating point. They proposed that sensitivity indices can indicate the changes in power losses with respect to DG current injection. However, the proposed technique was developed considering load characteristics and representing a constant current model. The usefulness of the proposed method was tested and verified using MATLAB software on long radial distribution system (Rao & Obulesh, 2013).

According to Afazalan & Taghikhani (Afazalan & Taghikhani, 2012), optimal sizing and integration of DG in the distribution network is an optimization problem with continuous and discrete variables. Afzalan & Taghikhani in their paper recommended a hybrid algorithm (PSO&HBMO) for optimal incorporation and sizing of distributed generation (DG) in a radial distribution system to improve the voltage profile and reduces the total power losses of the network. A 13-bus radial distribution system was used as the test system; however, MATLAB software was used for the simulation and the results obtained indicate that (PSO&HBMO) technique can offer better results than the simple heuristic search technique and PSO algorithm they said that the technique has the capacity to be a tool for identifying the best location and rating of a DG to be integrated for enhancing the voltage condition and line loss reduction in an electrical power network.

In Suyono & Hasanah (Suyono & Hasanah, 2016), the impact of power losses and the penetration level in the application of distributed generation on a distribution system was investigated. It was aimed to examine the levels of power losses on the distribution network with different DGs penetration. A steady-state power flow analysis was applied to investigate the different voltage profile and power losses during the variation of the DGs penetration.

The different DGs technologies applied are wind power turbine, photovoltaic power system and micro-hydro power plants. Four different cases were analyzed beginning from the original grid in the first case, followed by addition of photovoltaic plant, the second case using wind power plant, the third and fourth cases were the addition of micro-hydro power plant to the grid. From the analyzed results, the introduction in case micro hydro power plant and its size indicates the best impact as compared to the three other cases. The micro-hydro power plant potential was greater than that of wind power plant and photovoltaic plant as they noted. The integration of renewable power plants in the study was their priority despite it was the least favorable but in general it improves the voltage margins and reduces the power losses in the system.

Shayani et al., investigated the high PV penetration impact on the electrical networks. The authors found that the increase of voltage and the continuous maximum current of the conductor which is generally known as conductor ampacity were the main indices that surpass the allowable limits in presence of high DG penetration. After various simulations, the authors concluded that it is possible to install DG values between 1 and 2 pu of the load power. Practical rules of thumb were proposed in that study to determine the maximum allowable DG penetration according to the specified performance limit selected by the operator. From the voltage rise perspective, they proposed that the voltage drop at the base case of the system i.e. without DG and the voltage rise that will occur at the maximum DG penetration should have same value approximately.

1.4 Solar Output Characteristics

Solar power generation is fluctuating, uncontrollable and unpredictability and depends on resources that are location dependent. The three distinct aspects that create distinct challenges for generation of solar power and grid operators in integrating solar PV plant are as follows.

1.4.1 Un-controllable Variability

Solar output varies in a way that generation operators cannot control, because available sunlight varies from moment to moment and affect the output from PV plant. Figure 2.1 provides a graphical example of hourly PV power variability. This fluctuation in power output results in the need for additional spinning reserve to balance supply and demand on the grid on an instantaneous basis, as well as ancillary services such as frequency regulation and voltage support.

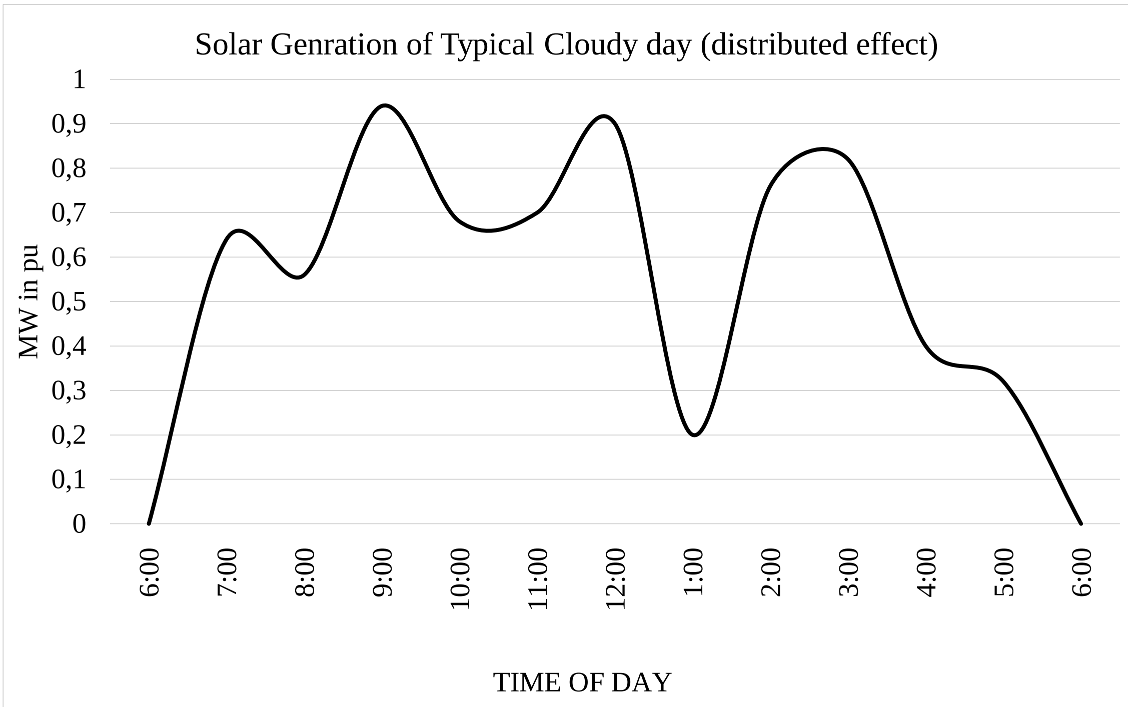


Figure 0-2: Typical Solar output of a cloudy and rainy day

1.4.2 Partial Unpredictability

The availability of sunlight is partially unpredictable. Solar PV system require the presence of sunlight in order to produce electricity. So output from the PV system cannot be predicted accurately. Unpredictability can be managed through improved weather and generation forecasting technologies, the maintenance of reserves that stand ready to provide additional power when PV plant produces less energy than predicted, and the availability of dispatch able load to “soak up” excess power when PV generation produces more energy than predicted.

1.4.3 Location Dependency

The solar resources are based in specific location and unlike coal, gas, oil or uranium, cannot be transported to a generation site. Generation must be co-located with the resource itself, and often these locations are far from the places where the power will ultimately be used. New transmission capacity is often required to connect solar resources to the rest of the grid.

1.5 Solar PV Integration Challenge

1.5.1 Technical Challenges of PV Hosting Capacity.

1. Impacts on Voltage Level

Voltage rise is caused by high penetration of solar PV into the utility grid.Studies presented by (MIT, 2014) attempted to establish the impact on the voltage and determination the maximum PV generation to the distribution grids in Sweden. Additionally, the studies in showed that voltage level and profile is not the ultimate factor in determining the maximum penetration level. Other parameters, for example line loading and losses, should be analyzed together with voltage level and profile in determining the hosting capacity of the grids. During normal radial feeder operation, there is a voltage drop across the distribution transformer and the secondary conductors, and voltage at the customer service entrance is less than at the primary. Under certain conditions with a Distributed Generation unit installed, other customers on the feeder may see higher than normal service voltage with associated unintended consequences. This situation can occur when (Solid-DER Project, 2006) The Distributed Generation introduces reverse power flow that counteracts the normal voltage drop, and even raises the voltage.

2. Voltage Stability

Voltage stability is defined as a phenomenon where a power system maintains steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. Voltage stability depends on the ability to maintain or restore equilibrium between load demand and load supply of a power system. When the need for reactive power in a power network system is met; voltage stability can be achieved. Inverters are responsible for keeping the power factor of the PV system at unity (Okerfor, et al., 2017). When the power factor is at unity there is no exchange of reactive power between the inverter and the grid. This becomes problematic when solar PV is connected to a weak grid and the capacity is large, static voltage instability problems will occur since the PV system will draw reactive power. However, with advancement in Solar PV inverter technology, this issue appears insignificant.

3. Impacts on Losses and Line Loading

Losses and line loading are very important parameters of a power system. Transmission lines and feeders have a limit to which they can be loaded. Additionally, losses can either reduce or increase the operation costs of a distribution grid. The studies conducted by (MIT, 2014) and presented the effects of photovoltaic integration on the grid losses. Different penetration levels were used to determine the impact of increased PV penetration on grid losses.

4. Impacts on Steady State Voltage Stability

Voltage stability of a grid determines the potential of the grid to restore initial operating voltage levels after being subjected to a disturbance. Small variations in load or generation could result to cascaded adverse effect in a system. Studies have been performed to observe the effect of Solar PV in steady state voltage stability. Study for investigation of Steady State voltage stability in Saudi Arabia shows that integration of photovoltaic to grid improves the steady state stability of the grid. (MIT, 2014)

1.6 Grid Impact Study

During the integration of new generation into an existing power network, the transmission operator requires a grid integration study. Usually, the study includes two part; grid impact study and grid code compliance study. The grid impact study is performed to confirm whether the existing power system is capable of accepting the new generation from different renewable source and carried out during the feasibility and detailed design stage. The grid code compliance study is performed during pre-installation stage to attest whether the new installation is compliant with the various grid code requirements. Although both studies are used to verify various technical requirements, the former is more focused on the system aspect, whereas the latter on the component aspect. This study is more focused on former i.e. in system aspect rather than in the component level.

Since a grid impact study verifies the impact of incoming generation unit on the existing electricity system, it is common for conventional and renewable energy assets. Typically, the impact study consists of following parts.

- Static load flow
- Short circuit calculations and Transient stability simulations

1.6.1 Static Load Flow

Load flow analysis is related to the steady state power flow study to determine line flow, generator loading, power loss and the voltage profile at various scenarios. In this study, one must ensure that these scenarios cover all extreme cases. The peak and minimum load scenario of the year of commissioning are typically considered. However, in the case of a PV park, these might not be the most relevant cases, as the peak load may coincide with the maximum irradiation. So, exercise should have done to choose the relevant scenarios, such that they represent all worst cases, ensuring that the new generation can evacuate its power at all times. Variation of irradiation over the seasons and during the day and variation in load must be considered. The composition of relevant scenarios is often region specific.

1.6.2 Effect of Variation of PV on Load Curve.

A typical example presented in Figure 0-3 shows how PV generation affects demand on that system over the course of a summer day. In each diagram, yellow areas are demand met by PV generation, and brown areas are “net demand,” that is, remaining demand that must be met by other power plants. Left to right, the diagrams show increasing PV penetration. Initially, PV generation simply reduces net demand during the middle of the day. But when the PV energy share reaches 58%, the solar generation pushes down net demand dramatically, such that when the sun goes down, there should be fast power ramping, a rapid power change that can be handled only by expensive gas-fired power plants. Interestingly, as PV penetration grows, the peak in net demand shifts in time but never decreases appreciably. As a result, meeting the net-demand peak will require the same installed non-PV generating capacity in each case, but that capacity will be used less as PV generation increases.

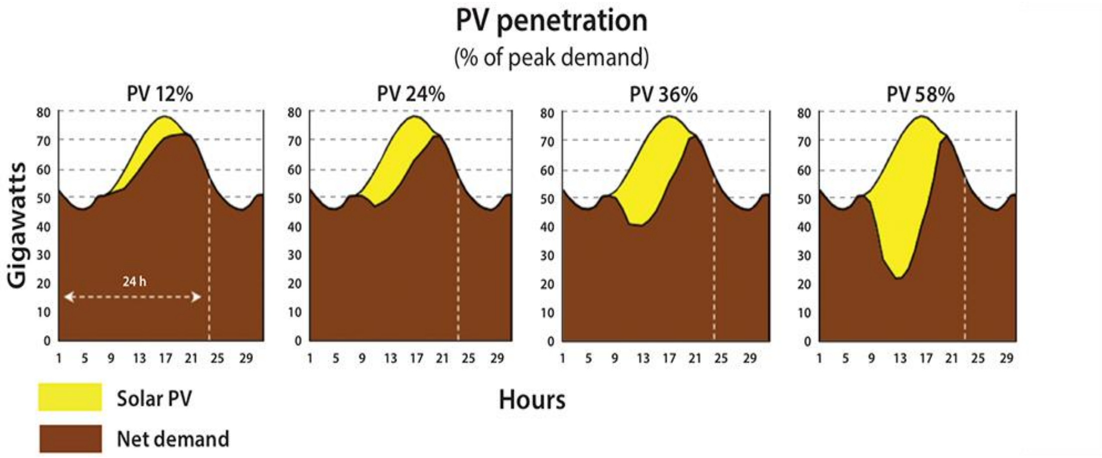


Figure 0-3: Changes in demand as PV penetration increases. (MIT, 2014)

In context of Nepal, the generation in power grid is subjugated by hydropower plants. This kind of situation can be handled with ease by Peaking Run of River type of plants. A practice being observed is integration of PV as well as pumped storage plant in the network together. Dubai Water and Electricity Authority is planning ot make use of energy from Gigawatt scale Mohammed Bin Rashid Al Maktoum Solar Park to provide a new hydropower plant with pumped storage capacity. (Bellini, 2019)

1.6.3 Short Circuit and Transient Analysis

The installation of a new PV plant will contribute to the short circuit power of the network. This has a beneficial effect by sustaining voltage drops in the network, but the additional short circuit current should be taken into account with respect to the rating of the equipment (circuit breakers) that are already installed or that will be upgraded after the connection of a PV system.

In the grid impact study, it is verified how the dynamic behavior of the system is impact by the new generation. The important parameter to note is the critical clearing time of neighboring machines. Therefore, three-phase short circuits on the lines close to the PV plant are simulated, cleared in base and backup times to show the impact of the PV park on the system response. The critical clearing time will be calculated for these faults and compared with the base and backup times to assess the adequacy of the protection scheme. Secondly, the simulation of the loss of the largest generation unit in the system is performed to show the impact of the PV Park on the system frequency response.

It is interesting to see that a variation of irradiation is a much slower phenomenon than faults that can happen in a power system. Due to meteorological reasons, the irradiance of on the PV panels may vary, resulting in a varying power output of the PV plant. Indeed, passing clouds create shadows on the individual PV panels. The worst case (i.e. the biggest variation in irradiance) is caused by a solar eclipse. In this case the entire PV plant is darkened at once. Variations in irradiance in normal weather conditions are much more limited due to the extent of the entire PV plant.

This study is focused on a 33kV network side. In an electrical power system, 33 kV networks are considered as distribution network. The resistance to reactance ratio of the conductors in 33 kV side is higher than that of transmission network. Hence, this analysis has not been considered in this study.

1.7 Interconnection Guideline/standards and Criteria (PV less than 10MVA)

Varieties of guidelines are being reported for PV integration to the grid in different countries. (Yuan Kang Wu, 2017) IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems, in large extent addresses the interconnection requirement for the DGs less than 10 MVA (IEEE, 2008). Also, there are some wind integration standards and interconnection guide applicable to PV systems. There are several other studies and organizations also researching and developing potential standards around the world for PV integration such including the US, Germany, Spain, etc. Based upon the study, the requirements for the utility scale PV integration requirements is summarized below.

Table 0-1: Interconnection Standards for Transmission- Connected Systems MVA (IEEE, 2008)

Voltage Tolerance	Ride through 3- phase fault POI for up to 150 ms
Frequency Tolerance	Based on interconnection requirements
Power Factor Capability	+/- 0.95 pf (or higher depending on study results)
Voltage Control	Power factor, reactive power or voltage control at the discretion of transmission operator

Frequency control for solar PV is possible but not to the same degree as frequency control with a governor on a classical generator. PV plants should not actively participate in primary frequency control during under-frequency. However, it is reasonable to recommend that a PV plant meet an off-nominal frequency operating condition similar to the appropriate operation standards (that is used by many utilities for wind farms and classical generating plants) –Table 2.2.

Table 0-2: Frequency range versus time MVA (IEEE, 2008)

Frequency Range (Hz)	**Time (seconds)**
> 61.7, <57	0
61.6 to 61.7	30
60.6 to <61.6	180
>59.4 to <60.6	Continuous Operation
>58.4 to 59.4	180
>57.8 to 58.4	30

RESEARCH METHODOLOGY

1.8 Description of Methodology

The outline of this work begins from the literature review, in which the solar power generation and the impact on the grid, when integrated to the existing grid is studied. At the review stage, issues of large-scale PV integration are investigated, the methodologies for system impact study relevant to assist PV integration is explored.

The location for the Point of Interconnection of solar PV plant is considered as Duhabi and Inaruwa bus of 33 kV network. The selected sites are provided with the built-in solar PV array in ETAP for load flow analysis. The built-in function of load flow analyses will use the Adaptive Newton-Rapson method to perform the load flow analysis of dry and wet season considering with and without PV-array.

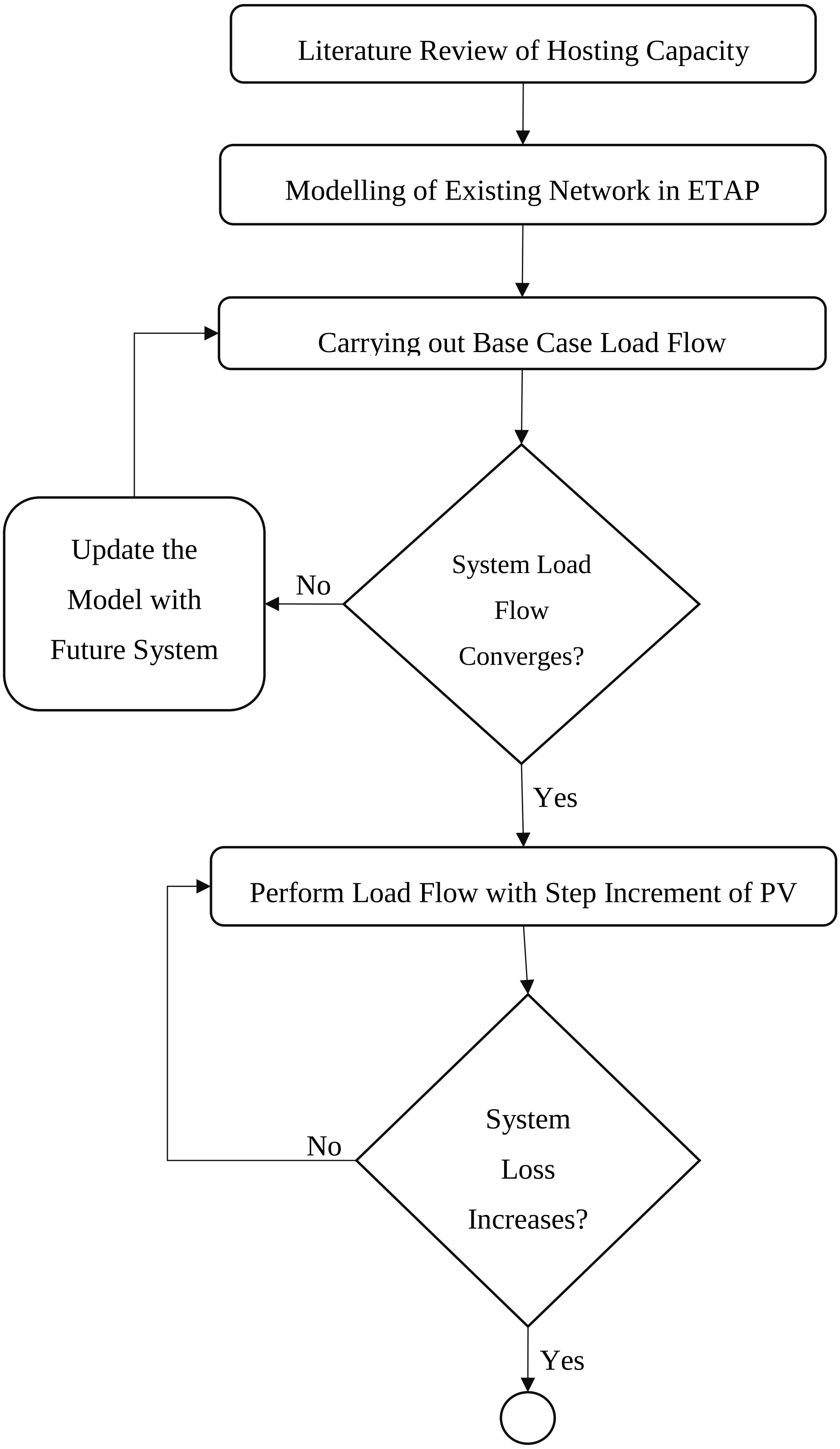
1.9 Modelling of Province 1 Network in ETAP

For the purpose of the study, from the Integrated Nepalese Power system, the 33 kV dominated network of Province 1 was chosen. The base case study for load flow analysis was performed until the performance indicators were violated. For further load flow additional generations coming in near future and upcoming transmission line were added. The 132-kV transmission line from Duhabi to Biratnagar was one of them, in absence of which the load flow failed to converge due to overloading of line connecting Duhabi bus to Tanki, Rani and Rangeli bus. This was due to overloading of lines in that region. The power system of the Province 1 region was then modelled in ETAP.

1.9.1 Modeling of Existing network of Province 1 in ETAP

The 132 and 33 kV network of Province 1 were modeled in ETAP initially without adding any upcoming lines in the future. All the generators and the loads for location east of Dhalkebar were modeled. Dhalkebar was considered as grid bus since, both the Upper Tamakoshi HEP line and Dhalkebar-Muzzaffarpur line converge at Dhalkebar substation. The load data was collected from NEA and modeled in the system. Similarly, the line parameters were also added from the collected data.

The load flow was attempted using Newton Rapson and Adaptive Newton Rhapson method. Due to high load of that region, especially of Rani and Rangeli substation, the load flow could not converge. The scenario shows that either the conductor needs to be upgraded or the higher voltages should be used in 33 kV sections in this line.



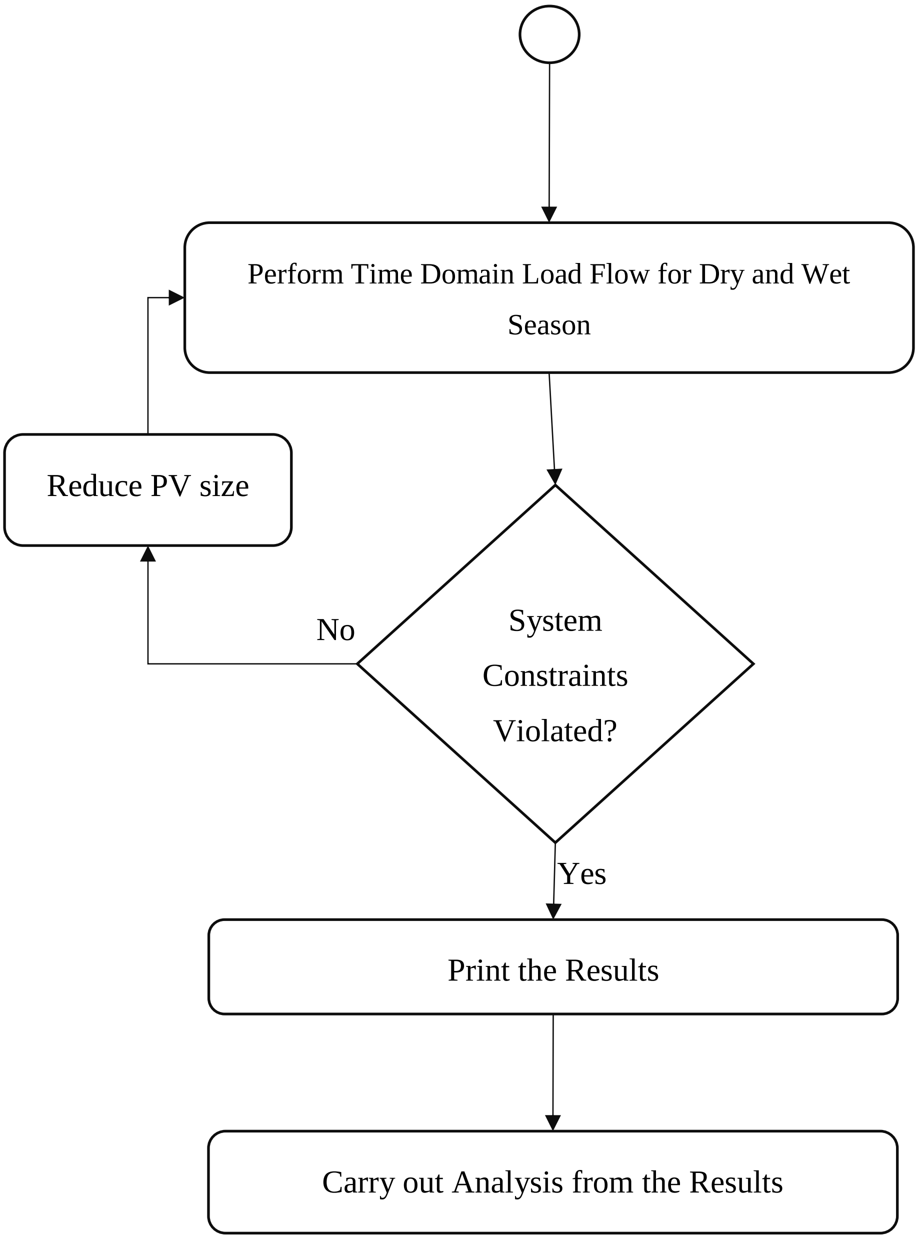


Figure 0-1: Block Diagram for Methodology of the work carried out in the Study

The on-field situation is also similar in the site with most of the lines and transformers running close to full operation. Field data shows that the voltage in the secondary side are usually in the range of 0.8 pu. Such system does not have a system reserve required for integration of renewable energy. Hence, the existing network is not be able to host any additional solar PV connection to the grid. In a scenario, it may be able to host distributed PV to the system with PV directly connected to the load bus of load substations. The intermittency, still may not be able to be covered due to lack of system reserve in present case. If a battery backed up PV system is supplied to the load substation, then the distributed PV can be hosted by this system. Since, 132 kV line is under construction parallel to the lines connecting Rani and Rangeli substation to

Duhabi substation, the study was then carried out considering the following lines and substation buses that are currently under construction in the region.

- 132 kV Double Circuit transmission line from Inaruwa to Biratnagar
- 132/33 kV substation in Biratnagar
- 33 kV transmission line from 132 kV substation Biratnagar to Rani Substation
- 33 kV transmission line from 132 kV substation Biratnagar to Rangeli Substation

The Single Line Diagram of the modelled system is shown in the Appendix A with the PV connected to Duhabi and Inaruwa buses highlighted. The system modelled in ETAP consists of the following.

- Number of Buses: 45 +2 (PV Buses)
- Number of Branches: 64 + (Lines Connecting PV Buses)
- Number of Generating Stations: 12
- Number of Loads: 25

The base case load flows were carried out for both Dry and Wet Seasons, with variation in generation considered for each season. Figure 0-2 shows the percentage loading of the rated load in this region throughout the day. Alike other places in Nepal, the load in this region is also residential dominated and has peak during 18:00 to 20:00 hours.

1.10 Base Case Load Flow Analysis

The ETAP software has multiple options for carrying out load flow analysis. In this case, the load flow was first attempted using Newton-Raphson method. Later on Adaptive Newton-Raphson method, available in the ETAP software was used for the load flow analysis.

The base case load flow analysis was carried out for Wet and Dry Season. Nepalese power system is primarily a hydro-dominated power system. The wet season sees abundance of generation with increase in water flow in the river. The dry season on the other hand, sees less generation with decrease in water flow in the rivers. The wet season is typically during June and July with increase in water flows in river due to monsoon rainfall. Whereas, the dry season is typically during February and March when the river water level is to minimum level.

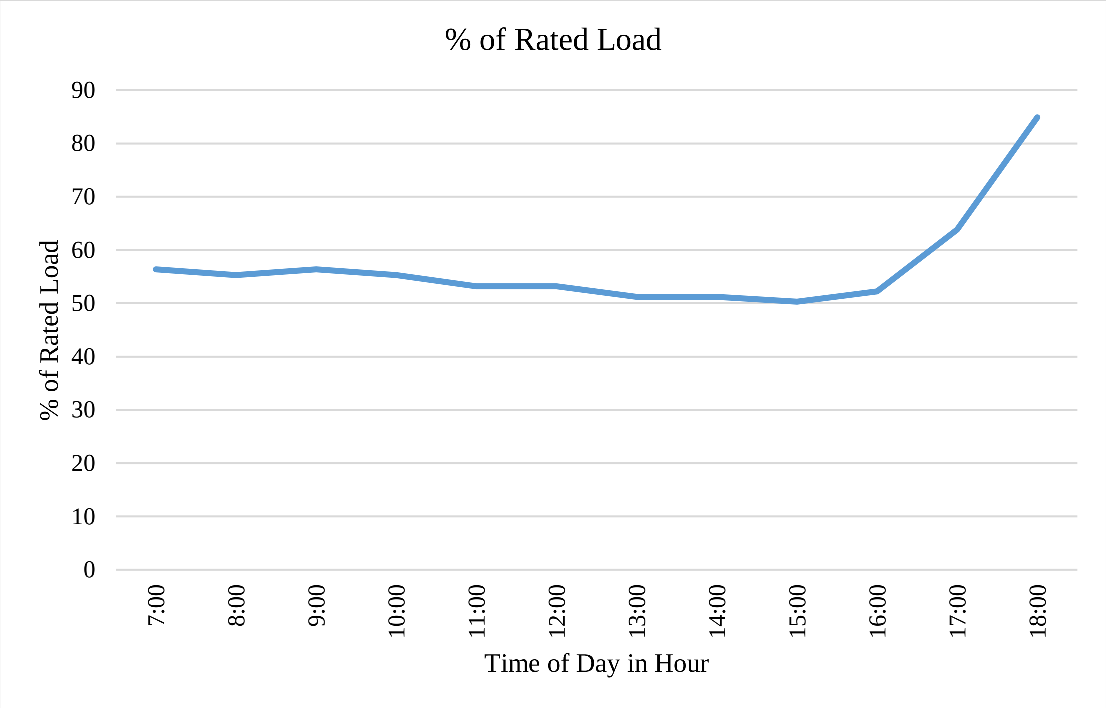


Figure 0-2: Percentage of loading in the model throughout the day (Nepal Electricity Authority, 2019)

The load dispatching mechanics in INPS is looked after by Load Dispatch Centre (LDC) of NEA. Currently Nepal has a single water reservoir Hydro Electric Project, namely Kulekhani HEP. Kulekhani HEP, combine Kulekhani I and Kulekhani II add up to 60 MW. NEA uses this hydroelectric project as system reserve. In practice, Kulekhani HEP is sometimes used to supply the peak demand during peak hours.

The results of both the wet and dry season load flows are presented in 0. The solar PV was connected to the existing system in two locations namely Duhabi and Inaruwa bus. The load flow was then carried out with step increment of Solar PV Capacity. The detail methodology for the Load Flow with Solar PV is discussed in subsequent sub-section.

1.11 Load Flow with Step Incremental of PV Farm.

Load flow analysis is performed with step increase in PV generation in the designated sites during 6:00 to 18:00 without altering the loading. For each step increase in PV size, loss, voltage profile and expected reserve and power swing (at slack bus) is observed. The constraint (Reserve and the Ramping of the Slack bus) is related to the system reserve and ramping rate. With same loading condition, injecting the intermittent PV cause counter swing of slack bus to balance the power.

While designing the PV, the PV power generation in a typical cloudy day of March is presented in the Figure 0-2. It is modeled in such that, there is fluctuation of generated power from 0.96 pu to 0.48 pu during 13:00-14:00-15:00 hours. This is done so as to study the effect of drop in PV output during peak generation period of Solar PV plant. The effect of this drop in PV generation will be to release equal power from the swing bus considering the same loading condition. Considering this constraint time domain load flow for both dry and wet season was performed.

Considering the constraint, we go on increasing the PV size in step of 4x1 MWp and evaluated the operational variables. The size of PV added to the system was reduced once the system losses start to increase after addition of the PV in the system.

After certain number of additions, The PV of 1 MW each was connected to the system in both the locations. In this manner, step increase of PV was carried out in both locations. After determination of the size of the PV to be injected in the system, financial analysis was carried out for the PV size.

1.12 Solar Power Generation

To study the effect of increasing PV penetration, the size of the PV plants is increased by 1 MW step. In simulation, the built-in dynamic PV model of the working ETAP version is used.

To determine the hourly solar power generation throughout the year, solar insolation data estimated by the NASA are adopted for the desired sites as horizontal solar insolation at clear sky. Due to lack of historic solar data at the sites, a general statistical weather condition is assumed based on the data from department of metrology and airports. The summary is presented in Table 0-1. Based on the data, statistical tool is used to get the expected solar insolation at a particular hour of day. The insolation value is then converted to the MW, considering the standard solar PV farm. It is expected that the power generation is highly intermittent depend upon the local weather condition. For the sites situated in large distant, the climatic condition is an independent statistical event. Hence the total effect is smoothened considerably.

Table 0-1: The clear sky situation in Nepal

% Solar Radiation Available at The Surface Due to Cloudy Condition	Days/Year
0	40
0.25	25
0.5	25
0.75	25
1	250

In order to achieve the objectives of the study, various literatures were assessed to identify the solar insolation in Duhabi region. Ground data was preferred to data from satellite, if available. A study performed by members from Institute of Engineering using CMP6 pyranometer seems suitable for our case. One of the locations for data collection of solar radiation potential was Biratnagar which is close to Duhabi substation.

1.12.1 Solar Insolation study in selected site region

The details of the location are as follows:

Site:	Biratnagar (26.45°N, 87.27°E)
Elevation from sea level:	72 m
Pyranometer used:	CMP6
Maximum Total Solar radiation measured:	704.51 W/m^2
Annual average solar energy in the site:	4.95 $kWh/m^2/day$

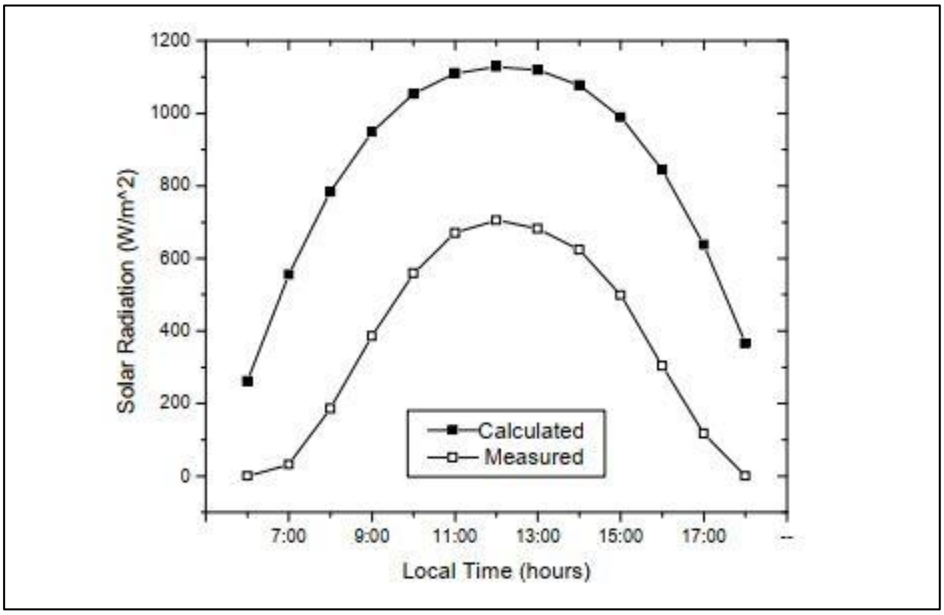


Figure 0-3: Diurnal Variation of Total Solar Radiation at Biratnagar (Khem N Poudyal, 2011)

The diurnal variation was obtained higher at mid time of the day. The daily variation of the solar PV plant was also measured in that publication.

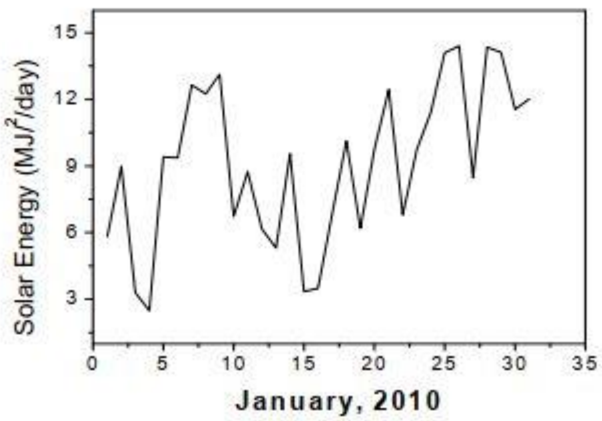


Figure 0-4: Daily Variation of Solar Energy at the site in January 2010 (Khem N Poudyal, 2011)

The input to the renewable energy source is sporadic and so is the output of the Solar PV. The land required for the maximum size of PV; the grid can handle shall be deduced from the solar irradiation data from the mentioned study.

This study was taken as reference for the modeling of PV in ETAP. The Solar irradiation input to the PV model was considered as per the report. However, in order to model the intermittency of the PV system, the PV input provided to the system has been modelled as per Figure 0-2.

1.13 Solar Site Selection

The location of solar farm significantly affects the economic and technical aspect of the overall power production and transmission. Therefore, while selecting the site for solar farm, special focus should be given on the availability as well as on the economic aspects of the space or land required. Considering all this factor, the site will be based on the data of the solar installation site provided by the Nepal Electricity Authority. The substation is chosen such that it is near to the solar farm, the distance of transmission line required for the transfer of power form the Solar Farm is less. Selection of specific location for the solar farm is beyond the scope of the study. The points of interconnection of PV plant is considered as Duhabi and Inaruwa Substation.

1.14 ETAP

Electrical Transient & Analysis Program (ETAP), software is used for the simulation of test system in this case. ETAP is the most comprehensive analysis platform for the design, simulation, operation, control, optimization, and automation of generation, transmission, distribution, and industrial power system. Inside the ETAP simulator, there exist different simulators like Load Flow Analysis, Transient Stability Analysis, Optimal Power Flow, Optimal Capacitor Placement, and Reliability Analysis & Short Circuit Analysis.

Among the above, the Load Flow Analysis will be used for primary purpose constructed Test System which will be run to find the bus Voltage Profile, Line Losses, Reactive and Active Power Flow through the lines.

1.14.1 Steady State Simulation

ETAP provides four load flow calculation methods: Adaptive Newton-Raphson, Newton-Raphson, Fast-Decoupled, and Accelerated Gauss-Seidel. They possess different convergent characteristics, and sometimes one is more favorable in terms of achieving the best performance. For this study, Newton Raphson was used initially, and later on Adaptive Newton Raphson method, an improvised version of Newton Raphson method by ETAP was used to facilitate convergence of the load flow.

ETAP makes use of improved Newton-Raphson Method that introduces a set of smaller steps for iterations where a potential divergence condition is encountered. The smaller increments may help to reach a load flow solution for some systems where the regular Newton-Raphson method might fail to reach one. The Newton-Raphson method is based on the Taylor series approximation. For simplicity and incremental steps, a linear interpolation/extrapolation of the additional time step increments is performed to improve the solution. The incremental steps are controlled by adjusting the value of I_k to find a possible solution for the following solution step. It is also considered to possibly improve convergence for systems with very small impedance values, but that is not guaranteed. One contrary effect of using this method is reduced calculation speed because of the incremental steps in the solution. Load flow analysis of INPS with and without PV plants was performed to assess the loading and generation scenario, availability of reserve, line flow, and voltage profile and loss evaluation. Load flow was evaluated with series of load and PV generation profile to take care of worst scenario. To determine the hosting capacity of INPS, incremental capacity of PV plants was introduced, until any of indices or constraints (such as voltage profile or line loading or availability of reserve) are violated.

RESULTS AND DISCUSSION

1.15 Load Flow of Dry Season

During the dry season, for a typical dry and hot day, Load Dispatch Centre (LDC) of NEA, manages to run its generator meeting the maximum load with minimum reserve as the water level in Kulekhani HEP is in lower side.

Thus, the important operation scenario is not to deteriorate existing operating and reserve condition, or PV generation should not demand additional reserve. In case of our study region, there exists a Duhabi Multifuel plant with a capacity of 39 MW. This can be considered as system reserve for this region. Thus, the system reserve in that area would be around 39 MW Multifuel with the Multifuel in operation. However, this study has been carried out considering the Duhabi Multifuel plant is out of service. Considering the constraint, we go on increasing the PV size in step of 4x1 MW and evaluated the operational variables.

The PVs were connected to 33_Inaruwa and 33_Duhabi bus. The PV were injected into the system were incremented in step size. Initially, larger size (4x1MW) was considered and the system loss was monitored. After an increase in system loss was observed, the incremental size was decreased and the size of PV suitable for injection in the system was determined.

Figure 0-1 depicts the curves for system losses with and without PV Injection at 15:00 hours during a dry season, when the generation in the system is minimum. The all-day round loading of the system shown in Figure 0-2 has been developed with reference to the system load curve presented in Annual Report 2018 published by NEA (Nepal Electricity Authority, 2018). The load curve is almost flat for the time of 10:00 to 17:00 when the PV generation is at peak. Thus, the loading for 15:00 during dry season was chosen for the incremental PV injection load flow analysis. Hence, this simulates the system with low generation and low loading.

It can be observed from Figure 0-1 that, the system losses decrease until PV injection is increased up to 30 MWp. System Losses start to increase with increase in PV Injection increasing from 30MWp. The system losses decrease as long as the PV injected are supplying the local loads. After 30MWp the PV starts to supply to loads far from the PV connected bus, as a result increasing the line loading and hence contributing to the system loss.

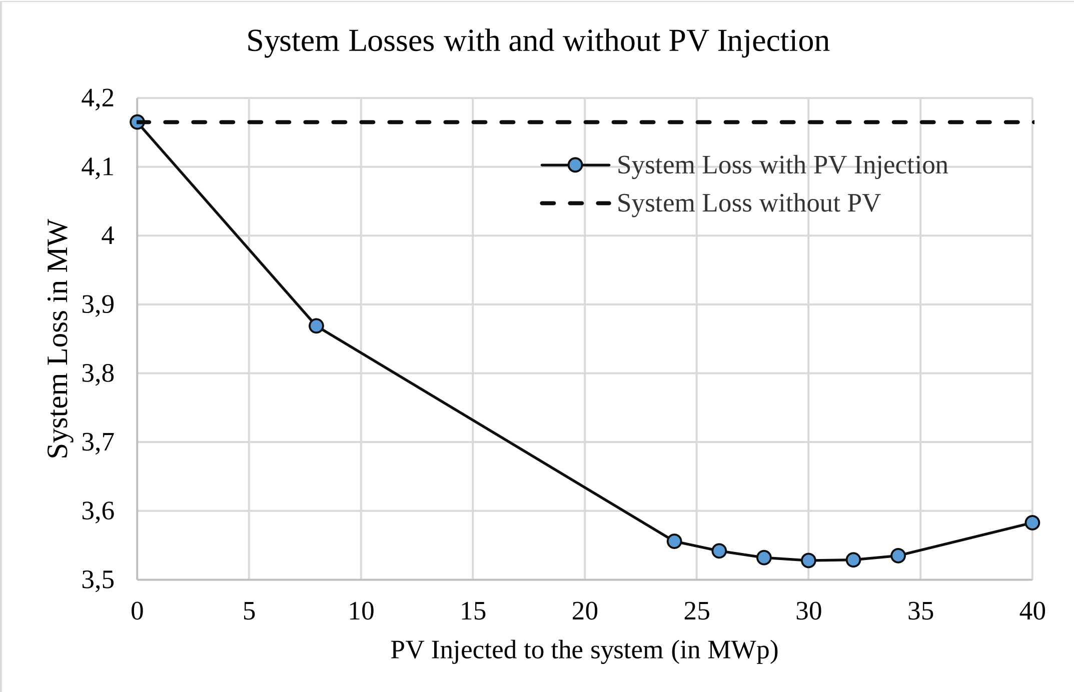


Figure 0-1: System Losses in Dry Season, with and without PV Injection at 15:00 hour

Thus, the maximum PV size that can be injected to the Province 1 power system is considered to be 30 MWp. This is well within the limit of the system reserve available at the location.

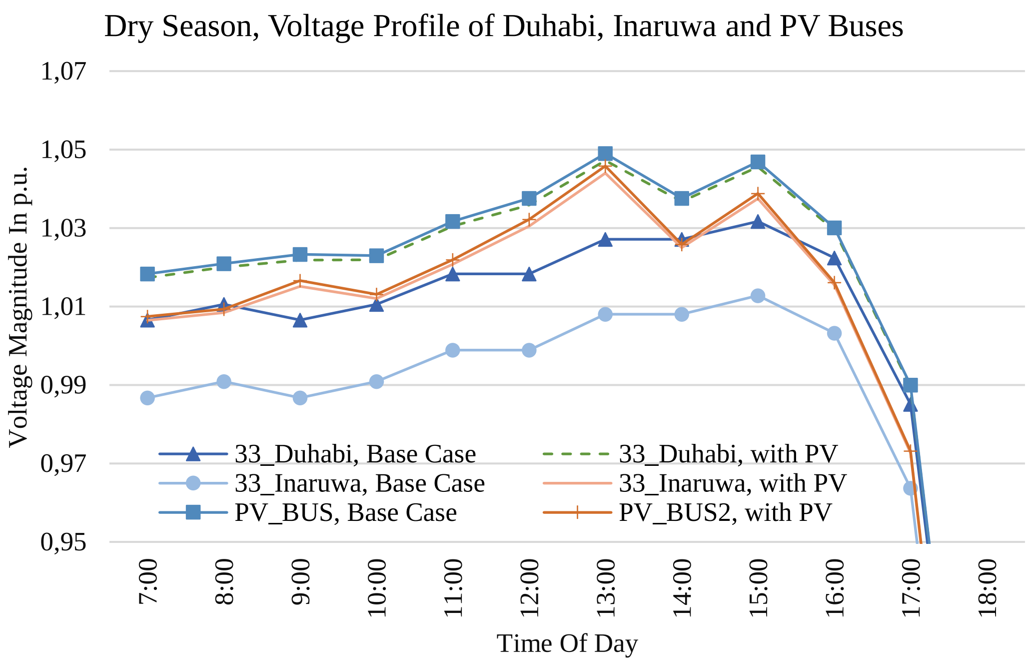


Figure 0-2: Voltage Profile of Duhabi, Inaruwa and PV Buses, for base case and with PV Injection in Dry Season

Next step was to verify the ability of the system to handle 30MWp solar input. Time domain load flow was carried out with PV injection to the system in both dry and wet season.

Figure 0-2 shows the voltage profile of 33_Inaruwa, 33_Duhabi and PV Buses during a typical day of a dry season. The voltage magnitudes during the evening tend to fall towards 0.95. The existing situation of the system shows that, the system peak lies during 18:00 hour and the voltage magnitude is much lower during the peak hour. Nepal Electricity Authority is carrying out different projects to upgrade the power delivery capacity to these regions.

Figure 0-3 shows the voltage magnitude of the weak buses in the system obtained from the Time domain load flow from hours 6:00 to 17:00. During the later hours, the voltage drop is due to the increase in system load. The PV generation lowers during the later hours and this drop of voltage has not been addressed in the study. It can be inferred from the figure that; the injection of Solar PV has improved the voltage magnitudes in the weak buses of the system.

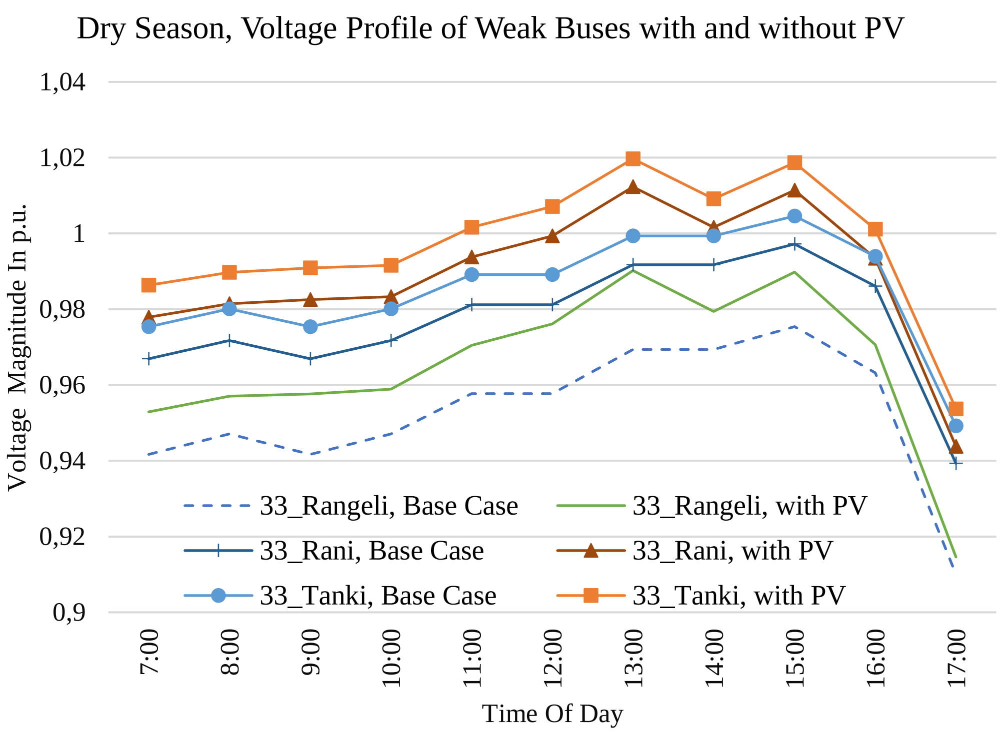


Figure 0-3: Voltage Profile of Weak Buses, with and without PV Injection in Dry Season

The weak buses in the system are identified by observing the voltages of all the 45 buses in the system in time domain load flow. The list of voltage magnitude in per unit of all the buses in the system is attached to the appendix.

The MW input from PV plant to the system was observed in Time Domain Load Flow. The plot of MW input from PV and from Swing bus, during base case and after PV injection is presented in Figure 0-4. One can infer from the diagram that the MW inflow from the swing bus to the decreases with increase in input in MW from PV plant to the network.

Figure 4-5 shows the line loading during dry season for base case as well as after injection of 30MWp PV in the system. It is clear that no line has been loaded more during the time of consideration. In practical the lines are overloaded during peak hours in the evening, i.e. 6 pm onwards. Nepal Electricity Authority is considering the upgradation of conductors to resolve these issues. The overloading of lines during peak hours has not been considered in this study.

In addition to the dry season time domain load flow, similar load flow has also been carried out for the wet season.

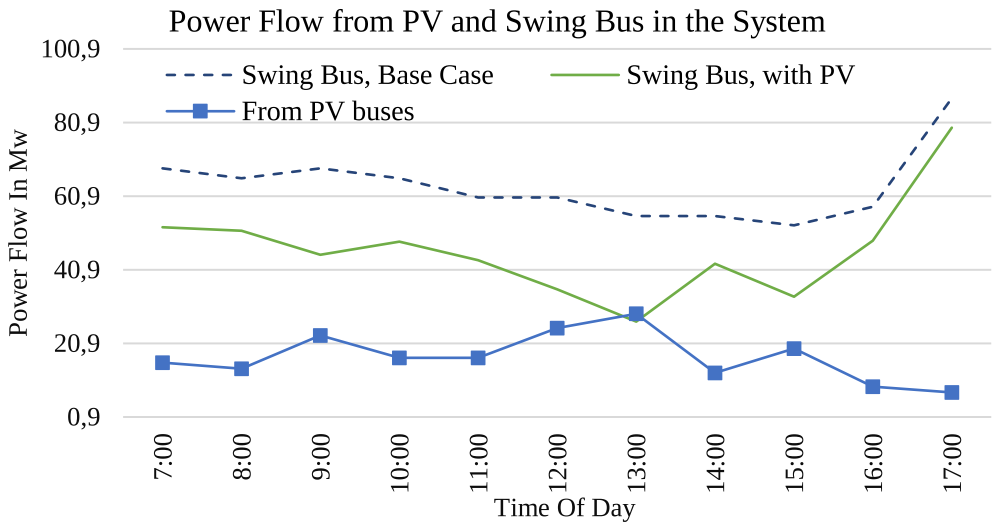


Figure 0-4: Power Flow in MW from PV and Swing Bus in the system during Dry Season

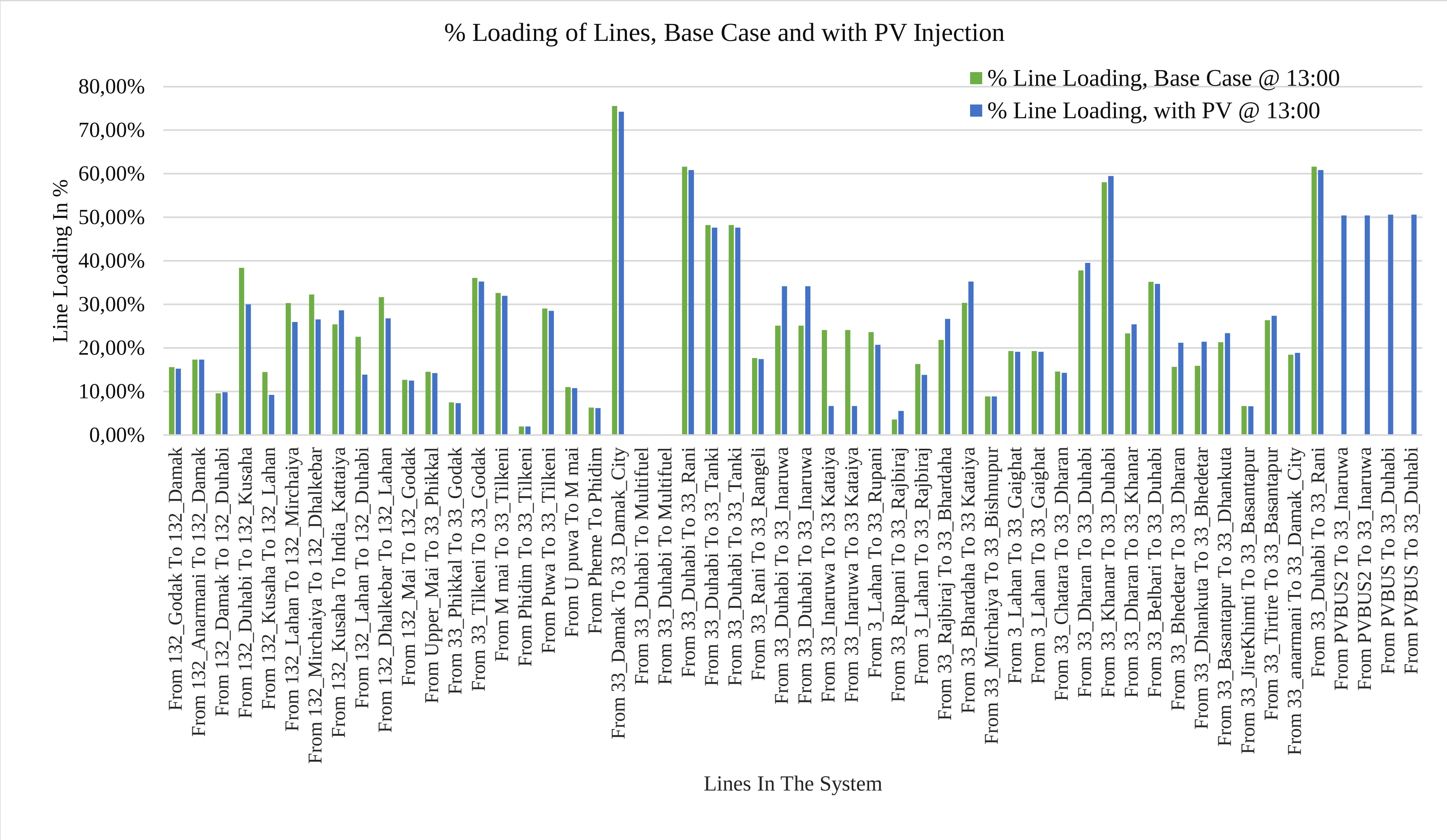


Figure 0-5: Percentage Line Loading of Transmission Lines in Province 1, Nepal during Dry Season

1.16 Load Flow of Wet Season

During wet season most of the generating units of both Independent Power Producers (IPP) and NEA runs at rated capacity. Usually, the Kulekhani Storage HEP is kept at standby at most of the time, i.e. at 0 MW. Similarly, the Multifuel plant at Duhabi is also generally at 0 MW. During the power swing in the PV, enough reserve margin is available in the system. The rivers have increased flow and hence, the power generated in the HEPs in this region is also increased to 87 MW from 76 MW during the dry season. As a result, the power input from the Swing bus to the system decreases.

Time domain load flow has been carried out for a typical day of the wet season (a day in July) and the swing bus input to the system, PV input to the system, voltage profiles of the system buses and line loading has been observed.

Figure 0-6 presents the MW inflow from PV to the system and the Power Input from Swing bus to the system during base case and after PV Injection. Alike the time domain load flow for the dry season, the swing bus input during wet season also decreases after 30MWp PV injection to the system.

During the wet season, it is essential to consider in this time that, the voltage criteria are not violated by the injected PV system.

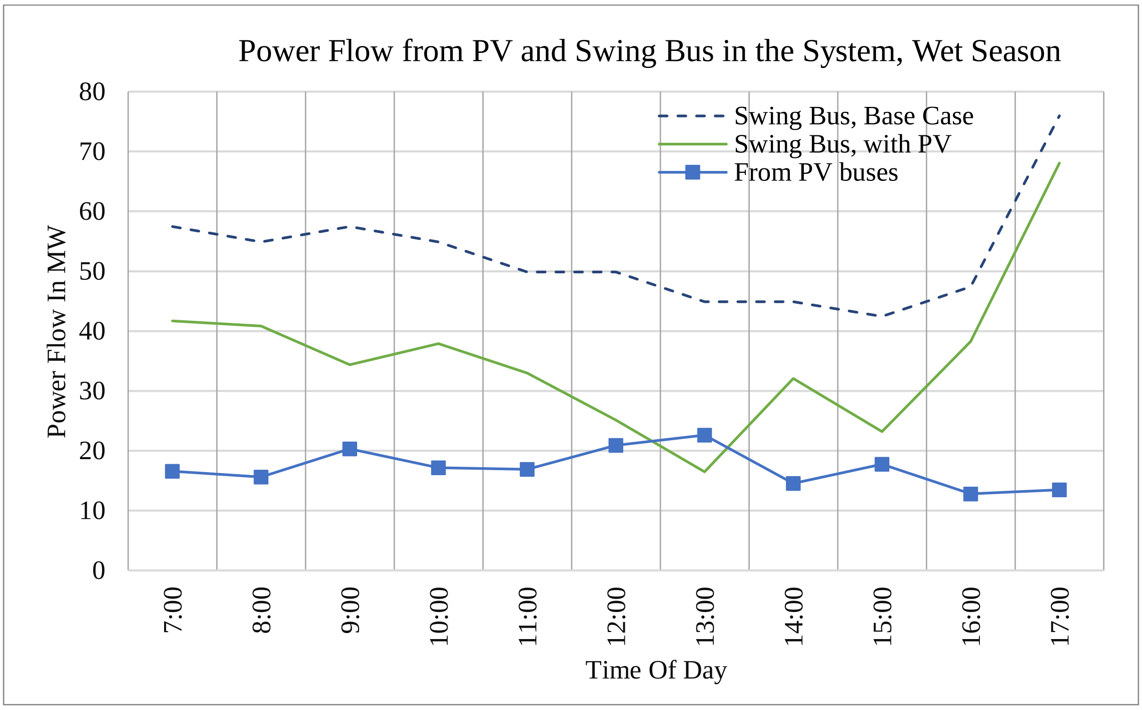


Figure 0-6: Power Flow in MW from PV and Swing Bus in the system during Wet Season

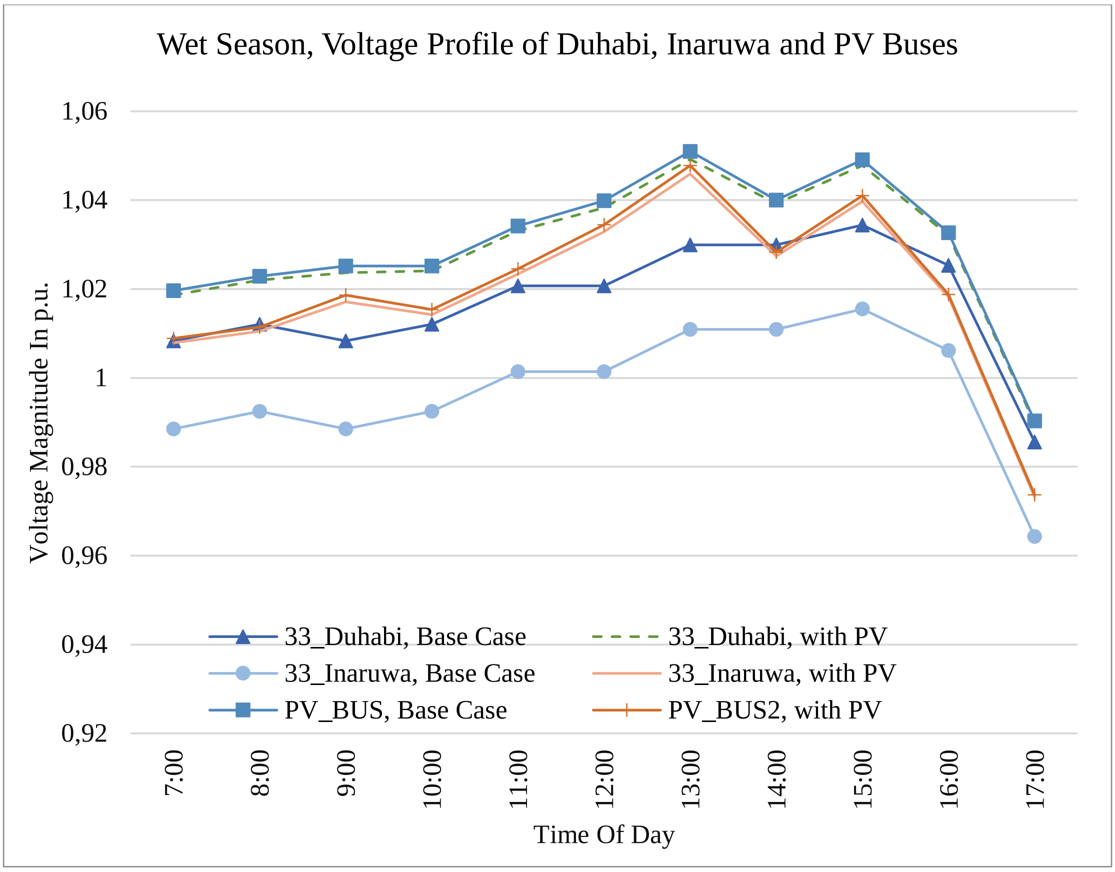


Figure 0-7: Voltage Profile of Duhabi, Inaruwa and PV Buses, for base case and with PV Injection in Wet Season

Figure 0-7 shows the voltage profile of PV buses and Duhabi and Inaruwa bus, to which the PVs are connected. It can be observed that, the buses do not violate the Voltage criteria. It was also observed that, the line flows before and after the PV connection do not violate the line limit of the system. The voltage profile of the weak buses identified during the time domain load flow for dry season are also presented here.

Figure 0-8 shows the voltage profile of the weak buses during the Wet Season after and before injection of PV to the system. It can be observed that the voltage profile of the weak buses in the system improve after addition of PV to the system in the specified location.

Since there is excess generation during wet season, there lie chances for overloading of lines in the network. The plot of percentage loading of lines in base case and with PV injection during wet season is shown in Figure 0-9. The figure states that no lines were overloaded during the hours considered for the study.

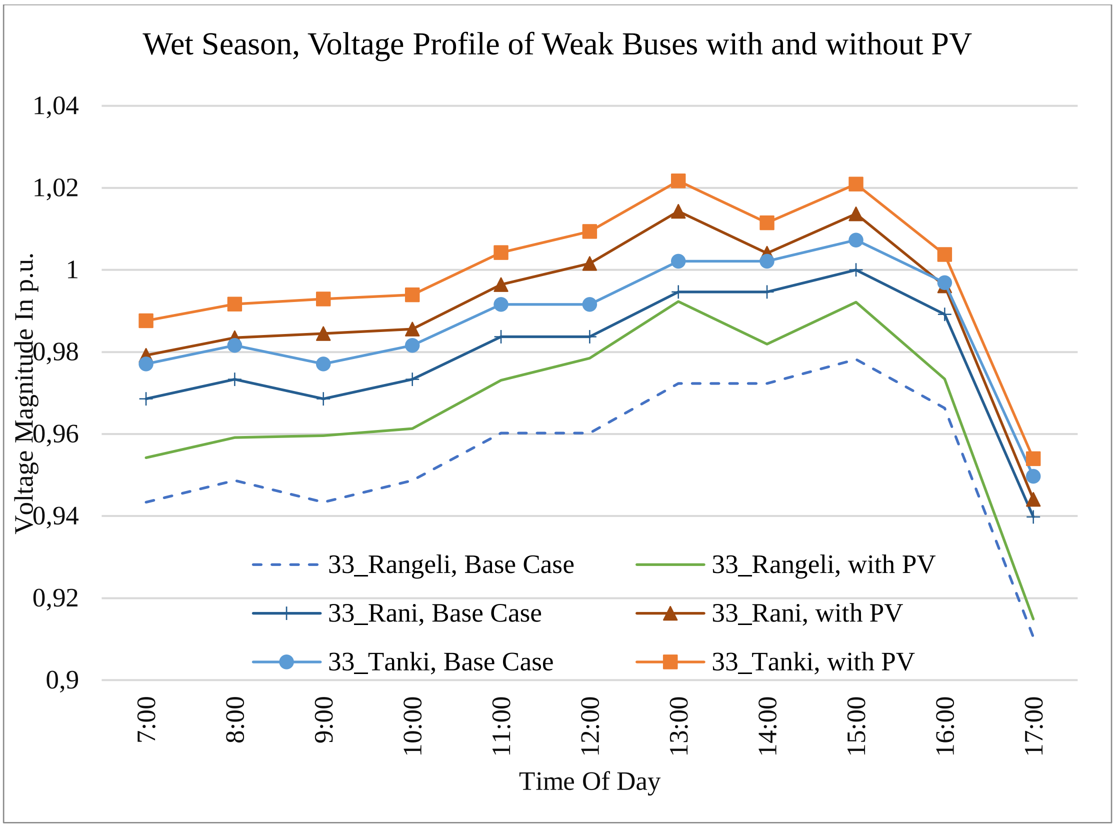


Figure 0-8: Voltage Profile of Weak Buses, with and without PV Injection in Wet Season

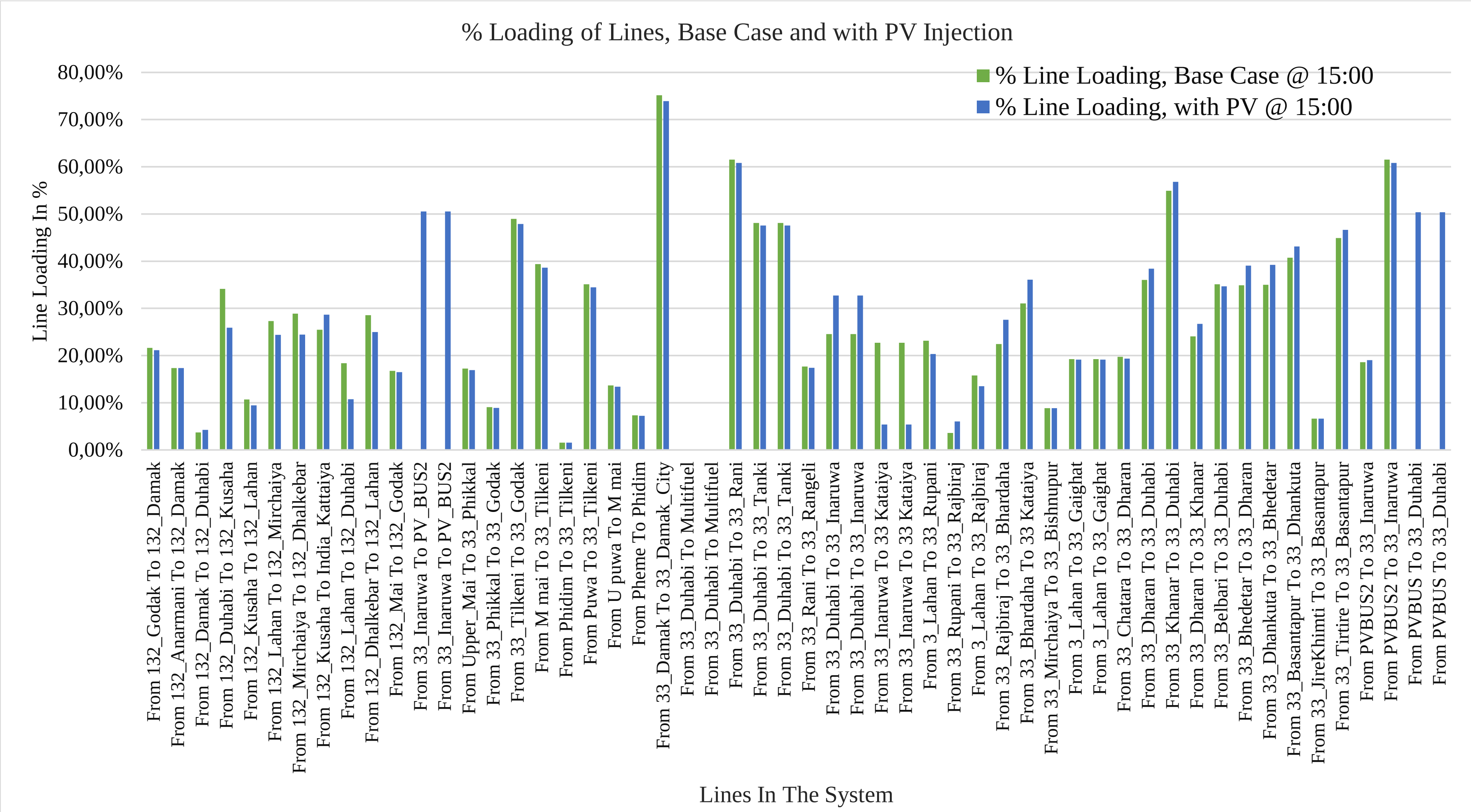


Figure 0-9: Percentage Line Loading of Transmission Lines in Province 1, Nepal during Wet Season

1.17 Financial Analysis of the 30MWp Solar PV Plant

In order to carry out the financial analysis following assumptions were taken for the plant. The assumptions are based on existing practice while developing the Solar PV plant in Nepal. The values for interest rate, annual costs, taxation system, energy generation were obtained from existing or under construction Solar PV plants. (Api Power Company Limited, 2019)

Number of Years for Construction:	2 years
Bank Interest Rate:	3% per annum
Social Discount Rate:	3% per annum
Annual Cost of Operation and Maintenance:	0.5% of Total Cost
Annual Cost of Insurance:	0.25% of Total Cost
Periodic Cost of Inverter Replacement:	2.5% of Total Cost, Every 10 years
Cost of Construction of Plant:	80MNPR per MWp; i.e.2400MNPR for 30MWp
Number of Years of Operation:	25 years
Domestic Inflation Rate:	6% per annum
Energy Sale Rate:	NPR 7.30/kWh
Annual Energy Generation	49.7 GWh
Taxation:	Tax Holiday until 10 years, 12.5% tax from 10th to 15th year and 25% tax there onwards on profit.

Table 0.1: Economic Parameters for Solar PV Plant

Present Value of Cash Flow (NPV)	MNPR 1,564.05
Internal Rate of Return	8.46%
Benefit to Cost Ratio	1.42

The detail sheet for financial analysis is appended to the Annex. It can be seen that, the benefit to cost ration is higher than 1, IRR more than 8% and NPV, a positive value. Reduction of costs from use of local resources, like manpower, and use of lands underneath the Solar PV plants for other purposes, like vegetable farming or even fishing could increase the generation of the plant. The subsidy from the government to some extent can also help in increasing. In order to simulate these situations, sensitivity analysis has been carried out for normalized value from 85% of base case to 115% for, capital investment, power purchase rate, energy generation and debt to equity ratio.

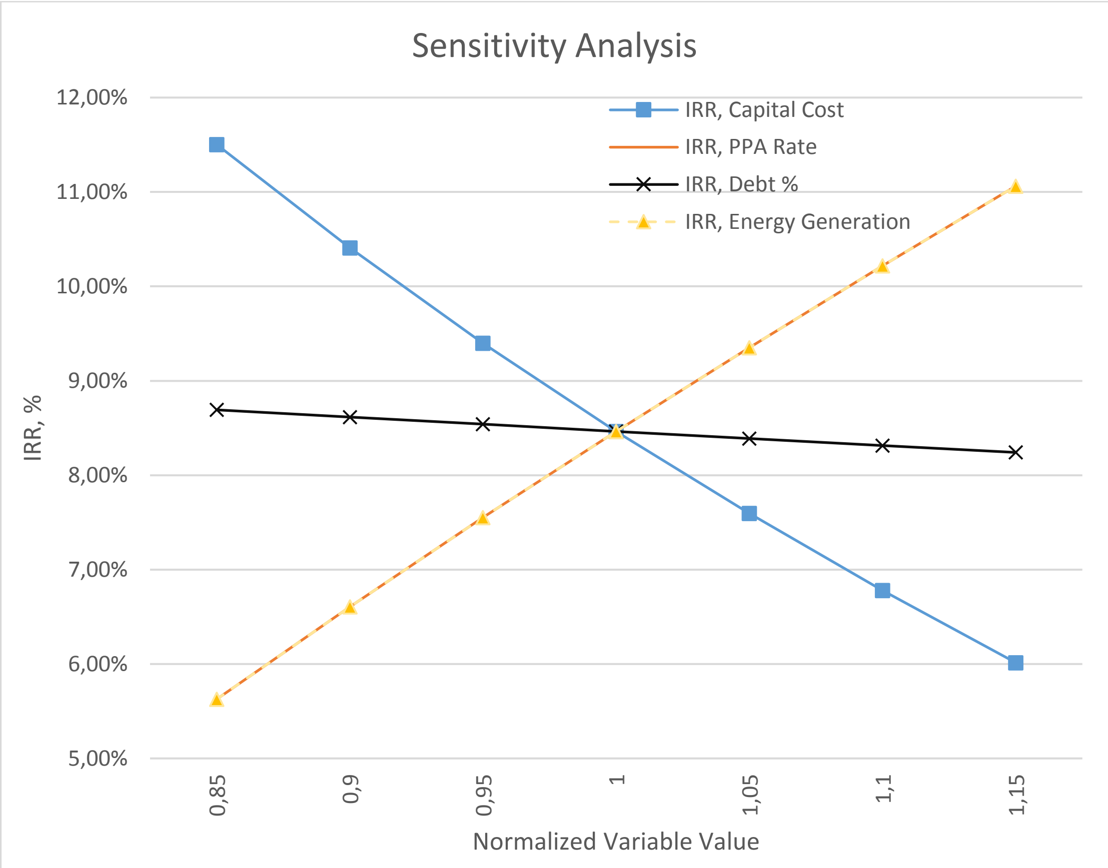


Figure 0-10: Sensitivity Analysis for change in Investment cost, Power Purchase Rate, Energy Generation and Debt to Equity Ratio for Solar PV Plant

The effect on change in major variables upon the IRR of the project is observed. Figure 0-10 shows the results obtained from the sensitivity analysis. The graph for variation in power purchase rate and energy generation overlaps as the Revenue generated is product of these two values. From the analysis it is seen that Capital Cost and Energy Generation are sensitive variables and debt to equity ratio is least sensitive one. The analysis was carried out by varying the value of input variable in the range of ±15%. The maximum value of IRR was found to be 11.50%, when the value of capital cost was set 0.85 times of actual investment. The minimum value of IRR was found to be 5.63% when the energy generation was 0.85 times of the actual energy generation. It is thus recommended to the developers to control the investment and try more to minimize the investment for maximum overall benefit as reflected by IRR.

CONCLUSION AND RECOMMENDATIONS

1.18 Conclusion

From this research following can be concluded:

1. The power system of Province 1, Nepal was modeled in ETAP Software. PV was injected into system in two buses, viz. Duhabi and Inaruwa. System losses decreased till the size of PV injected was 30MWp and increased thereafter. The maximum value of PV that could be injected to power system network of Province 1 was obtained to be 30MWp.
2. Time domain load flow was carried out to study the impact on Voltage Profile, Line loss and Line Loading after injection of PV. Voltage Profiles of weak buses increased after injection of PV into the system. The system loss decreased after PV injection. During the Wet Season, the line loading was not violated. It was observed that, injection of 30MWp into the system did not violate the system constraints. The active power flow from PV bus into the system were observed in both Dry and Wet Season. They did not violate the line constraints.
3. Financial Analysis of the PV plant to be connected to the system was carried out. The internal rate of return was obtained as 8.46% for a power purchase rate of NPR 7.30 per kWh. The sensitivity analysis shows that, the IRR shall increase with decrease in capital cost and reduces with reduction in energy generation.

1.19 Recommendations

The following recommendations are provided from the study:

1. It is recommended to carry out the construction work of the PV plant with maximum use of local resources so as to reduce the cost and make use of land under the PV farm to help increase the generation of the plant.
2. It is recommended to carry out the analysis with addition of all under construction lines and most likely generations in the region coming up in next five years.
3. This study focuses on integrating PV in the Medium Voltage Level. Integrating PV with battery backup facilities at Low Voltage Level could increase the PV injecting capacity in the system. Use of Artificial Intelligence in generation resource scheduling could help increasing the capacity of PV injection. It is thus recommended to carry out further study by injecting PV in distribution level with use of smart inverters and simulate the Smart Grid system with distributed generation.

REFERENCES

Afazalan, M. & Taghikhani, M., 2012. *DG Placement and sizing in radial distribution network using PSO&HBMO alogorithm,* s.l.: Energy and Power.

Al-Alamata, F. & Faza, A., 2017. Distributed PV Hosting Capacity Estimation and Improvement: 33kV Distribution System Case Study. *Jordan Journal of Electrical Engineering,* p. 4.

Api Power Company Limited, 2019. *Solar Projects of Api Power Company Limited.* [Online] Available at: http://apipower.com.np/home/pagesDisp/solar-projects [Accessed 11 November 2019].

Bellini, E., 2019. *PV Magazine.* [Online] Available at: https://www.pv-magazine.com/2019/08/19/dewa-to-use-solar-to-power-new-pumped-storage-project/ [Accessed 11 October 2019].

Bucher, C. & AG, B. &. H., 2013. INCREASING THE PV HOSTING CAPACITY OF DISTRIBUTION POWER GRIDS –. *Research Gate,* p. 2.

Chyou-Jong Lin, Y.-F. C., 2011. Impacts on the transmission Grid for Integrations of Renewable Energy in Taiwan. *Power and Energy Society General Meeting*, July, pp. 24-29.

Electric Power Research Institute, 2012. *Impact of High-Penetration PV on Distribution System Performance,* California: Electric Power Research Institute.

Electric Power Research Institute, 2015. *Distribution Feeder Hosting Capacity: What Matters When Planning for DER?,* s.l.: Electric Power Research Institute.

European photovoltaic Association, 2012. *Global Market Outlook,* s.l.: European photovoltaic Association.

Hardcastle, A. & Stacey, 2009. *Renewable Energy Industry Trends and workforce Developmentin Washington State*, Washington: s.n.

IEEE, 2008. *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.* s.l.:IEEE.

International Electrotechnical Commission., 2012. *Grid integration of large-capacity Renewable Energy sources and use of large capacity Electrical Energy Storage,* s.l.: International Electrotechnical Commission..

International Energy Agency, 2019. *Snapshot of Global Photovoltaic Markets, 2018,* s.l.: International Energy Agency.

Khem N Poudyal, B. K. B. B. S. B. K., 2011. Solar Radiation Potential at Four Sites of Nepal. *Journal of the Institute of Engineering,* 8(3), pp. 189-197.

Matthew J. Reno, K. C. J. S. R. J. B., 2017. Novel Methods to Determine Feeder Locational PV Hosting Capacity and PV Impact Signatures.. *No. SAND2017-4954. Sandia National Lab.(SNL-NM).*

MIT, 2014. The Future of Solar Enegry. *An Interdiscliplinary MIT Study.*

Nepal Electricity Authority, 2012. *A Report of Distribution and consumer services,* Kathmandu: Nepal Electricity Authority.

Nepal Electricity Authority, 2018. *Nepal Electricity Authority Annual Report,* Kathmandu: Nepal Electricity Authority.

Nepal Electricity Authority, 2019. *A year Book 2018/19 Distribution and Consumer Service Directorate, Nepal Electricity Authority,* Kathmandu, Nepal: Nepal Electricity Authority.

Nepal Electricity Authority, 2019. *Annual Report 2019,* Kathmandu: Nepal Electricity Authority.

Okerfor, F., Idoniboyeobu, D. & Bala, T., 2017. *Analysis of 33/11 KV RSU Injection Substation for Improved Performance with Distributed Generations (DG) Units,* s.l.: American Journal of Engineering.

Rao, G. & Obulesh, Y., 2013. *voltage profile improvements of distribution system using distributed generation,* s.l.: Internation Journal of Electrical and Computer Engineering.

S. KoohiKamali, S. Y. J. S. a. M. N. B. E., 2010. Impacts of grid-connected pv system on the steady-state operation of a malaysian grid. *IEEE International Conference on Power and Energy.*

S. KoohiKamali, S. Y. J. S. a. M. N. B. E., KoohiKamali, S., Yusof, J. & M.N, B. E., 2010. Impact of Grid connected PV system on steady state stability of a microgrid.. *IEEE.*

Shah, R., 2012. Influence of Large-scale PV on Voltage Stability of Sub-transmission. *Lomi International Journal on Electrical Engineering and Informatics,* Volume 4.

Shrestha, H., 2017. Facts and figures about hydropower development in Nepal. *Hydro Nepal: Journal of Water, Energy and Environment,* Volume 20, pp. 1-5.

Suyono, H. & Hasanah, R., 2016. *Analysis of power loss due to distributed generation increase in distribution system,* s.l.: Jurnal Teknologi, science and engineering..

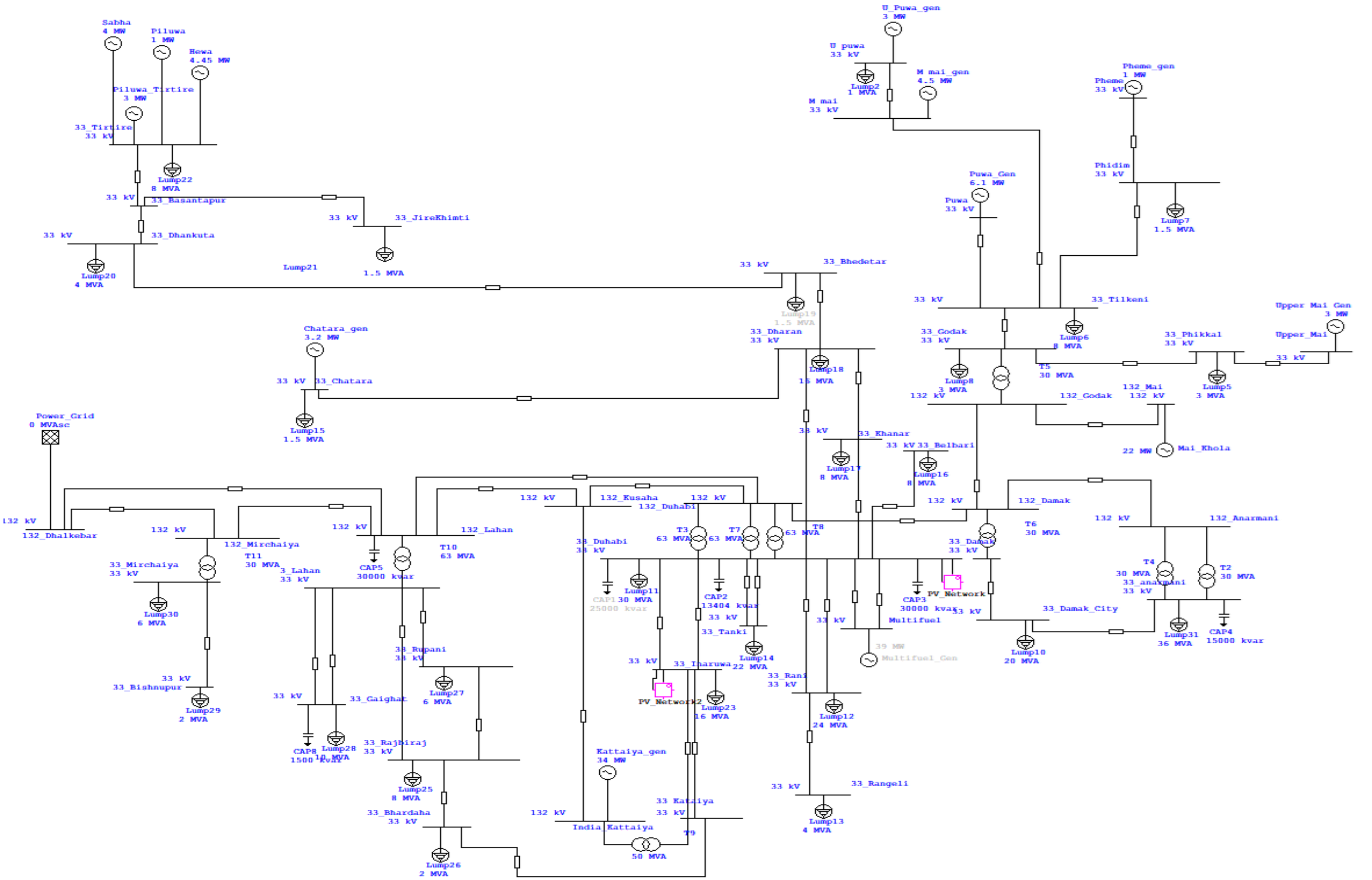
The Himalayan Times, 2018. *The Himalayan Times.* [Online] Available at: https://thehimalayantimes.com/business/nerc-regulations-pave-way-for-formation-of-energy-regulatory-body/ [Accessed 10 October 2019].

Weidong, Z. Y., 2010. *Impacts of large scale and high voltage level photovoltaisc penetration on the security and stability of power system.* s.l., Asia Pacific Power and Engineering Conference .

Widen, J. & Wackelgard, L., 2010. *Impacts of distributed photovoltaics on network voltages:Stochastic simulations Swidish voltage distribution grid,* s.l.: Electric Power System Research.

Yuan Kang Wu, J. H. L. H. J. L., 2017. *Standards and Guidelines for Grid-Connected Photovoltaic Generation Systems: A Review and Comparison.* s.l., IEEE.

APPENDIX A: Single Line Diagram of the Power Grid Modelled in ETAP



APPENDIX B: Generations in Dry Season

Dry Generation															
ID	**Terminal Bus**	**Type**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				MW	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**
Chatara_gen	33_Chatara	Synchronous	3.2 MW	2	2	2	2	2	2	2	2	2	2	2	2
Hewa	33_Tirtire	Synchronous	4.45 MW	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67
Kattaiya_gen	India_Kattaiya	Synchronous	34 MW	40	40	40	40	40	40	40	40	40	40	40	40
M mai_gen	M mai	Synchronous	4.5 MW	3	3	3	3	3	3	3	3	3	3	3	3
Mai_Khola	132_Mai	Synchronous	22 MW	15	15	15	15	15	15	15	15	15	15	15	15
Pheme_gen	Pheme	Synchronous	1 MW	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Dry Generation															
ID	**Terminal Bus**	**Type**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				MW	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**
Piluwa	33_Tirtire	Synchronous	1 MW	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Piluwa_Tirtire	33_Tirtire	Synchronous	3 MW	2	2	2	2	2	2	2	2	2	2	2	2
Puwa_Gen	Puwa	Synchronous	6.1 MW	4	4	4	4	4	4	4	4	4	4	4	4
Sabha	33_Tirtire	Synchronous	4 MW	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Upper Mai Gen	Upper_Mai	Synchronous	3 MW	2	2	2	2	2	2	2	2	2	2	2	2
U_Puwa_gen	U puwa	Synchronous	3 MW	2	2	2	2	2	2	2	2	2	2	2	2

APPENDIX C: Generations in Wet Season

Wet Generation															
ID	**Terminal Bus**	**Type**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				MW	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**
Chatara_gen	33_Chatara	Synchronous	3.2 MW	3	3	3	3	3	3	3	3	3	3	3	3
Hewa	33_Tirtire	Synchronous	4.45 MW	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56
Kattaiya_gen	India_Kattaiya	Synchronous	34 MW	40	40	40	40	40	40	40	40	40	40	40	40
M mai_gen	M mai	Synchronous	4.5 MW	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Mai_Khola	132_Mai	Synchronous	22 MW	20	20	20	20	20	20	20	20	20	20	20	20
Pheme_gen	Pheme	Synchronous	1 MW	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Wet Generation															
ID	**Terminal Bus**	**Type**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				MW	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**
Piluwa	33_Tirtire	Synchronous	1 MW	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Piluwa_Tirtire	33_Tirtire	Synchronous	3 MW	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Puwa_Gen	Puwa	Synchronous	6.1 MW	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
Sabha	33_Tirtire	Synchronous	4 MW	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Upper Mai Gen	Upper_Mai	Synchronous	3 MW	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
U_Puwa_gen	U puwa	Synchronous	3 MW	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4

APPENDIX D: Loading in Dry Season

Dry Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump2	U puwa	Lumped	1000 kVA	564	553	564	553	532	532	512	512	503	522	638	849
Lump5	33_Phikkal	Lumped	3000 kVA	1681	1650	1681	1650	1587	1587	1529	1529	1501	1557	1901	2514
Lump6	33_Tilkeni	Lumped	8000 kVA	4492	4408	4492	4408	4240	4240	4084	4084	4008	4159	5083	6726
Lump7	Phidim	Lumped	1500 kVA	842	826	842	826	795	795	766	766	752	780	952	1259
Lump8	33_Godak	Lumped	3000 kVA	1683	1652	1683	1652	1589	1589	1531	1531	1502	1559	1903	2515
Lump10	33_Damak_City	Lumped	20000 kVA	11133	10943	11133	10943	10559	10559	10181	10181	9992	10368	12504	16219
Lump11	33_Duhabi	Lumped	30000 kVA	16939	16646	16939	16646	16055	16055	15468	15468	15175	15760	19012	24775

Dry Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump12	33_Rani	Lumped	24000 kVA	13339	13112	13339	13112	12655	12655	12200	12200	11972	12426	14940	19319
Lump13	33_Rangeli	Lumped	4000 kVA	2331	2292	2331	2292	2213	2213	2134	2134	2095	2173	2607	3356
Lump14	33_Tanki	Lumped	22000 kVA	12269	12059	12269	12059	11637	11637	11217	11217	11007	11426	13747	17811
Lump15	33_Chatara	Lumped	1500 kVA	835	821	835	821	792	792	763	763	749	778	935	1201
Lump16	33_Belbari	Lumped	8000 kVA	4436	4361	4436	4361	4209	4209	4058	4058	3982	4133	4967	6415
Lump17	33_Khanar	Lumped	8000 kVA	4464	4387	4464	4387	4233	4233	4079	4079	4002	4156	5003	6465
Lump18	33_Dharan	Lumped	16000 kVA	8870	8718	8870	8718	8412	8412	8107	8107	7954	8259	9938	12766

Dry Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump20	33_Dhankuta	Lumped	4000 kVA	2214	2176	2214	2176	2098	2098	2020	2020	1981	2059	2486	3176
Lump21	33_JireKhimti	Lumped	1500 kVA	837	822	837	822	791	791	760	760	745	776	945	1203
Lump22	33_Tirtire	Lumped	8000 kVA	4505	4420	4505	4420	4250	4250	4080	4080	3995	4165	5100	6495
Lump23	33_Inaruwa	Lumped	16000 kVA	8963	8808	8963	8808	8496	8496	8186	8186	8031	8341	10055	13105
Lump25	33_Rajbiraj	Lumped	8000 kVA	4440	4362	4440	4362	4206	4206	4050	4050	3971	4127	4987	6588
Lump26	33_Bhardaha	Lumped	2000 kVA	1121	1102	1121	1102	1062	1062	1023	1023	1003	1042	1260	1662
Lump27	33_Rupani	Lumped	6000 kVA	3328	3269	3328	3269	3152	3152	3035	3035	2976	3093	3738	4945

Dry Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump28	33_Gaighat	Lumped	10000 kVA	5563	5465	5563	5465	5267	5267	5070	5070	4972	5169	6251	8296
Lump29	33_Bishnupur	Lumped	2000 kVA	1115	1094	1115	1094	1054	1054	1013	1013	993	1033	1257	1704
Lump30	33_Mirchaiya	Lumped	6000 kVA	3369	3307	3369	3307	3182	3182	3058	3058	2996	3120	3803	5171
Lump31	33_anarmani	Lumped	36000 kVA	20284	19939	20284	19939	19245	19245	18561	18561	18221	18899	22768	29401

APPENDIX E: Loading in Wet Season

Wet Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump2	U puwa	Lumped	1000 kVA	564	554	564	554	534	534	515	515	505	524	639	859
Lump5	33_Phikkal	Lumped	3000 kVA	1680	1649	1680	1649	1591	1591	1534	1534	1506	1563	1900	2539
Lump6	33_Tilkeni	Lumped	8000 kVA	4492	4408	4492	4408	4251	4251	4100	4100	4024	4175	5081	6795
Lump7	Phidim	Lumped	1500 kVA	842	827	842	827	797	797	769	769	755	783	953	1272
Lump8	33_Godak	Lumped	3000 kVA	1682	1651	1682	1651	1592	1592	1535	1535	1507	1564	1901	2538
Lump10	33_Damak_City	Lumped	20000 kVA	11149	10957	11149	10957	10581	10581	10205	10205	10016	10394	12508	16364

Wet Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump11	33_Duhabi	Lumped	30000 kVA	16950	16656	16950	16656	16071	16071	15486	15486	15191	15779	19016	24973
Lump12	33_Rani	Lumped	24000 kVA	13348	13120	13348	13120	12667	12667	12214	12214	11985	12441	14943	19475
Lump13	33_Rangeli	Lumped	4000 kVA	2333	2293	2333	2293	2215	2215	2136	2136	2097	2176	2608	3383
Lump14	33_Tanki	Lumped	22000 kVA	12277	12066	12277	12066	11648	11648	11230	11230	11018	11440	13750	17954
Lump15	33_Chatara	Lumped	1500 kVA	837	823	837	823	794	794	765	765	751	780	938	1217
Lump16	33_Belbari	Lumped	8000 kVA	4439	4363	4439	4363	4213	4213	4063	4063	3987	4138	4968	6467
Lump17	33_Khanar	Lumped	8000 kVA	4468	4391	4468	4391	4238	4238	4084	4084	4007	4161	5006	6529

Wet Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump18	33_Dharan	Lumped	16000 kVA	8881	8728	8881	8728	8424	8424	8119	8119	7965	8272	9949	12920
Lump20	33_Dhankuta	Lumped	4000 kVA	2215	2176	2215	2176	2099	2099	2021	2021	1981	2060	2488	3226
Lump21	33_JireKhimti	Lumped	1500 kVA	837	822	837	822	791	791	760	760	745	776	945	1229
Lump22	33_Tirtire	Lumped	8000 kVA	4505	4420	4505	4420	4250	4250	4080	4080	3995	4165	5100	6654
Lump23	33_Inaruwa	Lumped	16000 kVA	8969	8814	8969	8814	8505	8505	8196	8196	8040	8351	10057	13204
Lump25	33_Rajbiraj	Lumped	8000 kVA	4443	4365	4443	4365	4209	4209	4053	4053	3975	4131	4989	6622
Lump26	33_Bhardaha	Lumped	2000 kVA	1122	1102	1122	1102	1063	1063	1024	1024	1004	1043	1261	1672

Wet Season															
ID	**Terminal Bus**	**Type of Load**	**Rating**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**
				kW	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
Lump27	33_Rupani	Lumped	6000 kVA	3330	3271	3330	3271	3154	3154	3037	3037	2978	3096	3740	4969
Lump28	33_Gaighat	Lumped	10000 kVA	5566	5467	5566	5467	5271	5271	5074	5074	4976	5173	6253	8332
Lump29	33_Bishnupur	Lumped	2000 kVA	1115	1095	1115	1095	1054	1054	1013	1013	993	1034	1258	1708
Lump30	33_Mirchaiya	Lumped	6000 kVA	3370	3308	3370	3308	3184	3184	3060	3060	2998	3122	3804	5182
Lump31	33_anarmani	Lumped	36000 kVA	20314	19968	20314	19968	19287	19287	18609	18609	18266	18949	22774	29681

APPENDIX F: Financial Analysis of Solar PV Plant

Input to the system

30MWp Solar PV Project, Inaruwa_Duhabi					
Installed Capacity	30	MWp			
Capital Cost	2100	MNPR			
Price Level	2019	AD			
Annual Energy Production	49.74804	GWh			
Construction Period	2	Years			
Average Energy Rate	7.3	NPR/kWh			
	8.46%				
Loan %	70.00%	Loan Amount	1470	MNPR	
Equity %	30.00%	Equity Amount	630	MNPR	
Release in Year 1	40.00%	of Total Cost			
Release in Year 2	60.00%	of Total Cost			
Year 1	Loan %	40.00%	Loan Amount	588	MNPR
Year 2	Loan %	60.00%	Loan Amount	882	MNPR
Interest on Loan		3.00%			
Loan Repayment		3	years		
Interest Year 1		17.64	MNPR		
Interest Year 2		44.6292	MNPR		
Interest During Construction		62.2692	MNPR		
Total Loan Amount		1532.2692	MNPR		

Depreciation of Assets

Depreciation Type	**Linear**		
Depreciation Rate	**4.00%**		
SN	**Year**	**Depreciation**	**Remaining Value**
1	1	84.00	2,016.00
2	2	84.00	1,932.00
3	3	84.00	1,848.00
4	4	84.00	1,764.00
5	5	84.00	1,680.00
6	6	84.00	1,596.00
7	7	84.00	1,512.00
8	8	84.00	1,428.00
9	9	84.00	1,344.00
10	10	84.00	1,260.00
11	11	84.00	1,176.00
12	12	84.00	1,092.00
13	13	84.00	1,008.00
14	14	84.00	924.00
15	15	84.00	840.00
16	16	84.00	756.00
17	17	84.00	672.00
18	18	84.00	588.00
19	19	84.00	504.00
20	20	84.00	420.00
21	21	84.00	336.00
22	22	84.00	252.00

Depreciation Type	Linear		
Depreciation Rate	**4.00%**		
SN	**Year**	**Depreciation**	**Remaining Value**
23	23	84.00	168.00
24	24	84.00	84.00
25	25	84.00	-

Regular Costs

Annual Cost of O&M	0.40%	of Total Cost
Annual Cost of Insurance	0.25%	of Total Cost
Domestic Inflation Rate	6.00%	per Year
Discount Rate	2.86%	per annum
Inverter Replacement Cost	2.00%	of Total Cost

Loan Repayment

Year	PMT	Interest	Principle	Balance
1	541.70	45.97	495.74	1,036.53
2	541.70	31.10	510.61	525.93
3	541.70	15.78	525.93	-
4	-	-	-	-
5	-	-	-	-

Cash Flow Sheet

			Costs				**Revenue**							
Year	Income Tax Rate	Operation Year	Capital	O & M	Insurance	Total Cost	From Sales	Interest+Depreciation	Income	Loss Carried Forward	Taxable Income	Income Tax	Total Cost Including Tax	Net Cash Flow
0			840.00			840.00		17.64	-				857.64	(875.28)
1			1,260.00			1,260.00		44.63	-				1,304.63	(1,349.26)
2	0.00%	1.00	-	8.40	5.25	13.65	363.16	129.97	219.54	-	219.54	-	143.62	173.57
3	0.00%	2.00	-	8.90	5.25	14.15	363.16	115.10	233.91	-	233.91	-	129.25	202.81
4	0.00%	3.00	-	9.44	5.25	14.69	363.16	99.78	248.69	-	248.69	-	114.47	232.92
5	0.00%	4.00	-	10.00	5.25	15.25	363.16	84.00	263.91	-	263.91	-	99.25	263.91
6	0.00%	5.00	-	10.60	5.25	15.85	363.16	84.00	263.31	-	263.31	-	99.85	263.31
7	0.00%	6.00	-	11.24	5.25	16.49	363.16	84.00	262.67	-	262.67	-	100.49	262.67
8	0.00%	7.00	-	11.92	5.25	17.17	363.16	84.00	262.00	-	262.00	-	101.17	262.00
9	0.00%	8.00	-	12.63	5.25	17.88	363.16	84.00	261.28	-	261.28	-	101.88	261.28
10	0.00%	9.00	-	13.39	5.25	18.64	363.16	84.00	260.52	-	260.52	-	102.64	260.52
11	0.00%	10.00	42.00	14.19	5.25	61.44	363.16	84.00	217.72	-	217.72	-	145.44	217.72
12	12.50%	11.00	-	15.04	5.25	20.29	363.16	84.00	258.87	-	258.87	32.36	136.65	226.51

13	12.50%	12.00	-	15.95	5.25	21.20	363.16	84.00	257.96	-	257.96	32.25	137.44	225.72
14	12.50%	13.00	-	16.90	5.25	22.15	363.16	84.00	257.01	-	257.01	32.13	138.28	224.88
15	12.50%	14.00	-	17.92	5.25	23.17	363.16	84.00	255.99	-	255.99	32.00	139.17	223.99
16	12.50%	15.00	-	18.99	5.25	24.24	363.16	84.00	254.92	-	254.92	31.86	140.11	223.05
17	25.00%	16.00	-	20.13	5.25	25.38	363.16	84.00	253.78	-	253.78	63.44	172.83	190.33
18	25.00%	17.00	-	21.34	5.25	26.59	363.16	84.00	252.57	-	252.57	63.14	173.73	189.43
19	25.00%	18.00	-	22.62	5.25	27.87	363.16	84.00	251.29	-	251.29	62.82	174.69	188.47
20	25.00%	19.00	-	23.98	5.25	29.23	363.16	84.00	249.93	-	249.93	62.48	175.71	187.45
21	25.00%	20.00	42.00	25.42	5.25	72.67	363.16	84.00	206.50	-	206.50	51.62	208.29	154.87
22	25.00%	21.00	-	26.94	5.25	32.19	363.16	84.00	246.97	-	246.97	61.74	177.93	185.23
23	25.00%	22.00	-	28.56	5.25	33.81	363.16	84.00	245.35	-	245.35	61.34	179.14	184.02
24	25.00%	23.00	-	30.27	5.25	35.52	363.16	84.00	243.64	-	243.64	60.91	180.43	182.73
25	25.00%	24.00	-	32.09	5.25	37.34	363.16	84.00	241.82	-	241.82	60.46	181.79	181.37
26	25.00%	25.00	-	34.01	5.25	39.26	363.16	84.00	239.90	-	239.90	59.97	183.24	179.92
											Present Value of Cash Flow (NPV)			1,564.05
											Internal Rate of Return			8.46%
											Benefit to Cost Ratio			1.42