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**Power Grid Performance Evaluation with Evaluation with Large-Scale Solar PV
Integration: A Case Study of Nepalese Transmission Network**

By

Anjan Adhikari

A THESIS

**SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING IN
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ABSTRACT

Today's major concern over to reduce carbon footprint, it is increasing the development of clean and renewable energy to meet the energy requirements. In Nepal overall energy demand has been primarily met by hydropower electricity generation and some of solar photovoltaic (PV) power projects. The country aims to install a total electric capacity of 28,500 MW and export 15,000 MW to neighboring countries like India, Bangladesh and China by 2035 as per Energy Development Roadmap, 2081. To achieve this target, the Nepalese government is planning to integrate solar PV power plants into the grid alongside hydropower. Nepal is embracing this transition by incorporating PV plants to meet national energy demands and export surplus electricity. Recently, the Nepal Electricity Authority (NEA), a leading electric utility in Nepal, has issued Letters of Intent (LOI) for the grid connection of solar power plants in different parts of the country. This paper study and examines the grid impact of PV integration in the existing 33 kV and 132 kV transmission network line of Parasi and Nawalpur districts, mid-southern region of Nepal. The load flow analysis, flicker analysis, short circuit analysis, transient frequency and harmonics analysis are studied to assess the effects of PV interconnection at different locations of that area within the grid in ETAP platform. The key findings of this study provide insights into the different impacts as well as their performances and offer a concrete recommendations for maintaining grid stability and reliability.

Keywords: Nepal Electricity Authority, Impact Studies, Renewable Energy, Electrical Transient Analyzer Program (ETAP), Grid Stability

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ABBREVIATIONS AND ACRONYMS

PV	Photo Voltaic
POI	Point of Interconnection
DER	Distributed Energy Resources
THD	Total Harmonic Distortion
EPS	Electric Power System
GSU	Generating Step Up
NEA	Nepal Electricity Authority
ROR	Run of River
PROR	Peaking Run of River

CHAPTER 1 INTRODUCTION

1.1 Background

Electrical energy is an essential necessity for modern human life, and its absence is unimaginable. In the case of Nepal, the total theoretical hydroelectric capacity is 83 GW, with 43 GW being technically and economically achievable [1]. However, with the increasing energy demand and the limitations of conventional power sources, the need to explore alternative renewable energy solutions has become crucial. Among the various renewable energy sources, solar PV power holds immense potential for Nepal due to its significant solar radiation availability throughout the year. It is estimated that solar PV potential in the country is around 47 GW [2]. Investing in high-efficiency photovoltaic (PV) systems can play a vital role in enhancing energy security and sustainability of Nepal national grid.

The Integrated Nepal Power System (INPS) owned by NEA is Nepal's national grid and it is responsible for supplying power all across the country [3]. Till 2080/81 B.S., the total installed capacity connected to the grid has reached to 3,164.12 MW, with 183.56 MW generated from Alternative Energy Sources like Micro Hydropower, Photovoltaic, Co-Generation and Thermal Plants. 2,980.56 MW is contributed by hydropower (larger than 1 MW) out of which only 106 MW is produced by storage projects while the rest is contributed by ROR/PROR projects [4]. By the end of the fiscal year 2080/81 B.S., the total installed capacity of grid substations had reached 13,050 MVA and the transmission line circuit length has reached to 6,507 km [5]. Since most of the plants are ROR/PROR type, Nepal is facing energy deficit in dry seasons. NEA imported 1,895 MU energy in dry season in fiscal year 2080/81 B.S. To meet growing electricity demand involves the establishment and expansion of large centralized power plants, transmission networks, and distribution infrastructures. Nowadays solar PV can generate in range of MW and GW scale worldwide and it is more technological friendly which enhances the performance of grid. Photovoltaic (PV) distributed generation (DG) units are appropriate for decentralized generation, as they can be installed near load centers, enhancing grid performance by reducing power losses and improving voltage stability [6].

In Nepal, standalone PV systems have been widely adopted for rural electrification, providing power to remote areas where grid extension is not feasible. In recent years,

there has been a growing shift towards grid-connected solar power plants, driven by technological advancements and policy initiatives. The declining cost of PV systems, particularly with the reduction in battery storage dependency, has further accelerated the adoption of solar energy in Nepal. This transition towards distributed renewable energy resources, including PV systems, is expected to enhance energy access, grid stability, and sustainability in the country's power sector.

In Nepal, the integration of renewable energy into the national grid is critical to achieving the country's long-term energy objectives. Solar power generation, with its potential to supplement hydropower during dry seasons, is an essential component of Nepal's energy diversification strategy. However, the deployment of large-scale PV plants presents unique technical challenges that must be addressed to ensure stable and reliable grid operation. PV energy production is intermittent and variable, causing voltage fluctuations in the power system. These fluctuations can affect supply and demand balance, leading to voltage instability [7]. These challenges are further compounded by potential overloading of grid infrastructure and disruptions to protection coordination. The detailed studies of PV impacts in INPS are still not found in literature. This paper focuses on these impacts and their performances to assess and mitigate of Nepal's national grid in mid-southern region at Nawalpur and Parasi districts.

In this paper, a detailed modeled of transmission line network of Nawalpur and Parasi District is modelled and simulations has been carried out to understand the basic model before penetration of PV plant to the grid. Then the study compares the voltage profile, branch loading, line losses, short circuit, and flicker analysis before and after the penetration of PV plant to the grid system.

1.2 Project Definition and Planning

In Nepal, total electricity production has reached approximately 3,200 MW, of which around 90 MW is generated from alternative sources, according to the Energy Development Roadmap, 2081, published by the Government of Nepal. The total expected installed capacity by 2035 AD is projected to reach 28,500 MW. To achieve this target, solar power will contribute alongside hydropower energy. Nepal has huge potential of solar power energy due to appropriate irradiance throughout a year. The

average solar radiation in Nepal varies from 3.6 to 6.2 kWh/m²/day; sun shines for about 300 days a year and the number of sunshine hours amounts to 6.8 h per day (about 2100 h per year) [8].

Nepal Electricity Authority (NEA), the leading electric utility company in Nepal, plays a prominent role in electrification across the country. Recently, NEA has awarded 63 solar projects of varying capacities at different connection points (Grid/DCS) in substations. Among them, five projects have been awarded within the Parasi and Nawalpur district. This district, located in the Terai region of Nepal, experiences sunny weather for most of the year.

The location of Nawalparasi District is shown in following Map of Nepal.

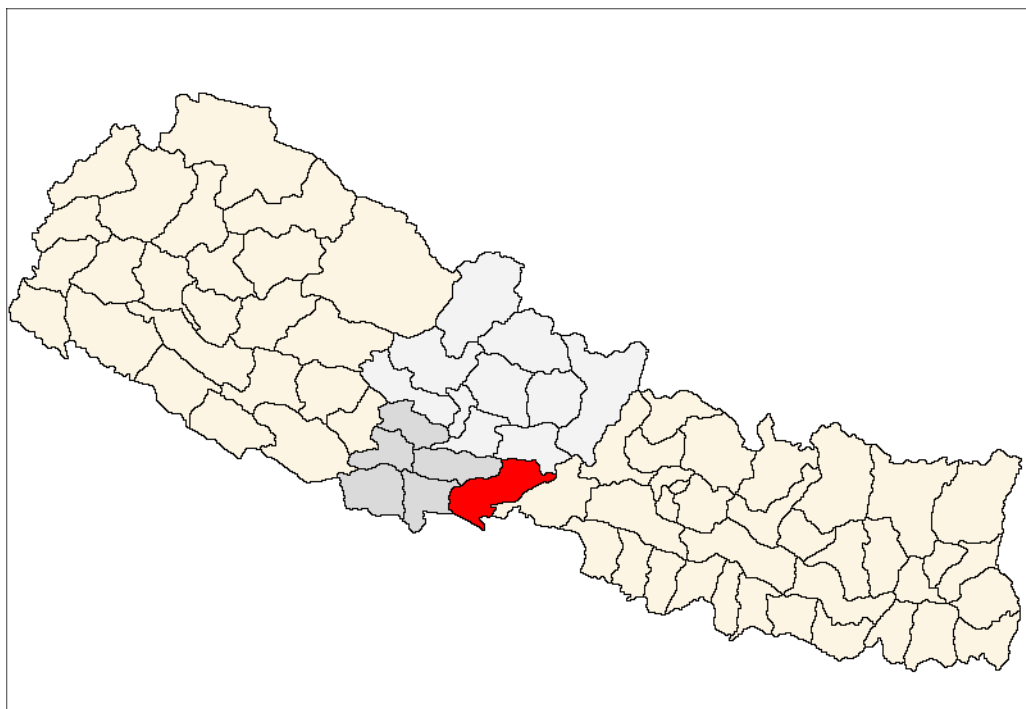


Figure 1.1: Map of Nepal showing Nawalparasi District

The detail of the projects awarded to connect PV Power Plants inside Parasi and Nawalpur district is tabulated in Table 1.1.

Table 1.1: Different Solar Projects awarded by NEA in Nawalparasi District

S.N	Proposed Substation	Substation Capacity(MVA)	Voltage Level (kV)	Awarded Capacity (MW)
1.	Mukundapur	24	33	10
2.	Gandak	93.2	132	25
3.	Parasi	40	33	15
4.	New Butwal	100	132	15
5.	Sunwal	148.5	132	50

1.3 Existing Transmission Line of Nawalpur-Parasi Districts

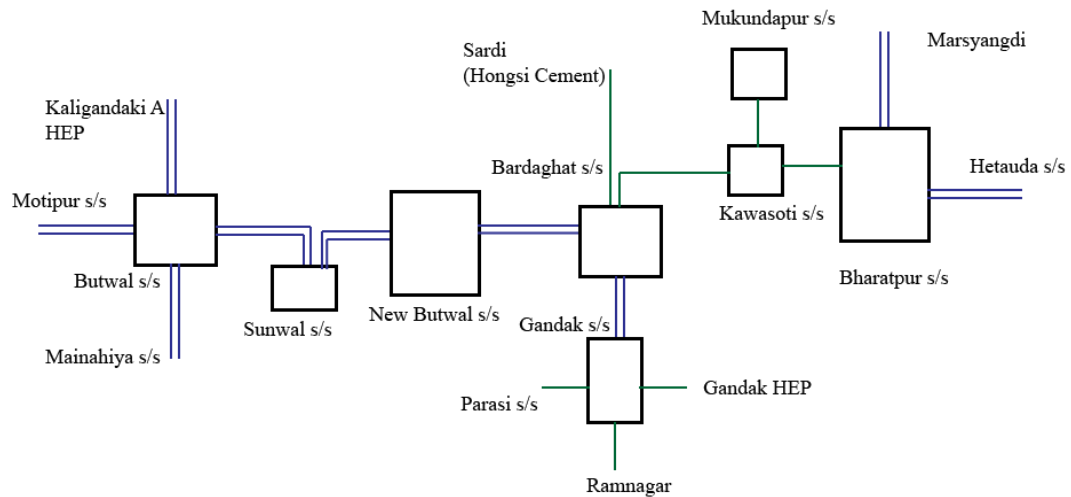


Figure 1.2: Existing Transmission Line of Nawalpur - Parasi Districts

Figure 1.2 illustrates the transmission line network within study zone. Nawalpur-Parasi are the mid-southern Terai districts of Nepal. The Bharatpur Substation is situated in the eastern region of Nawalpur district and is connected to Marsyangdi, Damauli and Hetauda Substation to the east. To the west, the Bharatpur Substation is linked to Kawaswoti Substation via a 132 kV transmission line spanning 36 km. The three feeder connect to the Kawaswoti Substation: Mukundapur, Bhojapokhari and Kawaswoti DCS. A transmission extending approximately 34 km leads to Bardaghat Substation located in the eastern part of Parasi District.

The Gandak Substation, positioned to the south of the Bardaghat substation, is connected through a 132 kV transmission line. Gandak Hydropower station with an install capacity of 15 MW, currently operating at around 4 MW linked to the Gandak Substation. The Bardaghat Substation, to its western part, is connected through a 132 kV double circuit line to the New-Butwal Substation. The 220 kV transmission line originating from the Kaligandaki-Corridor is stepped down to 132 kV at this substation. The New-Butwal Substation is connected to Sunwal Substation to the west via a 132 kV transmission line of 12 km in length.

Additionally, the Sunwal Substation is linked to the Butwal Substation by a 16 km long 132 kV transmission line. The Butwal Substation is linked to three primary areas: Kaligandagi hydropower to the north, Motipur to the west and Mainahiya to the south [3]. The eastern section of Bharatpur Substation, the western section of Butwal

Substation, and the southern section of Gandak Substation are modelled as a grid in Simulation.

1.4 Problem Statement

Reliability is one of the major issues in Nepal's power grid systems which face significant challenges during operation. The upcoming PV power projects penetration into the traditional grid can impact the grid more adversely. The grid impact study is most essential and required upon penetration of large PV systems into the grid.

- High PV penetration can lead to voltage instability, causing over-voltage or under-voltage conditions, especially in weak or lightly loaded networks.
- Voltage flicker due to sudden power outage of PV Plant.
- Inverters used in PV systems may introduce harmonic distortions into the grid, affecting the quality of power delivered to consumers and causing potential damage to sensitive equipment.
- Increased penetration of PV systems can lead to excessive loading on distribution lines and transformers, potentially exceeding their thermal limits and accelerating aging or failure.
- During periods of low demand and high PV generation, reverse power flow can occur which can affect disrupt protection coordination schemes.

1.5 Objectives

- To design and model the transmission network of Nawalpur and Parasi Districts using software ETAP, incorporating real feeder data and network topology.
- To evaluate the impact of PV integration on power quality parameters, including overvoltage, under voltage, short circuit levels, voltage flicker, harmonics, and frequency response.
- To identify any violations or adverse effects on system stability and reliability, and propose suitable mitigation strategies to ensure safe and efficient grid operation.

1.6 Scopes and Limitations

This thesis focuses on the modeling and analysis of a power distribution network with integrated photovoltaic (PV) systems in the Nawalpur and Parasi Districts. The scope includes designing the transmission network based on real feeder data, including network topology and electrical parameters, using simulation tool. A grid-connected PV system will be developed and integrated into the modeled network to study its effects on overall system performance. The study emphasizes the assessment of power quality issues such as overvoltage, under voltage, voltage flicker, harmonics, short circuit levels, and frequency response resulting from PV integration. Based on the simulation results, appropriate mitigation strategies will be proposed to address any violations and ensure stable and reliable grid operation.

This study has been carried out assuming maximum power penetration from the photovoltaic (PV) system. However, due to the inherently intermittent nature of solar energy, the actual output of PV systems can vary significantly, which may impact the grid differently under real-world conditions. The loads at the substations have been modeled as lumped, and the analysis is based on peak load conditions. Variations in load profiles throughout the day or across seasons could lead to different results. Additionally, only a selected portion of the Integrated Nepal Power System (INPS), specifically covering the Nawalpur and Parasi Districts, has been considered for this study. As a result, the findings may not fully represent the behavior of the entire national power network.

1.7 Thesis Organization

This dissertation is organized into five chapters. This section gives a brief outline of each chapter and the contents of each has.

- Chapter 1 gives the background of the dissertation. The problem statement is described, followed by objectives and the scope of the thesis work.
- Chapter 2 presents a review of relevant literature and provides the necessary background on photovoltaic (PV) energy. It discusses the potential challenges associated with PV integration into the power system and explores possible solutions.

- Chapter 3 outlines the methodology adopted in this thesis. It details the modeling of the transmission network and the integration of the PV system using simulation tools.
- Chapter 4 discusses the results obtained from the implementation of the proposed methodology. It analyzes the impact of PV integration on the power system and evaluates the outcomes based on various power quality parameters.
- Chapter 5 concludes the thesis by summarizing the key findings and offering recommendations for future research based on the observations and limitations of this study.

CHAPTER 2 LITERATURE REVIEW

2.1 Grid Impact Study of PV Plant to the Grid.

The grid impact study of Photovoltaic System is very important as penetration of multiple distributed energy sources can cause a serious issue in grid stability and reliability.

The paper conducted a case study on the integration of PV systems in Dubai's urban grid. Their findings demonstrated a 30% increase in renewable energy penetration and significant reductions in greenhouse gas emissions. This case study provides practical insights into the implementation of PV systems in densely populated areas [9].

The researcher clarifies the role of energy storage systems (ESS) in mitigating the intermittency of solar power in grid-connected PV systems. Their research showed that integrating lithium-ion batteries enabled peak shaving and output smoothing, resulting in a 25% improvement in grid stability metrics. This study emphasizes that coupling PV systems with advanced storage technologies is critical for enhancing grid reliability and addressing renewable energy variability. This method was applied in IEEE13 bus system and real Indian network for verification [10].

The author introduces a streamlined and computationally efficient method based on a two-bus equivalent model, designed to estimate the maximum voltage rise in a low-voltage (LV) network caused by photovoltaic (PV) generation over time. This model is validated through comparison with a detailed three-phase power flow analysis applied to an actual distribution network that includes LV areas. To demonstrate its practical application, the model is further employed in a case study assessing the effectiveness of reactive power injection in mitigating PV-induced overvoltage issues [11].

The paper aims to develop a sophisticated model predictive control strategy for a grid-connected wind and solar micro grid, which includes a hydrogen-ESS, a battery-ESS, and the interaction with external consumers. The proposed strategy consists of the economical and operating costs of the hybrid-ESSs, the degradation issues, and the physical and dynamic constraints of the system [12].

This paper proposes a novel dynamic voltage support (DVS) strategy aimed at enhancing short-term voltage stability (STVS) in residential distribution networks. Additionally, the design incorporates inverter current limits by considering the inverter's design margin, ensuring that the injected grid current remains within the maximum permissible range. [13].

The paper shows the impact of PV Penetration on Power Transmission Lines. The Kukës distribution area is selected as a case study, by connecting 4 PV systems (up to 54 MWp total installed capacity) at different bus bars voltage. Finally, considering all the studied performance parameters, this paper concludes to have (30-40) % of PV penetration as the best and appropriate case [14].

Due to the large installations of renewable power plants based on non-conventional synchronous generation that are expected in the coming years, the presence of synchronous condensers will be of vital importance to maintain the stability of the power systems, whether they are directly manufactured machines with this function, or generators that have undergone a retrofit [15].

2.2 Research Gap

Following research gaps are identified that are presented below:

- Small-scale penetration studies do not fully capture the challenges of larger systems, such as voltage variation, voltage flicker, and the risk of cascading failures. These issues are exacerbated when higher penetration levels are introduced into the grid, due to the intermittent and non-dispatch able nature of renewables like solar and wind.
- Despite extensive research into the integration of renewable energy sources (RES) and distributed energy resources (DERs), there is a significant gap in studies addressing short circuit fault and protection analysis in power systems. Many existing studies primarily focus on the impact of renewable energy penetration on grid stability, power quality, and energy efficiency, but they often overlook the critical challenges posed by short circuit faults and the corresponding adjustments needed in protection schemes

- While existing studies explore the challenges of integrating renewable energy sources (RES) and distributed energy resources (DERs) into power grids, many fail to propose effective mitigation strategies for addressing grid violations, such as voltage instability, frequency deviations, or thermal overloads, when they occur. This lack of actionable solutions limits the practical applicability of the research, as identifying problems without offering strategies to resolve those does not adequately support grid operators in managing real-world scenarios.

2.3 Photovoltaic Energy

Photovoltaic (PV) technology involves converting light into electricity using semiconductor materials that exhibit the photovoltaic effect—an area of study in physics, photochemistry, and electrochemistry. A photovoltaic system consists of solar panels, each containing multiple solar cells that generate electrical power. These installations can be mounted on rooftops, walls, or the ground. The mounting structure may either be fixed or equipped with a solar tracker to follow the sun’s movement.

Solar PV offers notable benefits as an energy source: after installation, it operates without producing pollution or greenhouse gas emissions. Additionally, it is easily scalable to meet varying power demands, and silicon, the primary material used, is abundantly found in the Earth's crust. However, PV systems have limitations, as they function most efficiently under direct sunlight. Environmental factors such as dust, clouds, and atmospheric obstructions further reduce output. Another challenge is that peak electricity generation occurs during periods of maximum sunlight, which often does not align with peak energy demand in human activity cycles.

2.3.1 Type of Potential Risk due to High Penetration of PV into the grid

2.3.1.1 Over Voltage/Reverse Flow

The excess power generated by solar PV systems must be effectively managed by the grid to ensure stable power flow and prevent critical issues such as power outages. For example, during periods of low demand, surplus PV generation may lead to active power being exported to the grid. This can cause overvoltage or reverse power flow,

potentially impacting the utility grid and household appliances, and introducing various safety and protection challenges.

2.3.1.2 Voltage Fluctuations

The variable output of solar photovoltaic (PV) systems is a major cause of voltage instability in grid-connected networks. Fluctuations in solar irradiance—driven by shifting cloud cover, the PV system's geographic placement, and panel orientation—can disrupt grid stability. These unpredictable shifts in power generation frequently lead to voltage flicker, higher transmission and distribution losses, and potential overloading problems in the electrical network.

2.3.1.3 Power factor

Grid-connected PV systems typically operate at unity power factor, meaning they generate only active (real) power. As a result, the grid remains responsible for supplying the necessary reactive power. However, this imbalance can disrupt the normal power flow, potentially leading to insufficient reactive power support. This condition may impair transmission efficiency and reduce overall power delivery capability.

2.3.1.4 Harmonics

Harmonic distortion is a significant factor that must be considered in the operation of grid-connected PV systems. The inverters responsible for converting DC to AC introduce both voltage and current harmonics into the network, leading to overall power quality degradation. Due to the increment in the number of inverters, the accumulation of harmonics can compromise system stability and reliability, potentially causing thermal heating in capacitor banks and transformers.

2.3.1.4 Protection Coordination Issues

The integration of high photovoltaic (PV) penetration into power grids introduces protection coordination challenges, primarily because traditional grid protection schemes were not designed for the dynamic and bidirectional power flows caused by distributed energy resources (DERs) like PV systems.

2.3.2 Possible Mitigation Strategies for any Violations.

2.3.2.1 Over Voltage

- Capacitor Banks Upgrade
- Install new voltage regulator or adjust/relocate existing ones
- Reconductoring i.e., increase conductor size (reduce the resistance)
- Non-Unity PF operation

2.3.2.2 Voltage Fluctuations

- Reconductoring
- Non-unity pf operation
- Static Var compensator

2.3.2.3 Short circuit and Protection

If the fault current injection of PV system goes beyond the violation limit, the following steps can be taken

- Install grounding reactor
- Updating Generating Step-Up (GSU) Transformer configuration from Yg-D to Yg-Yg
- Coordination Studies is required.

2.3.2.4 Harmonics Evaluation

- Employ High Quality Inverters
- Use of Active Filters

CHAPTER 3 METHODOLOGY

This chapter describes the method, tools, and techniques used, starting with data collection from the feeder and charging station, and their detailed modeling for harmonic analysis of the charging station on the distribution network.

3.1 Approach

The methodology adopted in this thesis involves a systematic approach to model the transmission network, integrate a photovoltaic (PV) system, and analyze the resulting impact on power quality parameters. The primary focus is to evaluate issues such as overvoltage, under voltage, short circuit levels, voltage flicker, harmonics, and frequency response, and to propose appropriate mitigation strategies if any violations occur.

The process begins with the collection of necessary data, including feeder topology, line lengths, transformer ratings, and load details from the Nawalpur and Parasi districts. Based on this data, a transmission network model is developed using ETAP.

A grid-connected PV system is then designed and integrated into the developed network model. The PV system is sized considering maximum penetration levels to evaluate the worst-case impacts on the grid. The model is subjected to simulations under peak load conditions to identify any power quality issues caused by the intermittent nature of PV output.

The simulation results are then analyzed against IEEE standards to determine the extent of any violations. If significant issues are found, suitable mitigation strategies, such as reactive power compensation, voltage regulation devices, or harmonic filters, are proposed and implemented in the simulation environment.

The entire process—from data collection and system modeling to simulation, analysis, and mitigation—is documented for result validation and future reference.

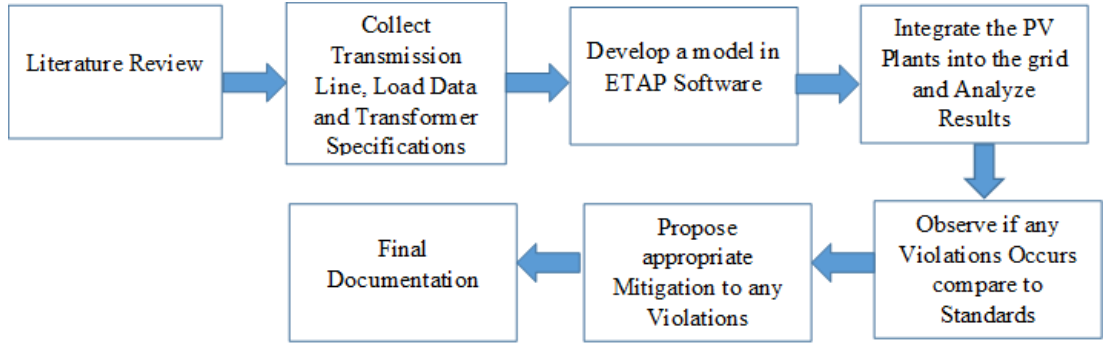


Figure 3.1: Flowchart for Approach Model

Subsequently, a solar power plant is designed and modeled within the software and integrated into the grid by connecting it to various substation bus bars. After incorporating the PV system, the circuit parameters are re-evaluated to assess the impact of PV penetration on the grid. Finally, the study identifies any violations or technical issues arising from the integration and proposes appropriate mitigation strategies to ensure stable, reliable, and efficient grid operation.

3.2 Power Flow Analysis

Load flow study is very crucial to know the circuit performance and to plan for the future expansion as well. It helps to know the different electrical parameters like voltage, current and power flow at different node and branches. The goal of a power flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions [16].

The Y bus can be written as:

$$(Y_{Bus}) = \sum_{i=1, i \neq k}^n Y_{ik} \quad (1)$$

The nodal current is calculated as,

$$I_k = \sum_{i=1, i \neq k}^n Y_{ik} V_k \text{ where } i=1, 2 \dots n \quad (2)$$

The complex power delivered to bus k is given by,

$$S_i = P_i + j Q_i = V_i [\sum_{i=1, i \neq k}^n Y_{ik} V_k]^* \quad (3)$$

Separating real and imaginary parts, Power balance equations can be written as,

$$P_i = \sum_{k=1}^n |V_i| |V_k| Y_{ik} \cos(\theta_{ik} + \delta_k - \delta_i) \quad (4)$$

$$Q_i = - \sum_{k=1}^n |V_i| |V_k| Y_{ik} \sin(\theta_{ik} + \delta_k - \delta_i) \quad (5)$$

We have,

$$\Delta f = J \Delta X$$

Where, J is Jacobian matrix

$$\Delta P_i = P_{i(sp)} - P_{i(cal)} \quad (6)$$

$$\Delta Q_i = Q_{i(sp)} - Q_{i(cal)} \quad (7)$$

Where the subscripts sp and cal refers to specified and calculated value respectively. Then equation (6) and (7) can be written as,

$$J \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (8)$$

Where J is Jacobian matrix, contain partial derivatives of power equations.

In this way, the change in power angle and change in voltage is determined and power flow solutions of the network is obtained.

3.3 Modeling of Transmission Line Networks

The modelling of Transmission Line is done in ETAP and the data is extracted from Nepal Electricity Authority Annual Report 2081, Transmission/Project Management Directorate (NEA), Distribution and Consumer Services Directorate (NEA). The designing of transmission line from Bharatpur to Butwal of Nawalparasi District is based on the data listed in Annex A.1. The load on each bus is assumed to be lumped load for simplicity. The loads on different buses is based on the data listed in Annex A.2. The substation capacity is presented in Annex A.3. The detail design and modelling of Transmission line, Substation and feeder load done in ETAP is shown below. Figure 3.2 represents the model before penetration of PV on grid.

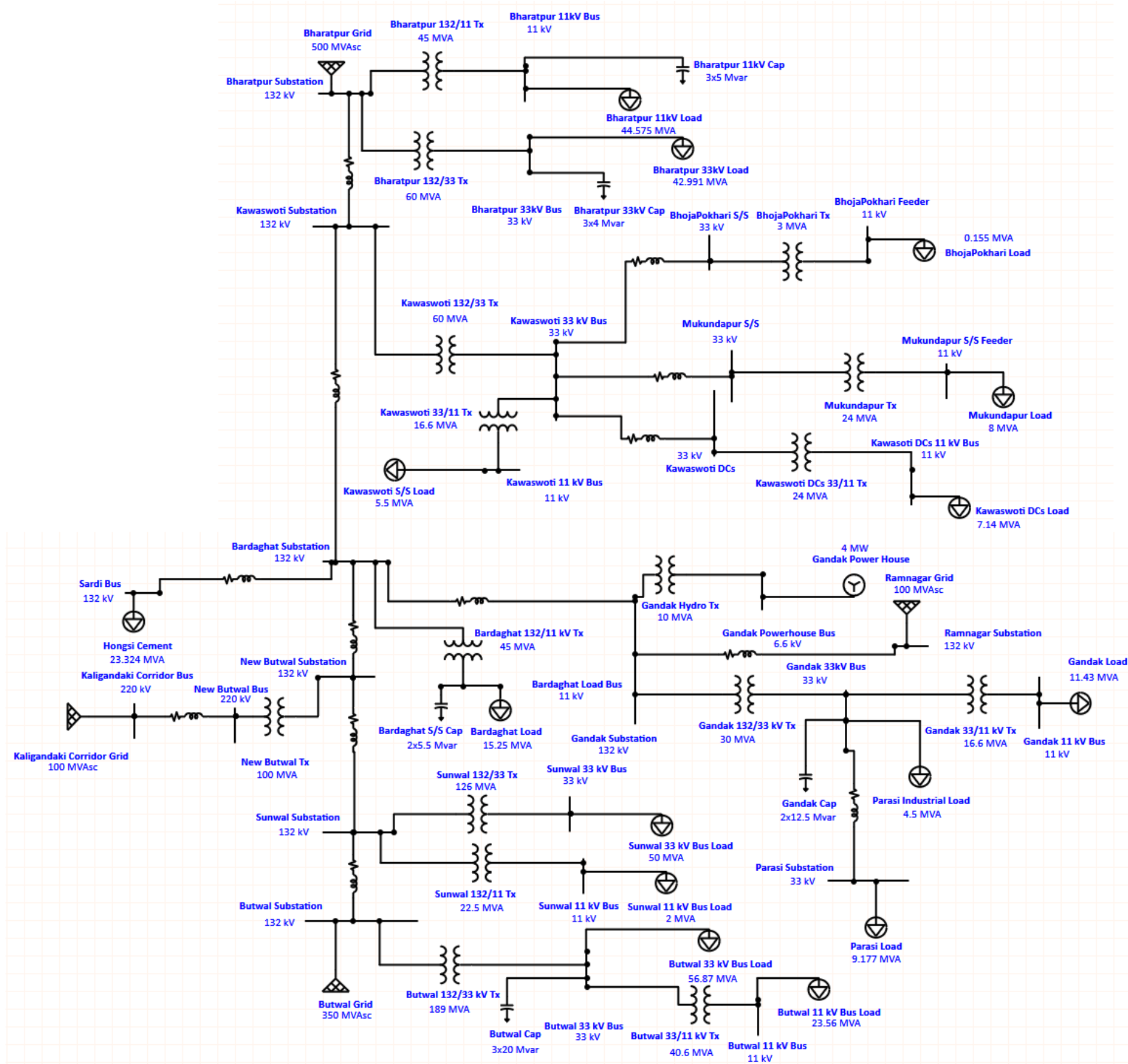


Figure 3.2: Transmission Line Network Modeling

The above figure 3.2 illustrates a grid-connected distribution network model developed in ETAP for power system analysis. The network consists of multiple 132 kV substations—such as Bharatpur, Kawasoti, Bardaghat, Sunauli, Butwal, and Gandak—interconnected through transmission lines and step-down transformers to 33 kV and 11 kV voltage levels. These substations distribute power to various load centers through 33 kV and 11 kV buses.

The system includes several transformers (132/33 kV and 132/11 kV) and capacitor banks for voltage regulation and reactive power compensation. Major loads like Bharatpur (45.575 MVA), Gandak (11.43 MVA), and Parasi Industrial (4.5 MVA) are connected at different voltage levels. The Gandak Hydro Power Plant, with a capacity of 4 MW, is integrated into the system, feeding power into the 6.6 kV Gandak Powerhouse Bus, which is then stepped up and distributed.

This model provides a comprehensive platform for conducting load flow analysis, voltage profile assessment, and system stability studies, and it reflects a practical scenario for analyzing power distribution performance under grid-connected conditions.

3.3 Modeling of PV Power System

There are altogether 5 solar Plants, which are planned to connect in Nawalparasi and Nawalpur district of Nepal. Nepal Electricity Authority (NEA) has awarded five project at different locations with different capacity.

3.3.1 Specification of PV Panel

The solar panel Vertex N-type i-TOPCon bifacial dual glass Monocrystalline module of Trina Solar (715Wp) cell is selected for study. The specification used for the PV panel for the array is listed below in Table 3.1.

Table 3.1: Electrical Datasheet of PV Panel

S.N	Parameters / Designation	SG 2500HV-20
Input (DC)		
1.	Max PV Input Voltage	1500 V
2.	Min PV Input Voltage	800 V / 840 V
3.	MPP Voltage range for nominal power	800-1300 V
4.	Max PV Input Current	3508 A
Output (AC)		
5.	AC Output Power	2750 KVA @ 45 degree Celsius
6.	Max AC Output Current	2886 A
7.	Nominal AC Voltage	550 V
8.	AC Voltage Range	495-605 V
9.	THD	< 3% (at nominal power)

According to manufacturer, the I-V and PV characteristics of PV Panel used in study is presented in figure 3.3. The I-V and P-V characteristics of a 715 W photovoltaic (PV) module are shown in the above figures for various levels of solar irradiance ranging from 200 W/m² to 1000 W/m². The I-V curve illustrates the relationship between the output current and voltage of the PV module. As the irradiance increases, the current output increases significantly, while the voltage remains relatively stable. At 1000 W/m², the module delivers the highest current, whereas at 200 W/m², the current is considerably lower. The curve starts with a maximum current at short-circuit condition (voltage = 0) and drops sharply after the maximum power point (MPP), reaching zero at the open-circuit voltage.

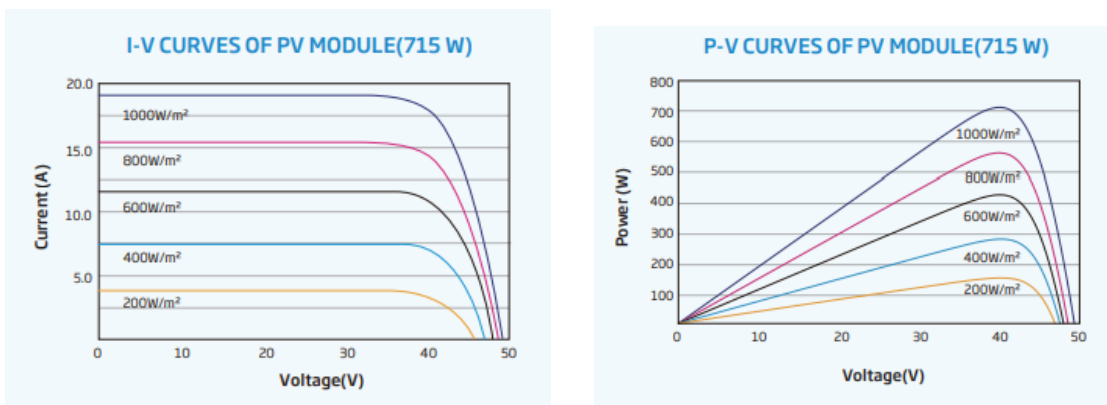


Figure 3.3: I-V and P-V characteristics of a PV Panel

The corresponding P-V curves show the power output versus voltage for the same irradiance levels. Each curve forms a distinct peak, indicating the maximum power

point (MPP) at that specific irradiance. As irradiance increases, the power output also increases, with the module achieving its rated power of approximately 715 W at 1000 W/m². The design of PV array in this study is done at a standard conditions like irradiance of 1000 W/m² and Temperature 25° Celsius.

3.3.2 Specification of an Inverter

The inverter of Sun grow manufacturer (Model SG 2500HV-20) is used for the design. The specification of the inverter is shown in Table 3.2.

Table 3.2: Specifications of an Inverter

S.N	Parameters / Designation	SG 2500HV-20
Input (DC)		
1.	Max PV Input Voltage	1500 V
2.	Min PV Input Voltage	800 V / 840 V
3.	MPP Voltage range for nominal power	800-1300 V
4.	Max PV Input Current	3508 A
Output (AC)		
5.	AC Output Power	2750 KVA @ 45 degree Celsius
6.	Max AC Output Current	2886 A
7.	Nominal AC Voltage	550 V
8.	AC Voltage Range	495-605 V
9.	THD	< 3% (at nominal power)

3.3.3 Modeling of an Solar Array

At first, the design of one solar Array suitable to give input to inverter as specified in Table 3.2 is done. PV array should design in such that it can give maximum power of 2500 KW to the inverter as an input. Since the power output of one solar panel is 715 Watt.

Assuming oversizing of PV Array by factor of 1.1. We get,

$$\text{Total PV Panels for 2750 KWp power} = (2750 \times 1000) / 715 = 3846.15$$

So, 3846 panels will be selected.

Open circuit voltage of a PV panel is 49.2 V.

From inverter datasheet we have,

Maximum DC voltage is 1500V and Minimum DC voltage to start is 840 V.

So, Minimum Panels in a string = $(840/49.2)=17.073 \sim 17$ Panels

Maximum Panels in a string= $(1500/49.2) = 30.48 \sim 30$ Panels

Deploying 25 Panels in a series in an array, we get

Voltage input to inverter= $25*V_{oc} = 25*49.2 = 1230 \text{ V} < 1500 \text{ V}$.

Panels in a parallel in an array = Total panels / Panels in a series

$$= 3846/25 = 153.84 \sim 153 \text{ Panels}$$

Current injected into the input of inverter = $153*I_{sc} = 153*18.44 = 2821.32 \text{ A} < 3508\text{A}$.

So, for one inverter of SG2500HV-20, we require a string of 25 panels in series and 153 panels in parallel as shown in Figure 3.4 to compliance with the specifications of PV panel and inverters.

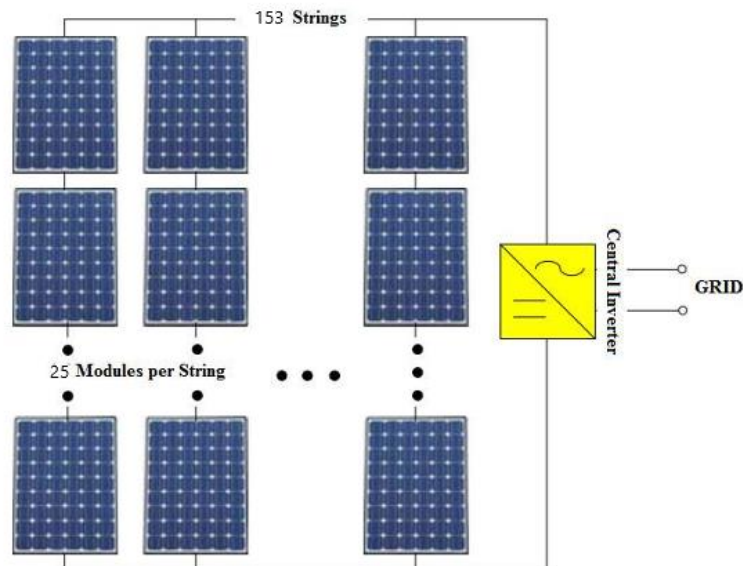


Figure 3.4: Configuration of Strings for One Central Inverter

3.3.4 Layout of grid connected PV system with the central inverters

The different capacities of PV Plant is connected to the grid at different locations. Let us take one design of 10 MW of PV Plant which will be connected at Mukundapur Substation at Nawalpur district. There are two distribution transformers, each with a rating of 5 MVA. The modules were distributed across 4 arrays, with each pair of arrays

connected to one transformer through two separate central inverters. The primary sides of the two transformers are connected to the 11 kV grid bus bar. The 11 kV will be stepped up to either 33 kV or 132 kV on the basis of point of interconnection. The inverters are connected to the panels in such a way that each inverter is connected to 153 parallel strings, and each string consists of 25 modules connected in series. Figure 3.5 below presents the connection scheme of the arrays, inverters, transformers, and bus bars.

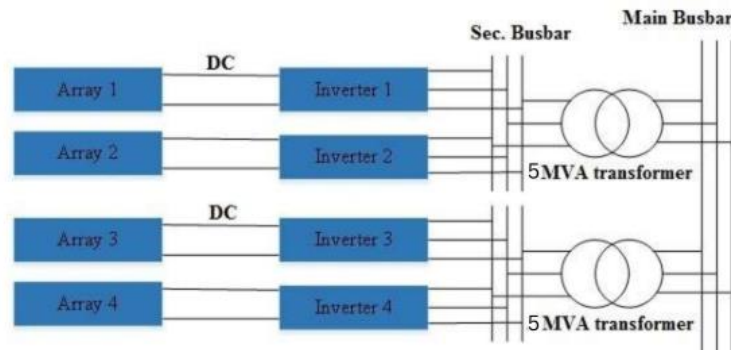


Figure 3.5: General structure of the arrays with the inverters

3.3.5 Modeling of PV Plants in ETAP Software

The PV System was modeled based on the above PV array and Inverter Configuration. According to the required Power, five different PV network are modeled with different capacities.

In the design of the PV array for different power capacities, various configurations have been employed to meet the required output. The voltage generated from the PV system, typically at 0.4 kV, is stepped up in two stages: initially to 11 kV, and subsequently to either 33 kV or 132 kV, depending on the grid connection and system requirements. A 5 MVA transformer is used at the 11 kV bus, which is capable of handling two inverters connected in parallel, each rated at 2.5 MVA. To meet higher power demands, additional inverters are arranged in parallel as necessary, allowing the system to be scaled appropriately based on the desired capacity. The PV network configuration at Mukundapur, Parasi, Gandak, New-Butwal and Sunwal substation is shown in Figure 3.6, 3.7, 3.8, 3.9 and 3.10 respectively.

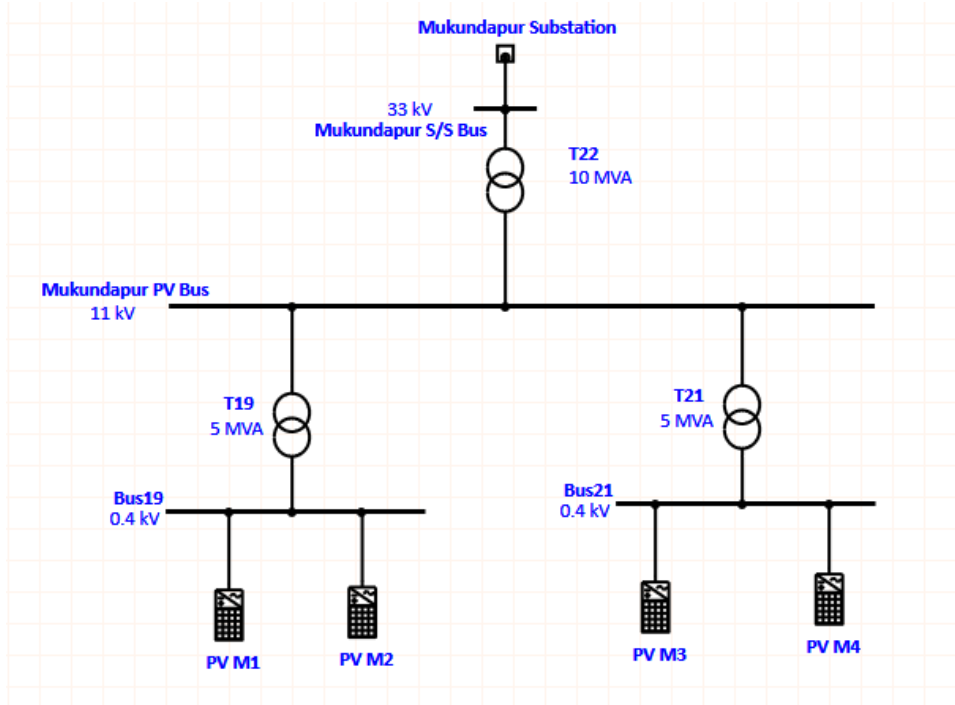


Figure 3.6: Mukundapur PV Network

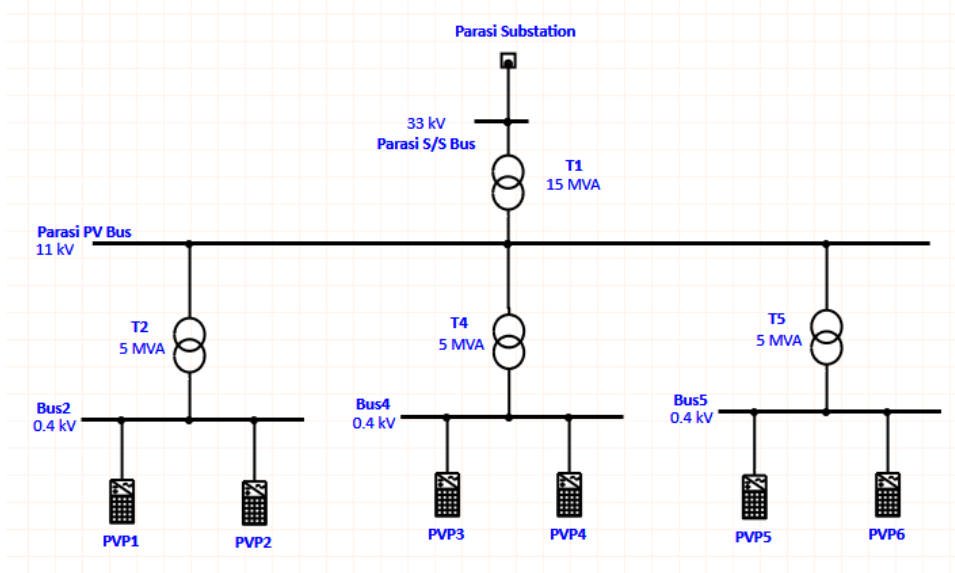


Figure 3.7: Parasi PV Network

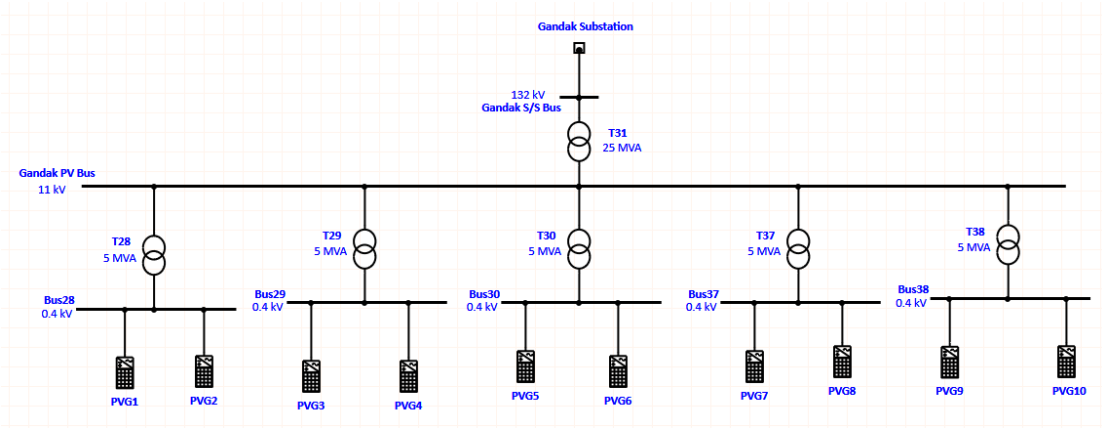


Figure 3.8: Gandak PV Network

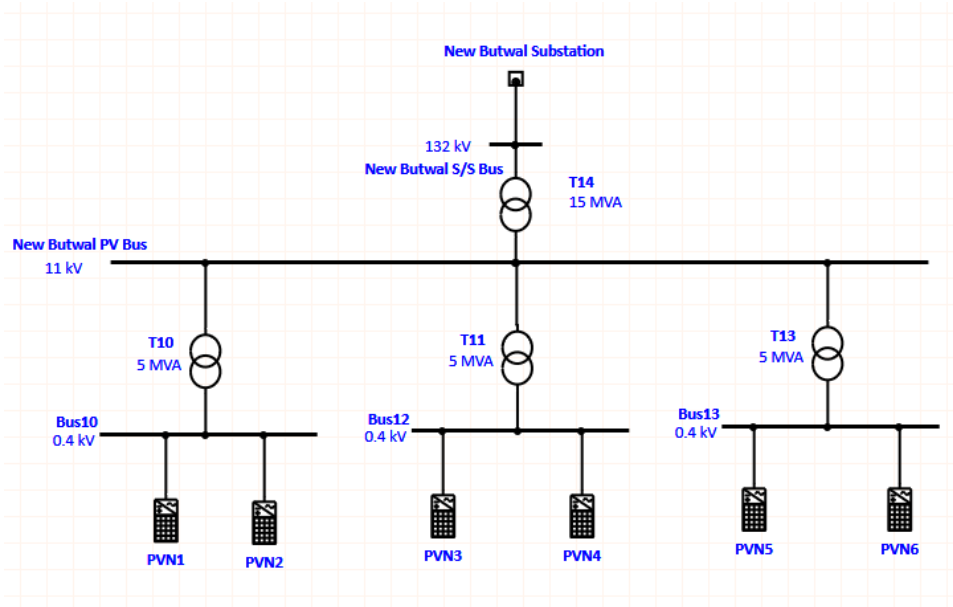


Figure 3.9: New Butwal PV Network

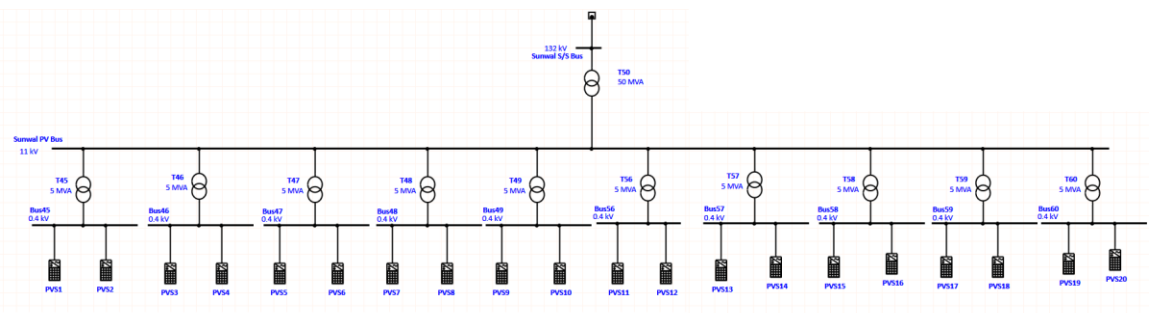


Figure 3.10: Sunwal PV Network

The transmission network of Parasi and Nawalpur district after penetration of above 5 PV power plants is shown in figure 3.11. The pink square box in the figure represents the PV network.

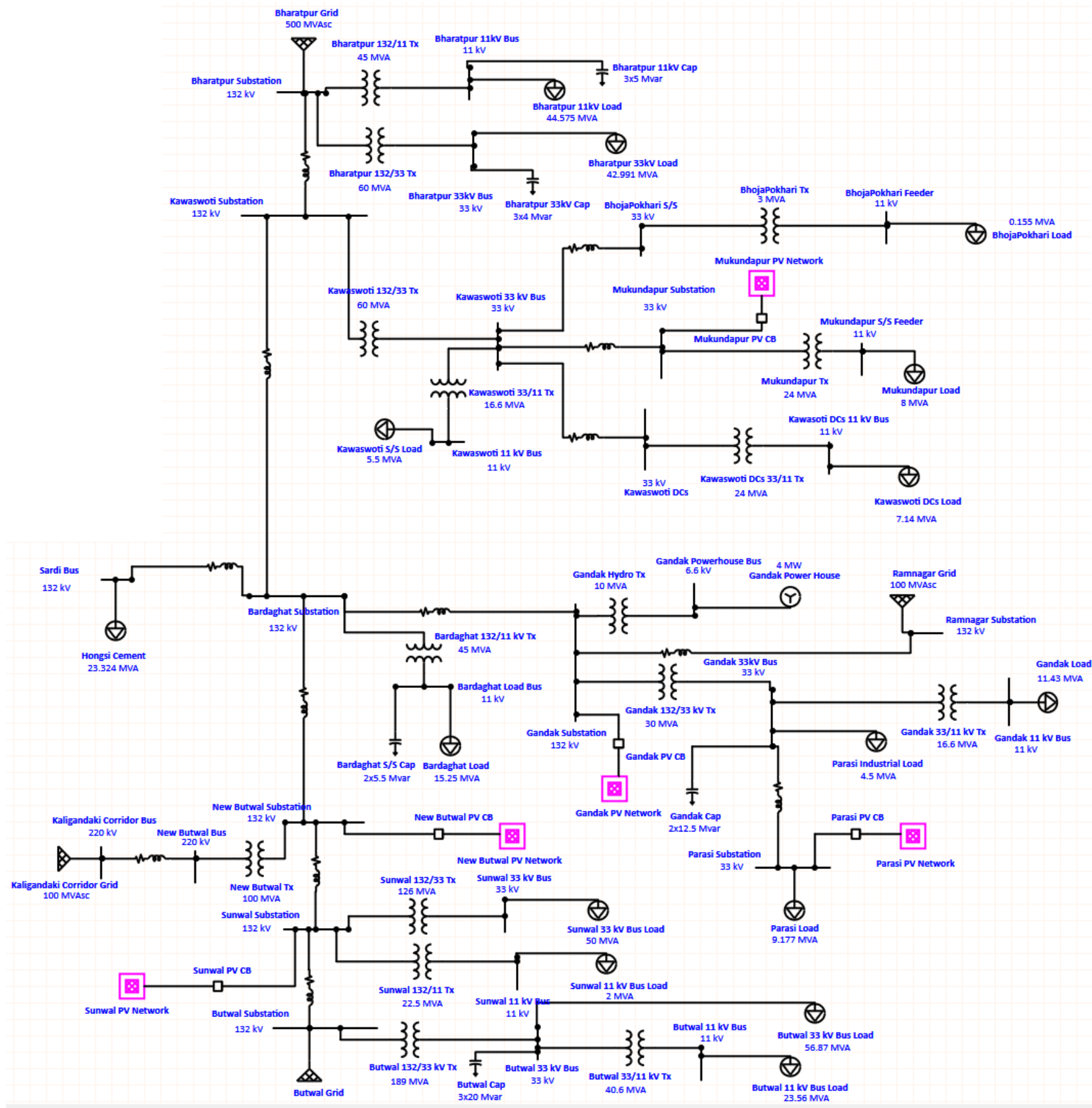


Figure 3.11: Model of Transmission Line with PV penetration

3.3.6 Standards for Grid Stability

3.3.6.1 Nepal Electricity Grid Code 2080:

- Voltage Variation: The designated system operator must ensure that, under normal operating conditions, the supply voltage at key connection points in the grid does not deviate by more than $\pm 10\%$ from its nominal value for voltages up to 132 kV, and by no more than $\pm 5\%$ for voltages of 220 kV and above.
- Frequency Variation: The designated system operator shall ensure that the system's fundamental frequency is maintained within the range of 48.75 Hz to 51.25 Hz, corresponding to a deviation of $\pm 2.5\%$ from the nominal frequency of 50 Hz.
- Transmission Loss: The Grid Owner shall ensure that the Transmission Loss does not exceed 4.5% of the Received Energy.

3.3.6.2 IEEE Std 1453:

It is the IEEE Recommended Practice for the Analysis of Fluctuating installations (DER) on Power Systems.

- Voltage Flicker at Point of Interconnection (POI) should be less than 3%.
- Voltage Change at Regulating Devices should be less than half of its bandwidth.

3.3.6.3 Short Circuit and Protection Analysis:

- DER injects fault current into the EPS.
- Determine fault levels and check if it violates the fault duty on any upstream devices.
- Some utilities flag the violation if the contribution during a ground fault $> 10\%$

3.3.6.4 IEEE Std 519:

It is the IEEE Recommended Practice and Requirements for Harmonic control in Electric Power System.

- Accepted THD is 5%.

3.4 Single Tuned Filter to mitigate Harmonics

The design considerations for designing the single tuned passive filter is governed by following mathematical equations.

A Single-Tuned Filter (STF) is essentially a series LC circuit tuned to a specific harmonic frequency. The resonant frequency of the filter is chosen to match the targeted harmonic frequency, and the filter is typically connected in parallel with the power system.

The resonance condition of a single-tuned filter is given by:

$$f_r = \frac{1}{2\pi \sqrt{L_f C_f}}$$

Where, L_f is inductance of filter.

C_f is capacitance of filter.

f_r is resonant tuned frequency.

The capacitor is typically designed first, based on the desired reactive power Q at the fundamental frequency f .

$$C_f = \frac{Q}{2\pi f V^2}$$

Where, Q = Reactive power provided by the filter capacitor (VAR).

V = RMS line-to-neutral voltage (V)

Once the capacitor value is determined, the inductor can be calculated using the resonant frequency formula.

$$L_f = \frac{1}{(2\pi f_r)^2 C_f}$$

In a Single-Tuned Filter, a resistor R_f is included to control the quality factor Q_f the filter.

$$R_f = \frac{1}{Q_f} \sqrt{\frac{L_f}{C_f}}$$

The substations at which five PV plants are connected to the grid are at different voltage level i.e. 33 and 132 kV. So based on the voltage level and required reactive power compensation the parameters are selected for single tuned filter design.

3.5 Software and Tools

ETAP (Electrical Transient Analyzer Program) is a comprehensive and powerful software used for the analysis, design, and optimization of electrical power systems. It is widely used by electrical engineers for various applications related to power

generation, distribution, and industrial electrical systems. ETAP offers a range of features for both steady-state and dynamic simulations. The ETAP has the following solution capabilities:

- **Power System Analysis:** ETAP allows engineers to model and analyze electrical networks, including power distribution systems, transmission systems, and generation facilities. It can perform load flow analysis, short-circuit analysis, and protection coordination studies.
- **Dynamic Simulations:** ETAP provides tools for transient and dynamic analysis, such as motor start-up, fault clearing, and generator synchronization. It can simulate power system behavior during disturbances, allowing engineers to predict system responses and optimize system performance.
- **Protective Device Coordination:** The software supports the coordination of protection devices such as relays and circuit breakers, ensuring the proper functioning of the system during faults.
- **Relay and Protection Settings:** ETAP includes modules for protection system design and the calculation of relay settings based on fault analysis. It helps in selecting appropriate protection schemes and optimizing the protection of electrical assets.
- **Real-Time Monitoring and Control:** ETAP offers solutions for real-time monitoring and control of power systems.

ETAP is used across various industries, including utilities, industrial plants, oil and gas, and renewable energy projects, providing solutions for both large-scale power networks and smaller systems. Its user-friendly interface and powerful simulation capabilities make it an essential tool for modern electrical engineers and power system operators.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Load Flow Analysis

The load flow is done in ETAP Simulation Software Which uses Adaptive Newton Raphson Method for study. The maximum Iteration is 99 and precision is 0.0001.

4.1.1 Load Flow Analysis without PV Interconnection

At first, the transmission line, feeder and loads are modelled for Parasi and Nawalpur districts. Before penetration of PV Plant, the load flow was done for the base model. The following diagram shows the MW and MVAR power flowing into the transmission network and voltage is showing in terms of percentage rating. The circuit breaker related to specific project is turned off to analyze the circuit before penetration of PV. As per report, the maximum loading of transformer in a network is 132/11 Transformer connected to Bharatpur substation with 86.6% loading and minimum is of Sunwal substation 132/11 Transformer with only 8.9 % loading. The maximum loss is seen on Gandak-Parsi Transmission line of 33 kV with 291.9 KW. Detailed load flow report, Branch Loading and Losses before penetration of PV into the network is listed in Appendix B.1.

4.1.2 Load Flow Analysis with PV Interconnection

Five PV power plants are connected to the respective substations as indicated in table 1.1. With the PV interconnected, the transformer loading, feeding to the network, decreases as PV has supplied the demand load. The Kawaswoti 132/33 Transformer loading has reduced from 35.9% to 26.2% and Gandak 132/33 transformer loading has reduced from 79.9% to 43.4% upon PV interconnection. The load flow upon interconnection of PV is shown below in Figure 4.2 and Load flow report, Branch loading and Losses data is presented in Appendix B.2.

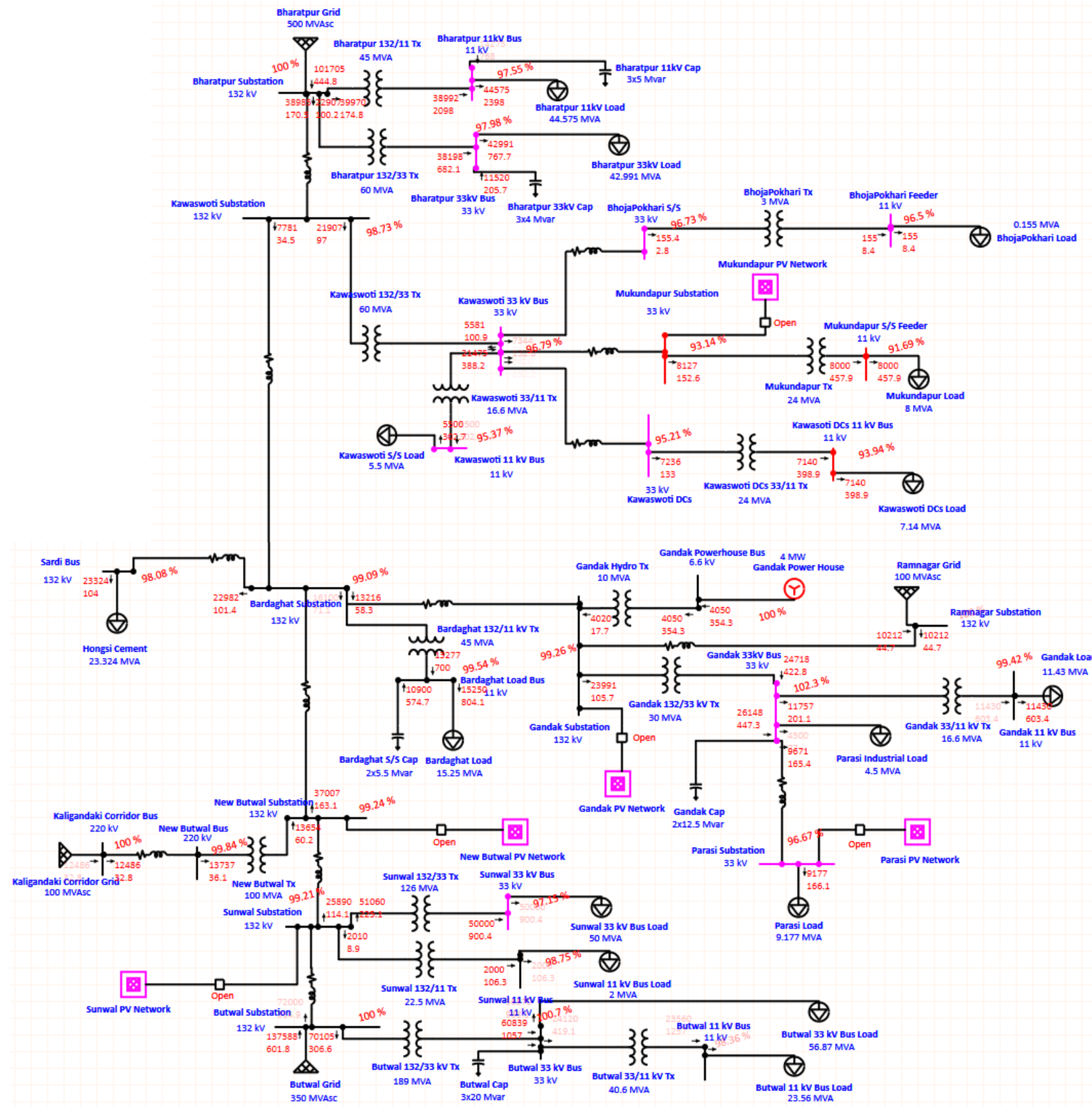


Figure 4.1: Load Flow Analysis without PV Penetration

4.1.3 Voltage Profile

Figure 4.3 shows the voltage profile of all the substation point where the PV is penetrated. The voltage profile, upon interconnection of the PV Plant improves. The improvement is observed noticeably in Mukundapur and Parasi Substation with 95.05% and 100.5% of rated value voltage respectively. The primary cause of voltage rise at the Mukundapur and Parasi substations is the integration of large photovoltaic (PV) plants into the lower voltage 33 kV grid, as opposed to the higher voltage 132 kV transmission line.

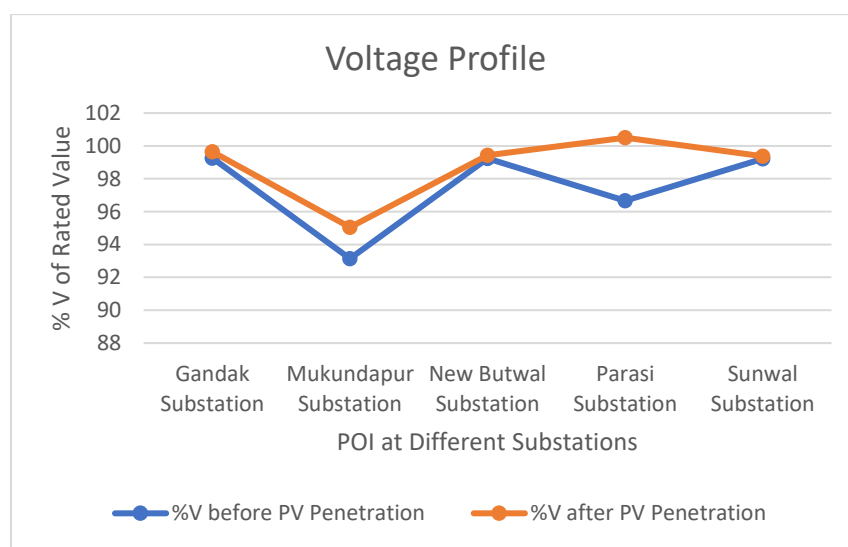


Figure 4.3: Voltage Profile before and after PV Penetration

4.1.4 Branch Loading

As observed in the figure 4.4, Most of the Substations transformers loading is not affected whereas some of the transformer loading has decreased due to penetration of PV Power Plants. The loading of Gandak 132/33 kV transformer has decreased from 80% to 40.1%, Kawaswoti 132/33 kV transformer decreased from 35.8% to 25.8% and New Butwal decreased from 13.7% to 4.9%. Hence the loading of the branch improves upon interconnection of the PV System. However, during light load conditions, reverse power flow from the PV system can potentially overload the substation transformer.

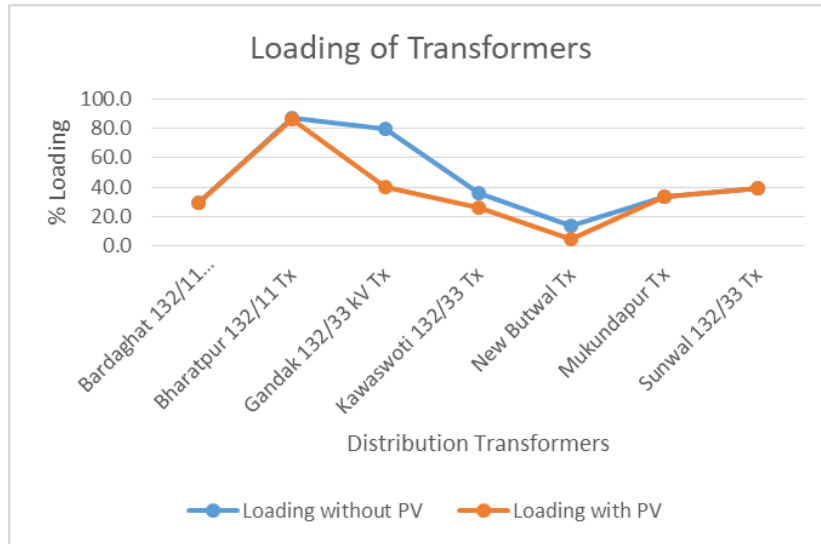


Figure 4.4: Branch loading before and after PV penetration

4.1.5 Losses in Transmission Line

Integrating distributed energy sources, such as photovoltaic (PV) plants, can significantly reduce these losses. Figure 4.5 shows losses in line before and after penetration of the PV into the grid. For example, losses in the Kawaswoti- Mukundapur Transmission Line were reduced from 172.8 kW to 106.4 kW. In the New-Butwal to Sunwal Transmission Line, losses dropped from 25.7 kW to 1.0 kW, while the Sunwal-Butwal Transmission Line saw a reduction from 266.1 kW to 48.4 kW. Hence the losses in the transmission line network reduced significantly upon interconnection of the PV Plant into the grid.

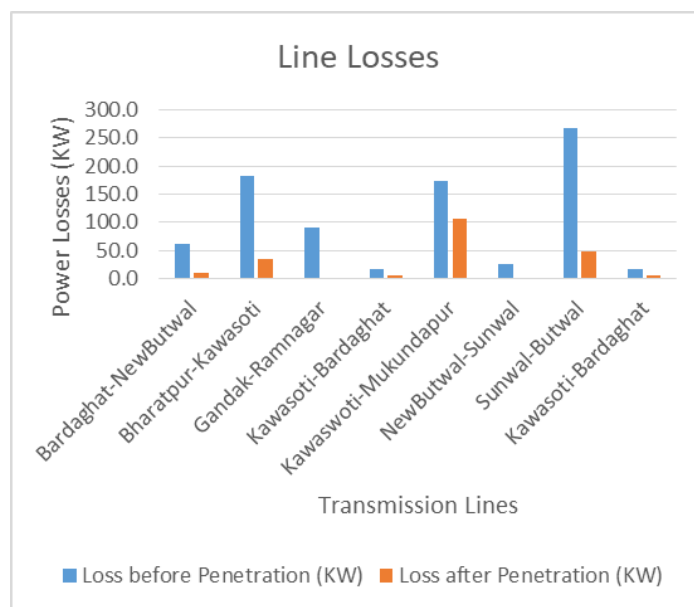


Figure 4.5: Line Losses before and after penetration of PV

4.2 Short Circuit Analysis

4.2.1 Short Circuit Analysis without PV Interconnection

The short circuit Analysis has been done to find the maximum interrupting duty. The three phase fault was calculated. The three phase short circuit current before interconnection of PV is shown in figure 4.6 below with fault at different bus location, where PV plant will be connected afterwards. The overall short circuit report is presented in Appendix C.1.

The LG and LLG fault along with three phase fault current before penetration of PV was calculated at different buses and the results are tabulated below in Table 4.1.

Table 4.1: Fault Current Contribution before PV Penetration

S.N.	Fault Point Substations	Three Phase Fault (KA)	L-G Fault (KA)	L-L-G Fault (KA)
1	Mukundapur	3.317	1.669	1.113
2	Gandak	5.684	3.749	2.795
3	Parasi	2.864	1.222	0.776
4	New Butwal	6.818	6.384	5.992
5	Sunwal	6.969	5.091	4.008

4.2.2 Short Circuit Analysis with PV Interconnection

The PV Plants are connected and short circuit analysis was done. The injection of PV power into the grid increases the short circuit current in the system which may affect the interrupting duty of protective systems. The figure 4.7 shows the three phase fault contribution if fault occurs at respective buses. The table 4.2 shows all the data for L-G, L-L-G and three phase fault current. The overall short circuit report is presented in Appendix C.2.

Table 4.2: Fault Current contribution after PV Penetration

S.N.	Fault Point Substations	Three Phase Fault (KA)	L-G Fault (KA)	L-L-G Fault (KA)
1	Mukundapur	3.526	1.693	1.17
2	Gandak	6.002	3.762	2.892
3	Parasi	3.183	1.224	0.844
4	New Butwal	7.231	6.476	6.284
5	Sunwal	7.389	5.149	4.186

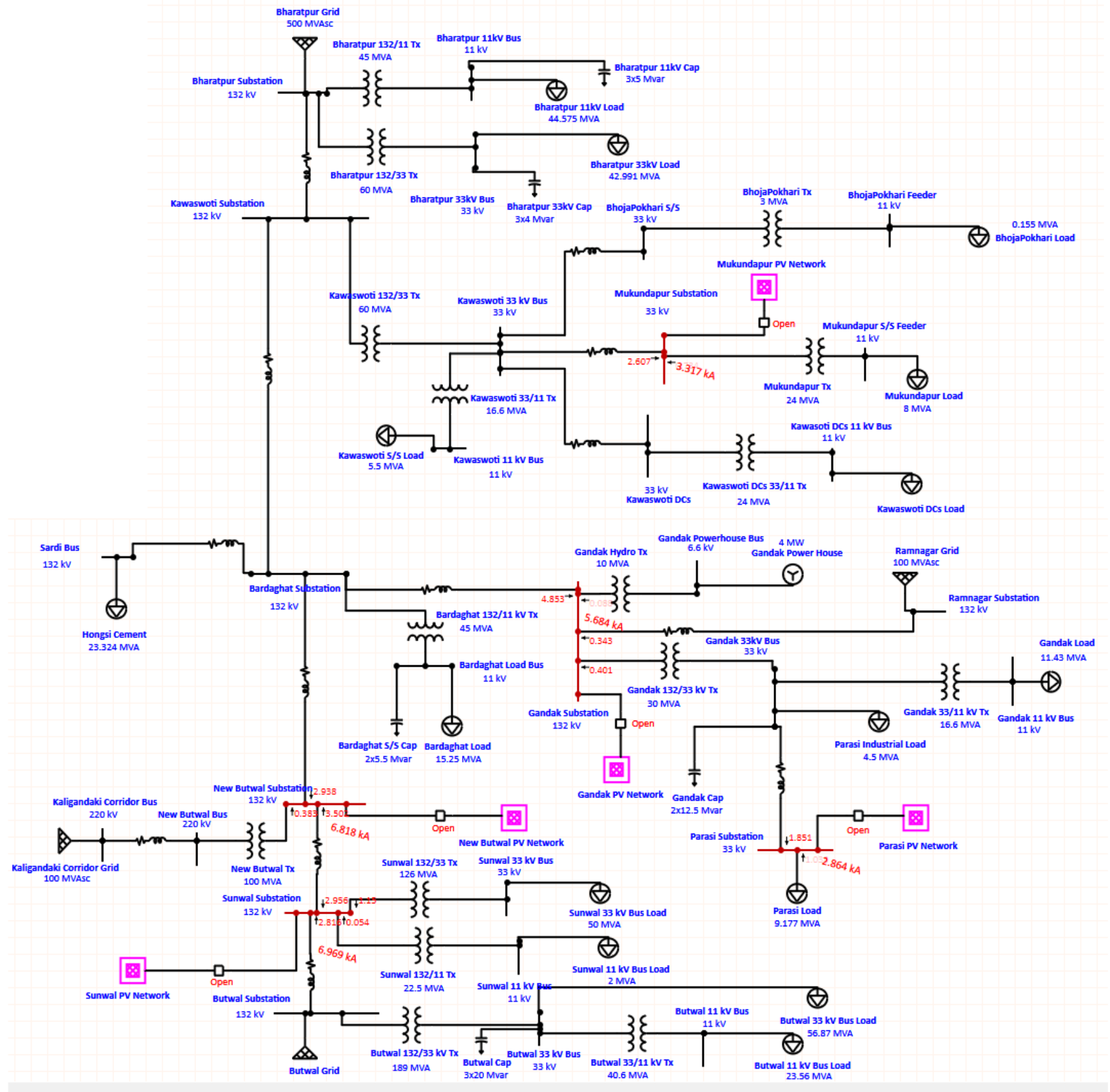


Figure 4.6: Three phase fault contribution without PV interconnection

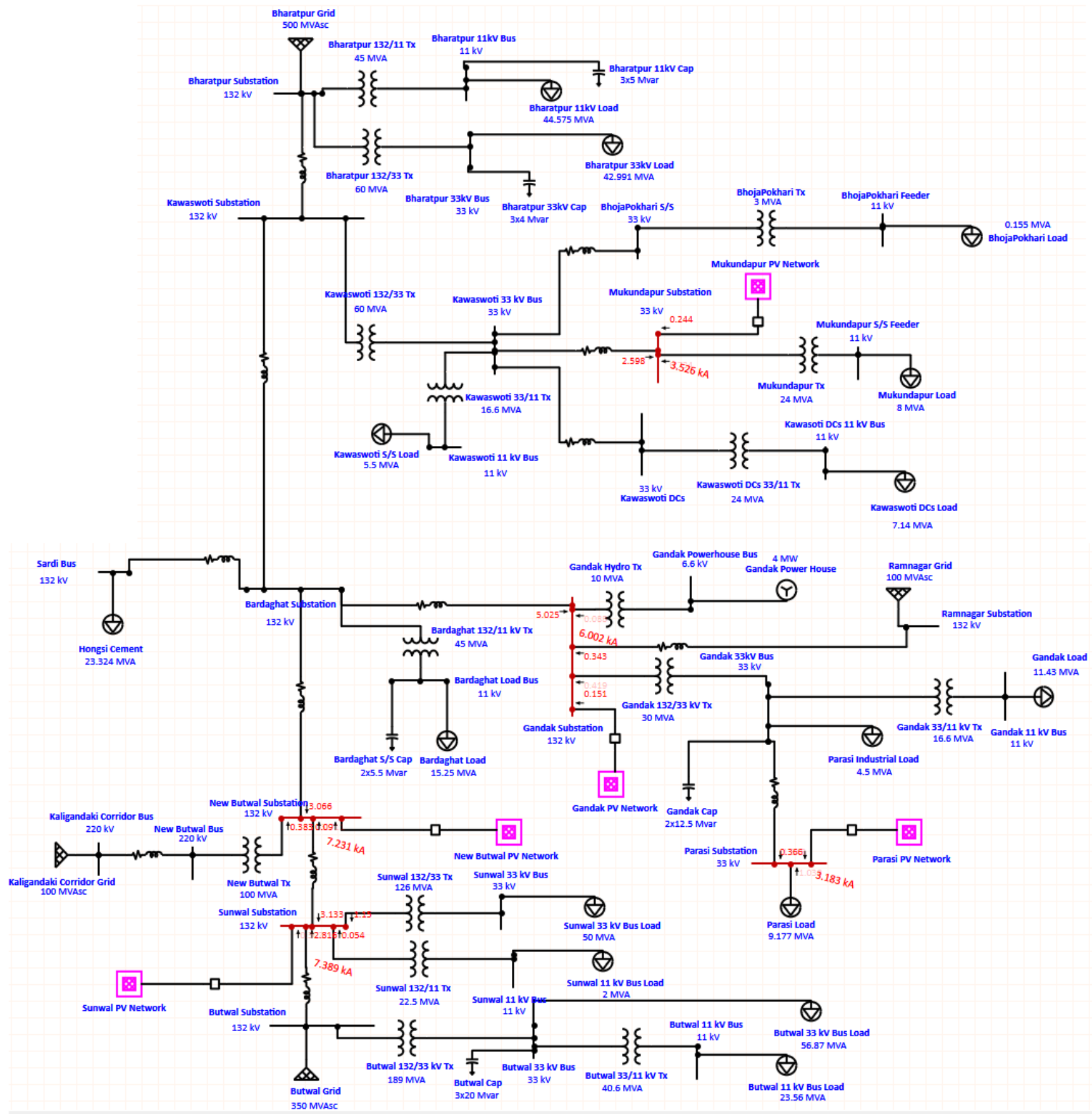


Figure 4.7: Three Phase Fault Current after penetration of PV

4.2.3 Short Circuit Fault Current Comparison

The short circuit fault current before and after interconnection of PV is shown in Figure 4.8.

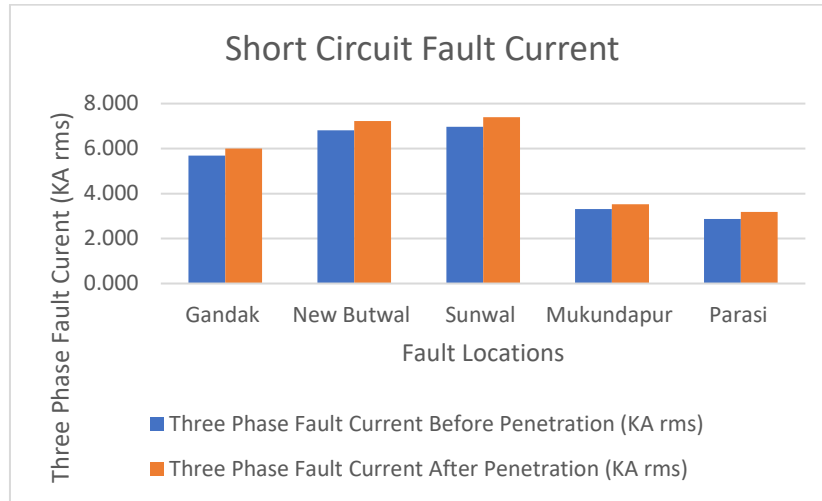


Figure 4.8: Three Phase Short Circuit Current before and after penetration of PV

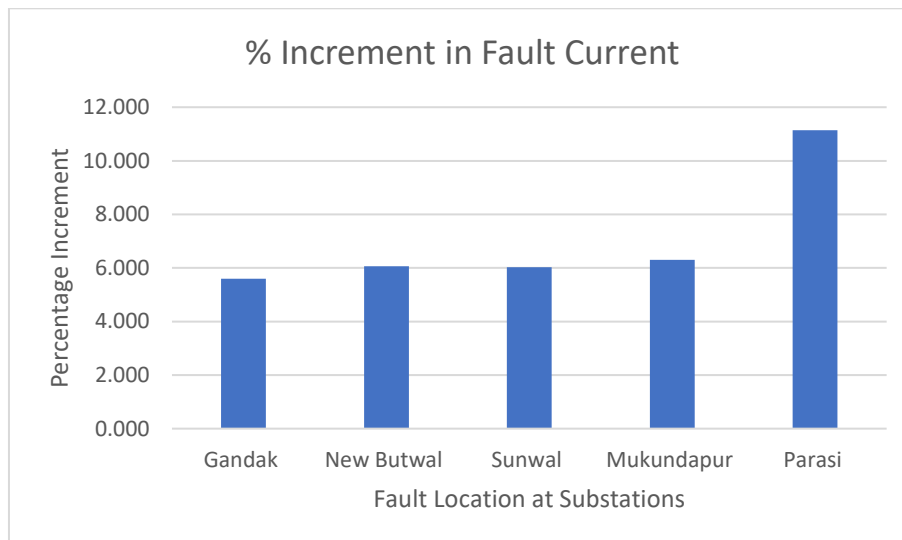


Figure 4.9: Percentage Increment in Fault current due to PV Penetration

The PV penetration to the grid increases the fault current which may affect the interrupting duty of the Protective device. The three phase fault current has increases slightly upon interconnection of PV Power Plant. The maximum increment is seen in Parasi Substation bus bar with greater than 10% increment. However the short circuit current does not exceed 87.5% of the interrupting capacity of protective devices. So the interconnection of PV Power Plant does not have serious impact on fault duty.

4.3 Voltage Flicker Analysis

The PV power plant depends on the intensity of the sunlight. Due to the intermittency of the source, the power output of PV plant may vary accordingly. If the voltage variation is large, then it might cause Flickering issue to the consumer. Since PV Power is intermittent in nature, the voltage Flicker analysis must be done. At point of Interconnection, the Voltage Flicker should not cross 3% [17]. To see the voltage differences upon disconnection of PV output, the transient condition of voltage is seen on the same bus where PV plant is connected. To observe the voltage fluctuation, an event has occurred, where the circuit breaker of respective PV plant will be in off position in 5 Sec of simulation. Then, the difference of voltage before and after PV disconnection is observed.

4.3.1 Voltage Flicker at Mukundapur and Parasi Substation

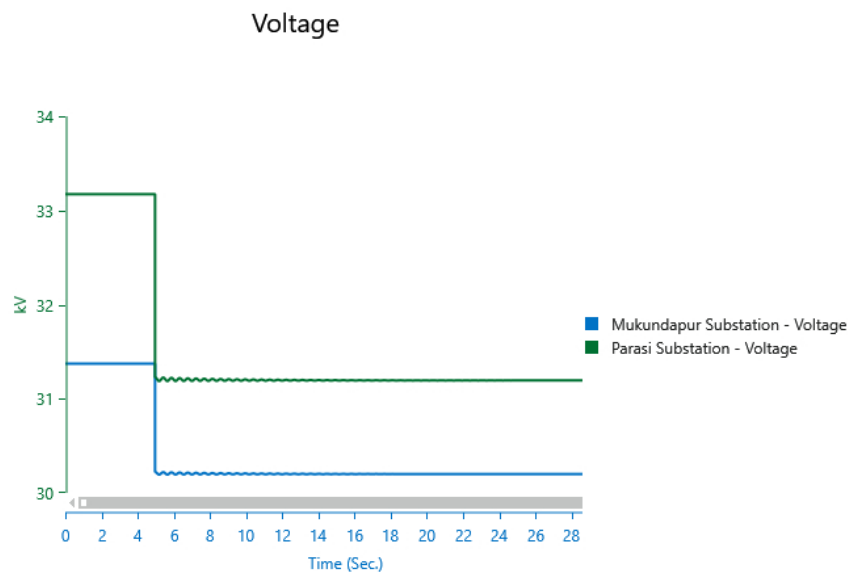


Figure 4.10: Voltage Flicker at Mukundapur and Parasi Substation

Figure 4.10 shows the voltage variation after the disconnection of PV Plant after 5 sec of simulation time. When the circuit breaker of respective PV Plant opens, the voltage dropped from 31.35 kV to 30.6 kV resulting in 2.39% in Mukundapur and 33.2 kV to 31.5 kV resulting in 5.12% reduction in Parasi Substation at POI. The voltage flicker at Mukundapur Substation is within the range, however the voltage flicker at Parasi Substation is greater than 3%.

4.3.2 Voltage Flicker at Gandak, Sunwal and New-Butwal Substation

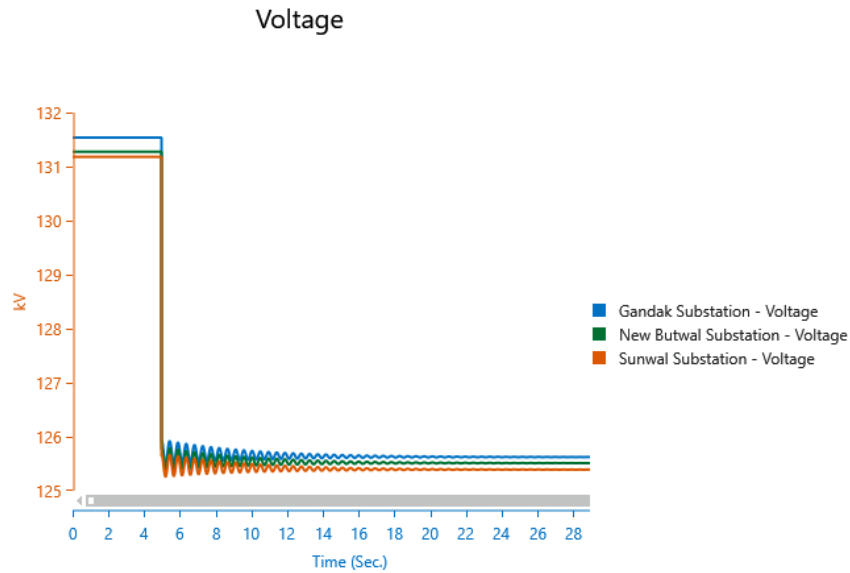
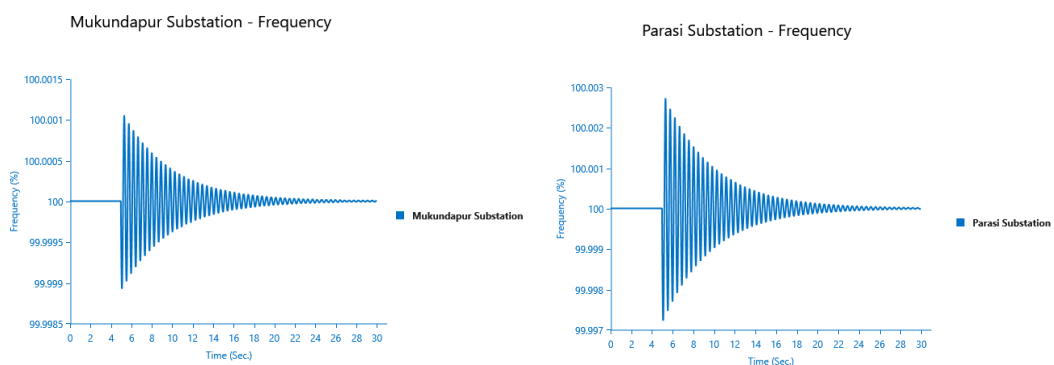


Figure 4.11: Voltage Flicker at Gandak, Sunwal and New-Butwal Substation

After 5 seconds, the circuit breaker of the PV power plant was opened, leading to voltage fluctuations, as shown in Figure 4.8. The voltage dropped from 131.6 kV to 129.3 kV at Gandak Substation, a 1.75% decrease. At Sunwal Substation, the voltage declined from 131.5 kV to 127.1 kV, resulting in a 3.346% reduction. Meanwhile, at New-Butwal Substation, the voltage decreased from 131.3 kV to 129.8 kV, reflecting a 1.142% drop. The voltage flicker at Sunwal Substation exceeds 3%, whereas at Gandak and New-Butwal Substations, it remains within acceptable limits.

4.4 Frequency Response of the System upon PV disconnection

The transient frequency was analyzed in the simulation. The PV Plants was made to disconnect in 5 sec and the base model was check whether the system do have capacity to maintain the frequency within the limit or not.



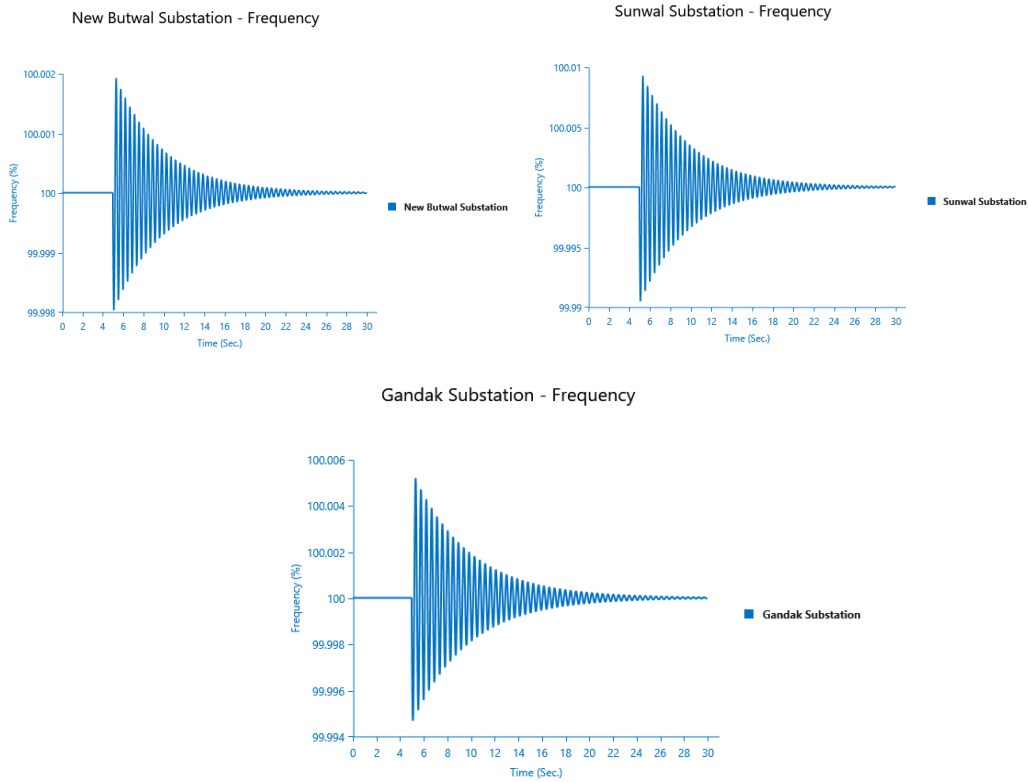


Figure 4.12: Frequency Response of Grid upon PV disconnection

Figure 4.12 shows that the transient frequency response of the system is stable. The system can maintain the frequency within the limit upon disconnection of the PV Power Plants.

4.5 Harmonics Study upon interconnection of PV

As photovoltaic (PV) systems become increasingly integrated into modern power grids, concerns about power quality issues such as harmonics have grown significantly. Harmonics are voltage or current components at frequencies that are integer multiples of the fundamental frequency. These are undesirable in a power system because they can lead to overheating of equipment, malfunctioning of protection devices, and increased losses. In this study, the 12 pulse inverter is modelled to convert the generated DC to AC power. The harmonics spectrum of 12 pulse inverter is shown in figure 4.13 [18].

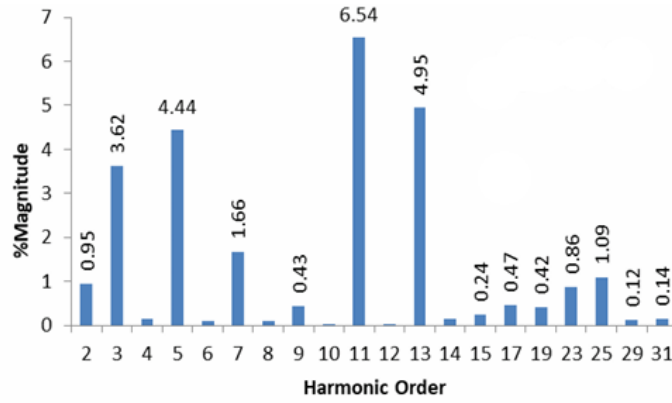


Figure 4.13: Harmonics Spectrum of 12 pulse Converter

The harmonics appeared due to penetration of PV plants is shown in figure 4.11. Due to the penetration of PV, Harmonics has appeared in the system exceeding 5%. The maximum harmonics has appeared in Parasi Substation with 15.38%. Other substation has also suffered harmonics more than 5%. Hence a single tuned filter is designed to eliminate the 11th harmonics present dominantly.

After connecting a single-tuned filter, the harmonic levels at all five substations were significantly reduced and brought within the 5% limit. The harmonic levels before and after the installation of the single-tuned filter are presented in the table 4.3 below. The harmonics after incorporating single tuned filter at five specified substations is shown in figure 4.15

Table 4.3: Harmonics before and after employing filter

S.N	Substations	Harmonics before employing filter (THD) %	Harmonics after employing filter (THD) %
1.	Mukundapur	12.26	1.26
2.	Gandak	8.34	2.19
3.	Parasi	15.38	1.72
4.	New Butwal	7.09	1.22
5.	Sunwal	6.44	1.67

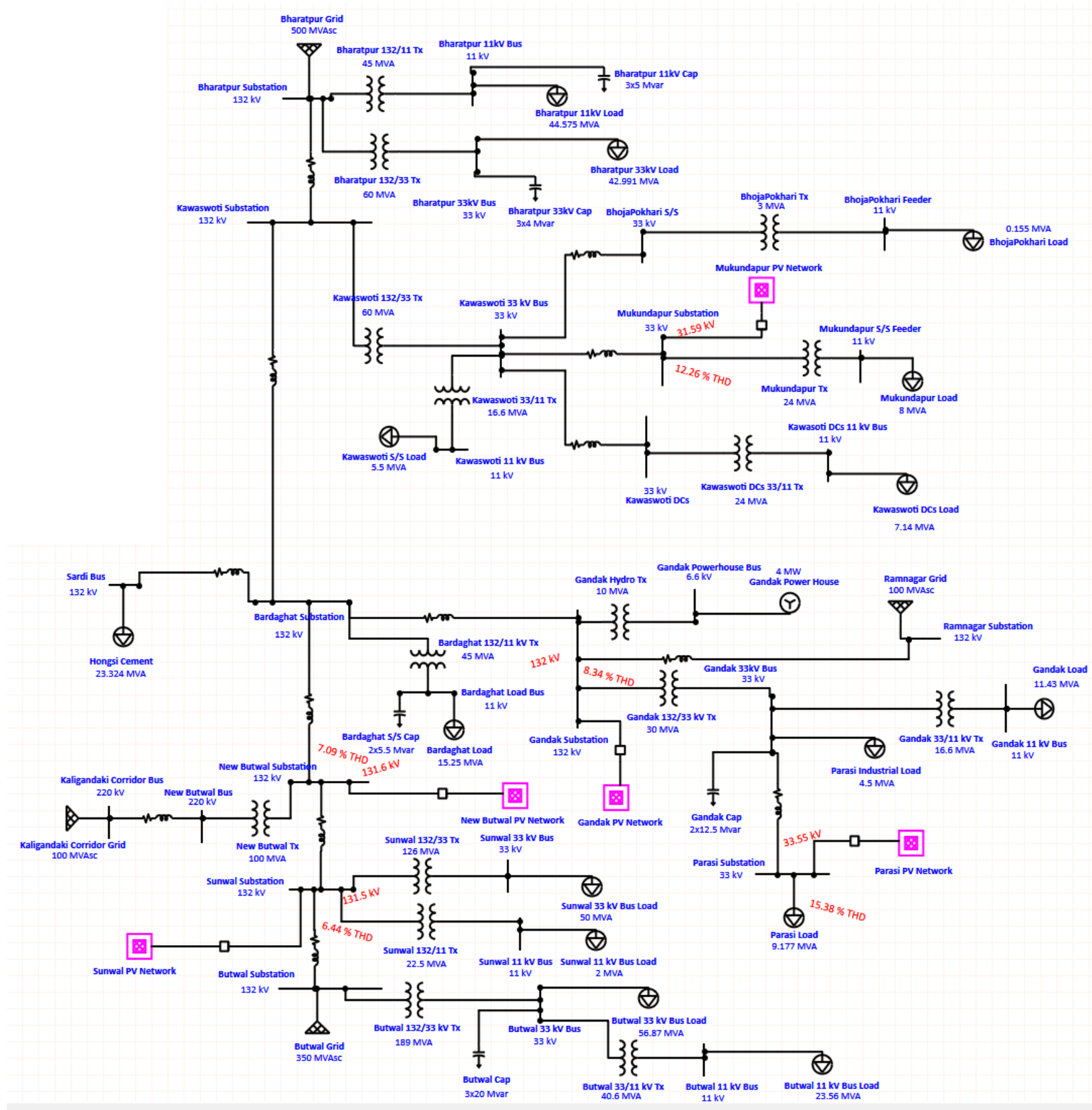


Figure 4.14: Harmonics due to penetration of PV

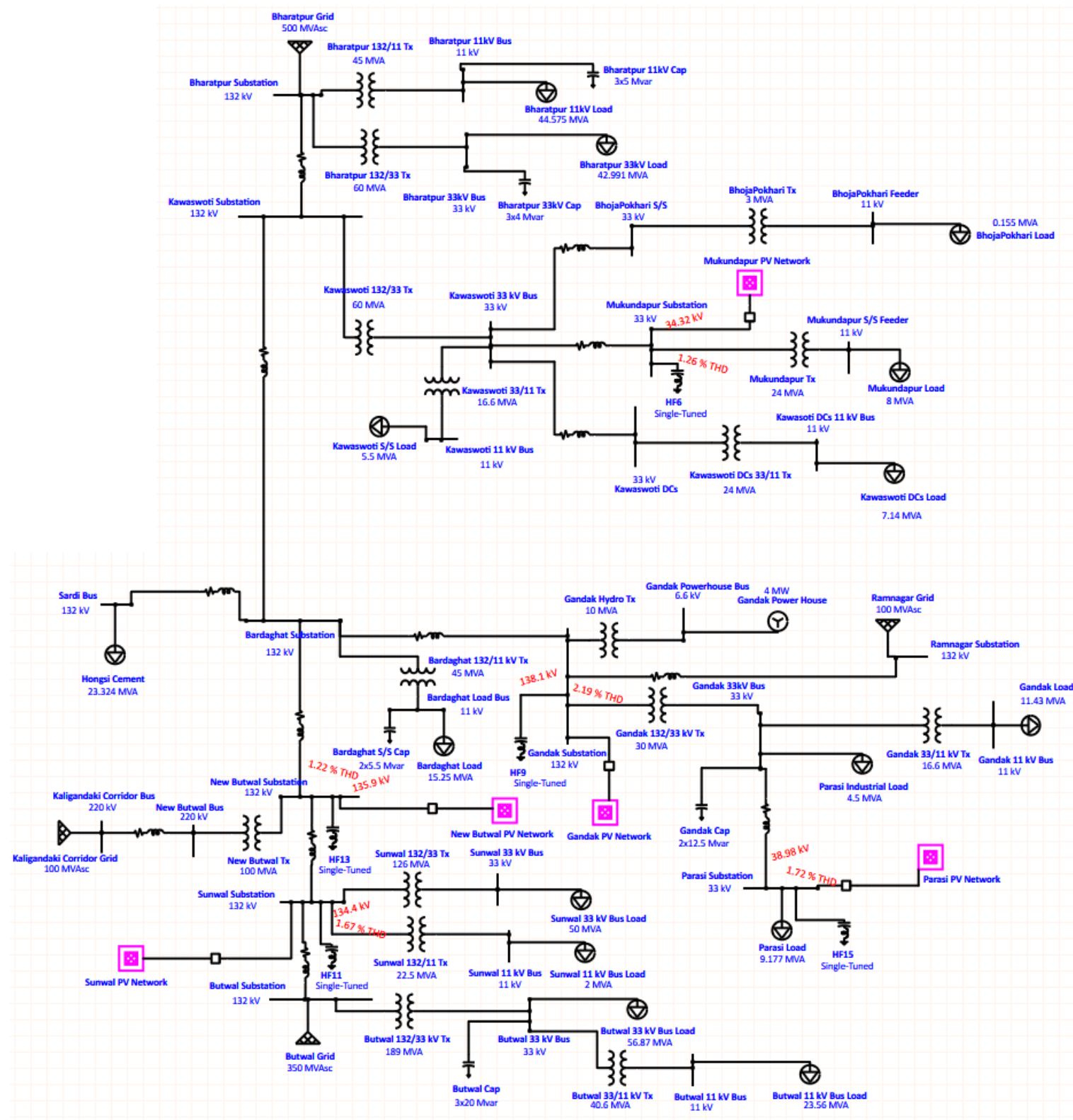


Figure 4.15: Applying single tuned filter to reduce harmonics

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

The actual transmission line network of the Parasi and Nawalpur districts was modeled using ETAP software. Simulation results indicate that, with minor mitigating measures, the interconnection of PV plants has positive impacts on the grid.

5.1 Conclusions

During load flow analysis, the voltage profile at the Mukundapur and Parasi substations improved to 95.05% and 100.5% of nominal, respectively. Slight voltage improvements were also observed at the Gandak, New Butwal, and Sunwal substations. Transformer loading was significantly reduced: Gandak's 132/33 kV transformer from 80% to 40.1%, Kawaswoti's from 35.8% to 25.8%, and New Butwal's from 13.7% to 4.9%. Line losses also decreased notably: from 172.8 kW to 106.4 kW in the Kawaswoti–Mukundapur line; from 25.7 kW to 1.0 kW in the New Butwal–Sunwal line; and from 266.1 kW to 48.4 kW in the Sunwal–Butwal line. These results show that both transformer loading and line losses improved following PV interconnection.

Upon PV penetration, the short circuit current during three-phase, L-G, and L-L-G faults increased slightly across the grid. Except for the Parasi substation, all increases were within a 10% range. At Parasi, the fault current increased by approximately 11%, reaching 3 kA. However, since the interrupting capacity of the Parasi substation is 25 kA, the system remains well within safe operational limits. Therefore, PV interconnection does not pose a significant issue during fault conditions.

A worst-case scenario was analyzed by simulating the disconnection of the entire PV plant 5 seconds after the start of the simulation. Voltage flicker was found to be within acceptable limits (under 3%) at Mukundapur (2.39%), Gandak (1.75%), and New Butwal (1.142%). However, flicker violations were observed at Parasi (5.12%) and Gandak (3.346%). To mitigate this, it is recommended to operate the PV plants in a non-unity power factor mode. This reduces active power injection while supplying reactive power, thereby alleviating voltage flicker issues.

The dynamic response of the grid was tested by simulating the opening of the circuit breakers connected to the respective PV plants. Frequency remained stable and within permissible limits during the transient study.

Inverter-based PV systems are known sources of harmonics due to the DC-AC conversion process. Following interconnection, total harmonic distortion (THD) levels increased to 12.26% at Mukundapur, 8.34% at Gandak, 15.3% at Parasi, 7.09% at New Butwal, and 6.44% at Sunwal — all exceeding the 5% acceptable limit. To address this, single-tuned harmonic filters were modeled and installed at each substation according to their voltage level and reactive power needs. After filter deployment, THD levels were successfully reduced to 1.26% (Mukundapur), 2.19% (Gandak), 1.72% (Parasi), 1.22% (New Butwal), and 1.67% (Sunwal), all within permissible limits.

5.2 Recommendations

This study offers valuable insights into the integration of photovoltaic (PV) systems within a section of the Integrated Nepal Power System (INPS), providing a foundation for further exploration. Building upon this, future research could expand the scope to include the entire INPS network. Such an approach would help capture a wider range of operational scenarios and support more holistic conclusions about the nationwide impacts of PV integration.

While this study considered PV penetration under ideal operating conditions, future work could enrich the analysis by incorporating dynamic factors such as varying solar irradiance, partial shading, and real-time fluctuations. The inclusion of probabilistic modeling or real-time data analysis would further enhance the understanding of PV behavior under diverse environmental conditions.

Moreover, simulations in this study focused on maximum load scenarios to observe peak system behavior. Exploring seasonal and diurnal load variations in future research would provide deeper insights into system performance during off-peak periods, potentially uncovering new considerations for voltage stability, frequency regulation, and overall grid reliability.

An additional area that presents valuable opportunities for further investigation is the phenomenon of reverse power flow, particularly during periods of low demand and high PV generation. As PV penetration increases, understanding and managing reverse power flow becomes increasingly critical for maintaining grid stability and reliability.

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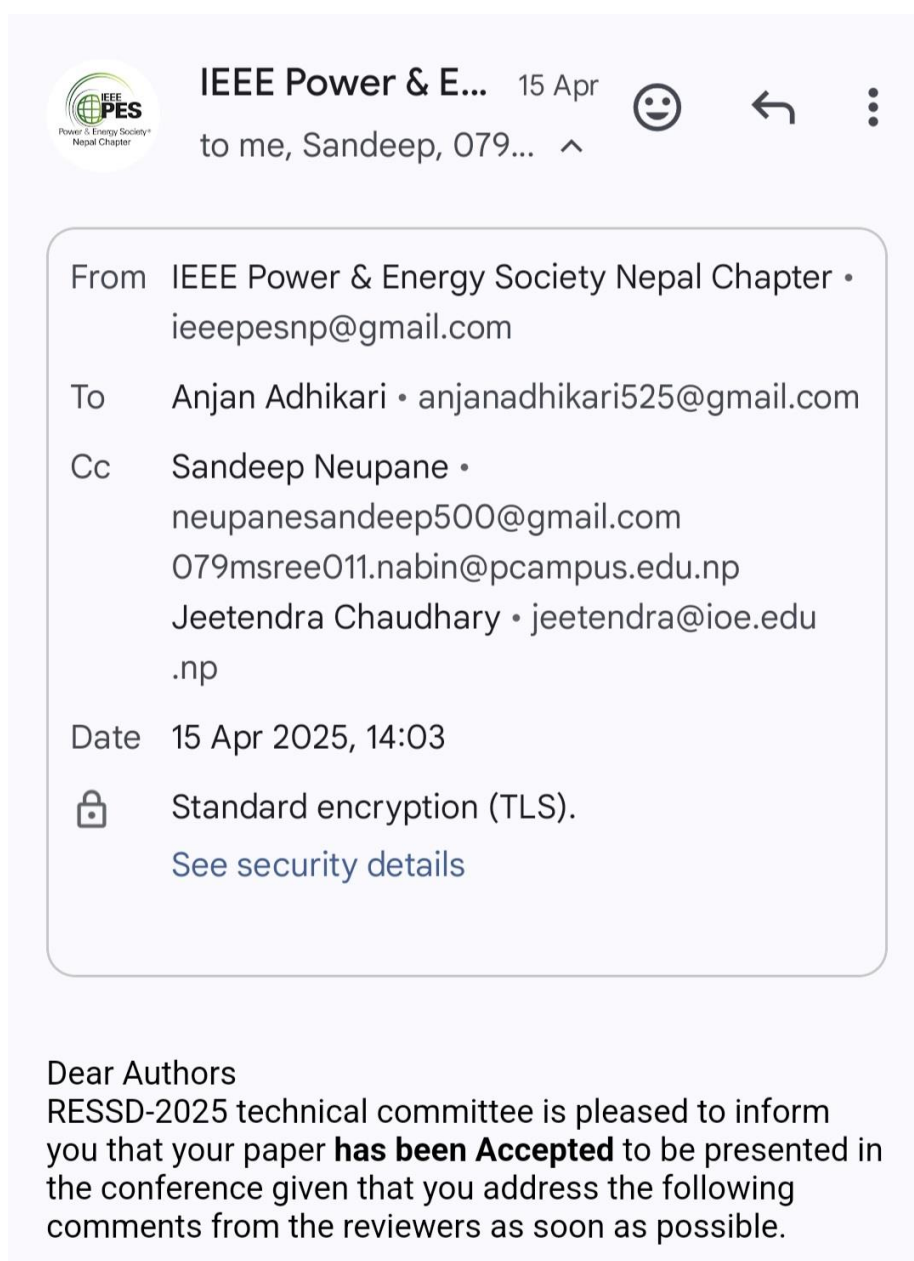
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APPENDICES

Appendix A: Publication

Title	Authors	Year	Conference	Comments
Performance Evaluation with Large-Scale Solar PV Integration to Grid: A Case Study of Nepalese Transmission Networks	Anjan Adhikari, Jeetendra Chaudhary, Sandeep Neupane, Nabin Raj Chaulagain	2025	IEEE Power & Energy Society Nepal Chapter	Accepted



The image shows a screenshot of an email notification. At the top left is the IEEE PES Nepal Chapter logo. The sender is 'IEEE Power & E...' and the date is '15 Apr'. The recipient is 'to me, Sandeep, 079...'. The email body contains the following information:

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Dear Authors
RESSD-2025 technical committee is pleased to inform you that your paper **has been Accepted** to be presented in the conference given that you address the following comments from the reviewers as soon as possible.

Performance Evaluation with Large-Scale Solar PV Integration to Grid: A Case Study of Nepalese Transmission Networks

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Abstract— Today's major concern over to reduce carbon footprint, it is increasing the development of clean and renewable energy to meet the energy requirements. In Nepal overall energy demand has been primarily met by hydropower electricity generation and some of solar photovoltaic (PV) power projects. The country aims to install a total electric capacity of 28,500 MW and export 15,000 MW to neighboring countries like India, Bangladesh and China by 2035 as per Energy Development Roadmap, 2081. To achieve this target, the Nepalese government is planning to integrate solar PV power plants into the grid alongside hydropower. Nepal is embracing this transition by incorporating PV plants to meet national energy demands and export surplus electricity. Recently, the Nepal Electricity Authority (NEA), a leading electric utility in Nepal, has issued Letters of Intent (LOI) for the grid connection of solar power plants in different parts of the country. This paper study and examines the grid impact of PV integration in the existing 33 kV and 132 kV transmission network line of Parasi and Nawalpur districts, mid-southern region of Nepal. The load flow analysis, flicker analysis, short circuit analysis and transient frequency analysis are carried to assess the effects of PV penetration at different locations of that area within the grid in ETAP platform. The key findings of this study provide insights into the different impacts as well as their performances and offer a concrete recommendations for maintaining grid stability and reliability.

Keywords—Photovoltaic, Nepal Electricity Authority, ETAP, Grid Stability

I. INTRODUCTION

Electrical energy is an essential necessity for modern human life, and its absence is unimaginable. In the case of Nepal, the total theoretical hydroelectric capacity is 83 GW, with 43 GW being technically and economically achievable [1]. However, with the increasing energy demand and the limitations of conventional power sources, the need to explore alternative renewable energy solutions has become crucial. Among the various renewable energy sources, solar PV power holds immense potential for Nepal due to its significant solar radiation availability throughout the year. It is estimated that solar PV potential in the country is around 47 GW [2]. Investing in high-efficiency photovoltaic (PV) systems can

play a vital role in enhancing energy security and sustainability of Nepal national grid.

The Integrated Nepal Power System (INPS) owned by NEA is Nepal's national grid and it is responsible for supplying power all across the country [3]. Till 2080/81 B.S., the total installed capacity connected to the grid has reached to 3164.12 MW, with 183.56 MW generated from Alternative Energy Sources like Micro Hydropower, Photovoltaic, Co-Generation and Thermal Plants. 2980.56 MW is contributed by hydropower (larger than 1 MW) out of which only 106 MW is produced by storage projects while the rest is contributed by ROR/PROR projects [4]. By the end of the fiscal year 2080/81 B.S., the total installed capacity of grid substations had reached 13,050 MVA and the transmission line circuit length has reached to 6507 km [5]. Since most of the plants are ROR/PROR type, Nepal is facing energy deficit in dry seasons. NEA imported 1,895 MU energy in dry season in fiscal year 2080/81 B.S. To meet growing electricity demand involves the establishment and expansion of large centralized power plants, transmission networks, and distribution infrastructures. Nowadays solar PV can generate in range of MW and GW scale worldwide and it is more technological friendly which enhances the performance of grid. Photovoltaic (PV) distributed generation (DG) units are appropriate for decentralized generation, as they can be installed near load centers, enhancing grid performance by reducing power losses and improving voltage stability [6].

In Nepal, standalone PV systems have been widely adopted for rural electrification, providing power to remote areas where grid extension is not feasible. In recent years, there has been a growing shift towards grid-connected solar power plants, driven by technological advancements and policy initiatives. The declining cost of PV systems, particularly with the reduction in battery storage dependency, has further accelerated the adoption of solar energy in Nepal. This transition towards distributed renewable energy resources, including PV systems, is expected to enhance energy access, grid stability, and sustainability in the country's power sector.

In Nepal, the integration of renewable energy into the national grid is critical to achieving the country's long-term

energy objectives. Solar power generation, with its potential to supplement hydropower during dry seasons, is an essential component of Nepal's energy diversification strategy. However, the deployment of large-scale PV plants presents unique technical challenges that must be addressed to ensure stable and reliable grid operation. PV energy production is intermittent and variable, causing voltage fluctuations in the power system. These fluctuations can affect supply and demand balance, leading to voltage instability [7]. These challenges are further compounded by potential overloading of grid infrastructure and disruptions to protection coordination. The detailed studies of PV impacts in INPS are still not found in literature. This paper focuses on these impacts and their performances to assess and mitigate of Nepal's national grid in mid-southern region at Nawalpur and Parasi districts.

In this paper, a detailed modeled of transmission line network of Nawalpur and Parasi District is modelled and simulations has been carried out to understand the basic model before penetration of PV plant to the grid. Then the study compares the voltage profile, branch loading, line losses, short circuit, and flicker analysis before and after the penetration of PV plant to the grid system.

II. EXISTING TRANSMISSION LINE OF NAWALPUR-NAWALPARASI DISTRICTS

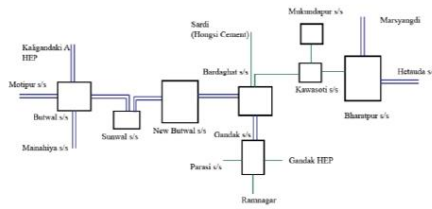


FIGURE 1: TRANSMISSION LINE OF NAWALPARASI-NAWALPUR DISTRICTS

Figure 1 illustrates the transmission line network within study zone. Nawalpur-Parasi are the mid-southern Terai districts of Nepal. The Bharatpur Substation is situated in the eastern region of Nawalpur district and is connected to Marsyangdi, Damauli and Hetauda Substation to the east. To the west, the Bharatpur Substation is linked to Kawaswoti Substation via a 132 kV transmission line spanning 36 km. The three feeder connect to the Kawaswoti Substation: Mukundapur, Bhojapokhari and Kawaswoti DCS. A transmission extending approximately 34 km leads to Bardaghat Substation located in the eastern part of Parasi District. The Gandak Substation, positioned to the south of the Bardaghat substation, is connected through a 132 kV transmission line. Gandak Hydropower station with an install capacity of 15 MW, currently operating at around 4 MW linked to the Gandak Substation. The Bardaghat Substation, to its western part, is connected through a 132 kV double circuit line to the New-Butwal Substation. The 220 kV transmission line originating from the Kaligandaki-Corridor is stepped down to 132 kV at this substation. The New-Butwal Substation is connected to Sunwal Substation to the west via a 132 kV transmission line of 12 km in length. Additionally, the Sunwal Substation is linked to the Butwal Substation by a 16 km long 132 kV transmission line. The Butwal Substation is linked to three primary areas: Kaligandaki hydropower to

the north, Motipur to the west and Mainahiya to the south [3]. The eastern section of Bharatpur Substation, the western section of Butwal Substation, and the southern section of Gandak Substation are modelled as a grid in Simulation.

III. METHODOLOGY

This section describes the design and process of the work we have done from preliminary phase to its completion. The existing transmission line is modelled, solar PV system is designed, and study is done before and after penetration of PV into the grid.

A. Transmission System Network

First, the transmission line, feeder and load data are collected. The transmission line of Nawalpur and Parasi Districts is taken for study. Fig 2 below shows the simulation model of Transmission line network for study.

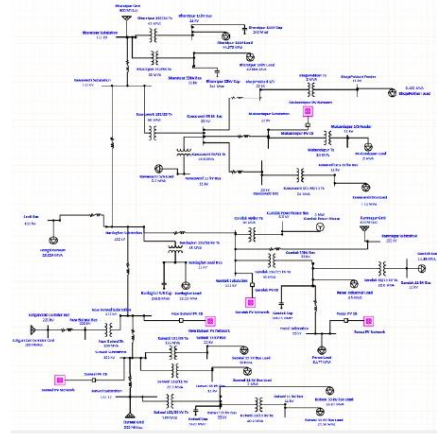


FIGURE 2: TRANSMISSION LINE WITH PV MODEL IN SIMULATION

This transmission line network consists of different substations. The PV plant is connected to five major substations: Mukundapur, Gandak, Parasi, New-Butwal and Sunwal Substations. The transmission line parameters, line loading information is extracted from annual report 2080-81 of Nepal Electricity Authority (NEA) [3].

Table 1 shows the details of transmission line network with information like Voltage level, circuit length, conductor used and circuit configuration.

TABLE 1: TRANSMISSION LINE DETAILS

S. N	Transmission Line	Voltage (kV)	Length (km)	Conductor	Circuit
1.	Bharatpur-Kawaswoti	132	36	Panther	Single
2.	Kawaswoti-Bardaghat	132	34	Panther	Single
3.	Bardaghat-Gandak	132	14	Panther	Double
4.	Gandak-Rannagar	132	10	Panther	Single
5.	Bardaghat-New Butwal	132	14	Bear	Double

6.	New Butwal-Sunwal	132	12	Bear	Double
7.	Sunwal-Butwal	132	16	Bear	Double
8.	Kaligandaki Corridor TL- New Butwal	220	44	ACCC Drake	Double
9.	Kawaswoti S/S- Bhojpokhari	66	14	Dog	Single
10.	Kawaswoti S/S- Mukundapur	66	14	Dog	Single
11.	Kawaswoti S/S- Kawaswoti DCS	66	7	Dog	Single
12.	Gandak-Parasi	66	20	Dog	Single
13.	Bardaghat-Sardi	132	23	Bear	Single

Table 2 shows the connected load capacity at rated voltage level at different substations.

TABLE 2: LOAD DATA DETAILS

S.N.	Substations	Voltage Level (kV)	Capacity (MVA)
1.	Bharatpur	11	44.575
2.	Bharatpur	33	42.991
3.	BhojPokhari	11	0.155
4.	Mukundapur	11	8
5.	Kawaswoti DCS	11	7.14
6.	Kawaswoti S/S	11	5.5
7.	Sardi	33	23.324
8.	Bardaghat S/S	11	15.25
9.	Gandak S/S	33	4.5
10.	Gandak S/S	11	11.43
11.	Parasi S/S	33	9.177
12.	Sunwal S/S	33	50
13.	Sunwal S/S	11	2
14.	Butwal S/S	33	56.87
15.	Butwal S/S	11	23.56

B. Power flow Study

Load flow study is very crucial to know the circuit performance and to plan for the future expansion as well. It helps to know the different electrical parameters like voltage, current and power flow at different node and branches. The goal of a power flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions [8].

The Y bus can be written as:

$$(Y_{Bus}) = \sum_{i=1, i \neq k}^n Y_{ik} \quad (1)$$

The nodal current is calculated as,

$$I_k = \sum_{i=1, i \neq k}^n Y_{ik} V_k \quad \text{where } i=1, 2, \dots, n \quad (2)$$

The complex power delivered to bus k is given by,

$$S_i = P_i + j Q_i = V_i \left[\sum_{t=1, t \neq k}^n Y_{ik} V_k \right]^* \quad (3)$$

Separating real and imaginary parts, Power balance equations can be written as,

$$P_i = \sum_{k=1}^n |V_i| |V_k| Y_{ik} \cos(\theta_{ik} + \delta_k - \delta_i) \quad (4)$$

$$Q_i = - \sum_{k=1}^n |V_i| |V_k| Y_{ik} \sin(\theta_{ik} + \delta_k - \delta_i) \quad (5)$$

We have,

$$\Delta f = J \Delta X$$

Where, J is Jacobian matrix

$$\Delta P_i = P_{i(sp)} - P_{i(cal)} \quad (6)$$

$$\Delta Q_i = Q_{i(sp)} - Q_{i(cal)} \quad (7)$$

Where the subscripts sp and cal refers to specified and calculated value respectively. Then equation (6) and (7) can be written as,

$$J \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (8)$$

Where J is Jacobian matrix, contain partial derivatives of power equations.

In this way, the change in power angle and change in voltage is determined and power flow solutions of the network is obtained.

C. Photovoltaic Power Plant Design

There are altogether 5 solar Plants, which are planned to connect in Parasi and Nawalpur district of Nepal. Nepal Electricity Authority (NEA) has awarded five project at different locations with different capacity. The list of awarded projects are listed in Table 3.

TABLE 3: DIFFERENT SOLAR PROJECTS AWARDED BY NEA IN NAWALPARASI DISTRICT

S.N	Name of Bidder	Proposed Substation	Awarded Capacity
1.	Kalika Sunlight Power Limited	Mukundapur	10 MW
2.	Mountain-Dordi Consortium	Gandak	25 MW
3.	Golyan Power - Pure Energy JV	Parasi	15 MW
4.	Golyan Power - Pure Energy JV	New Butwal	15 MW
5.	Gogreen Energy Pvt. Ltd.	Sunwal	50 MW

1) Solar PV Panel Specification

The solar panel of Trina Solar (715wp) cell is selected for study. The electrical specification of the PV panel is presented in Fig 3.

Electrical Data (STC & NOCT & BNPI) TSM-XXXNEG21C.20 (XXX-705-725)				
S.N	Testing Condition	STC	NOCT	BNPI
1.	Peak Power Watts- P _{MAX} (Wp)	715	547	792
2.	Binning Tolerance - P _{MAX} (W)	0 ~ +5		
3.	Maximum Power Voltage - V _{MPP} (V)	41.1	38.7	41.1
4.	Maximum Power Current - I _{MPP} (A)	17.40	14.14	19.28
5.	Open Circuit Voltage - V _{OC} (V)	49.2	46.7	49.2
6.	Short Circuit Current - I _{SC} (A)	18.44	14.86	20.43
7.	Module Efficiency η (%)	23		
STC: Irradiance 1000w/m ² , Cell Temperature 25 degree Celsius, Air Mass AM 1.5				
NOCT: Irradiance 800w/m ² , Ambient Temperature 20 degree Celsius, Wind Speed 1m/s				

FIGURE 3: ELECTRICAL SPECIFICATION OF A PV PANEL

2) Inverter Specification

The inverter of Sungrow manufacturer (Model SG 2500HV-MV) is used for the design. The specification of the inverter is shown below in Figure 4.

S.N	Parameters / Designation	SG 2500HV-20
Input (DC)		
1.	Max PV Input Voltage	1500 V
2.	Min PV Input Voltage	800 V / 840 V
3.	MPP Voltage range for nominal power	800-1300 V
4.	Max PV Input Current	3508 A
Output (AC)		
5.	AC Output Power	2750 KVA @ 45 degree Celsius
6.	Max AC Output Current	2886 A
7.	Nominal AC Voltage	550 V
8.	AC Voltage Range	495-605 V
9.	THD	< 3% (at nominal power)

FIGURE 4: INVERTER DATA SPECIFICATION

3) Design of Solar Farm

At first, the design of one solar array suitable to give input to inverter as specified in Fig 4 is done. PV array should design in such that it can give maximum power of 2500 KW to the inverter as an input. Since the power output of one solar panel is 715 Watt Power.

Assuming oversizing of PV Array by factor of 1.1. We get, Total PV Panels for 2750 KWp power = $(2750 \times 1000) / 715 = 3846.15$

So, 3846 panels will be selected.

Open circuit voltage of a PV panel is 49.2 V.

From inverter datasheet we have,

Maximum DC voltage is 1500V and Minimum DC voltage to start is 840 V.

So, Minimum Panels in a string = $(840/49.2) = 17.073 \sim 17$ Panels

Maximum Panels in a string = $(1500/49.2) = 30.48 \sim 30$ Panels

Deploying 25 Panels in a series in an array, we get

Voltage input to inverter = $25 \times V_{oc} = 25 \times 49.2 = 1230 \text{ V} < 1500 \text{ V}$.

Panels in a parallel in an array = Total panels / Panels in a series

$$= 3846/25 = 153.84 \sim 153 \text{ Panels}$$

Current injected into the input of inverter = $153 \times I_{sc} = 153 \times 18.44 = 2821.32 \text{ A} < 3508 \text{ A}$.

So, for one inverter of SG2500HV-20, we require a string of 25 panels in series and 153 panels in parallel to compliance with the specifications of PV panel and inverters.

4) Layout of grid connected PV system with the central inverters

The different capacities of PV Plant is connected to the grid at different locations. Let us take one design of 10 MW of PV Plant which will be connected at Mukundapur Substation at Nawalpur district. There are two distribution transformers, each with a rating of 5 MVA. The modules were distributed across 4 arrays, with each pair of arrays connected

to one transformer through two separate central inverters. The primary sides of the two transformers are connected to the 11 kV grid bus bar. The 11 kV will be stepped up to either 33 kV or 132 kV on the basis of point of interconnection. The inverters are connected to the panels in such a way that each inverter is connected to 153 parallel strings, and each string consists of 25 modules connected in series. Fig 5 below presents the connection scheme of the arrays, inverters, transformers, and bus bars.

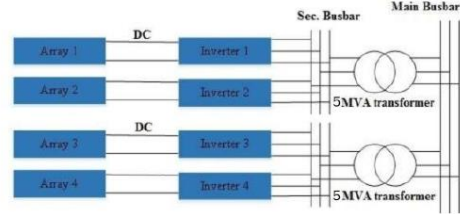


FIGURE 5: CONNECTION DIAGRAM OF PV ARRAY INTO THE GRID

D. Methodology of the Study

To meet the proposed objectives of the thesis, the following methodology will be implemented.

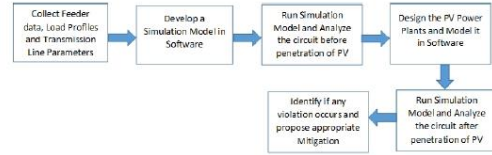


FIGURE 6: FLOWCHART OF METHODOLOGY

The flowchart mentioned in Fig 6 outlines a process for designing, modelling and analyzing the impact of photovoltaic (PV) in transmission line of Nepal. This thesis focuses on analyzing the impact of photovoltaic (PV) penetration into the power grid using ETAP software. The study begins with the collection of essential data, including feeder parameters, load profiles, and transmission line characteristics. This data is then used to develop a simulation model in ETAP, which allows for a detailed analysis of the circuit before integrating PV power.

Next, a solar power plant is designed and modeled within the software, after which it is integrated into the grid by connecting it to various substation bus bars. Once the PV system is incorporated, the circuit parameters are re-evaluated to assess any changes or impacts due to PV penetration. Finally, the study identifies any violations or technical issues arising from this integration and proposes suitable mitigation strategies to ensure stable and efficient grid operation.

IV. RESULTS AND DISCUSSIONS

The results are analyzed based on the different scenario. The comparative analysis of grid impact study before and after penetration of PV plants was compared.

A. Load Flow Analysis

The load flow is done in ETAP Simulation Software Which uses Adaptive Newton Raphson Method for study. The maximum Iteration is 99 and precision is 0.0001.

1) Voltage Profile

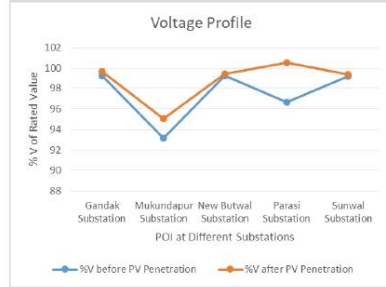


FIGURE 7: VOLTAGE PROFILE

Figure 7 shows the voltage profile of all the substation point where the PV is penetrated. The voltage profile, upon interconnection of the PV Plant improves. The improvement is observed noticeably in Mukundapur and Parasi Substation with 95.05% and 100.5% of rated value voltage respectively.

2) Branch Loading of Transformer

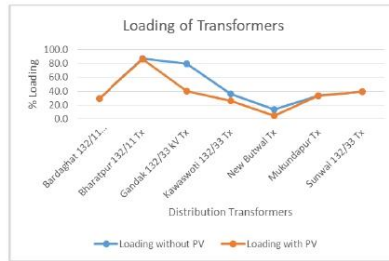


FIGURE 8: LOADING OF TRANSFORMERS

As observed in the Figure 8, Most of the Substations transformers loading is not affected whereas some of the transformer loading has decreased due to penetration of PV Power Plants. The loading of Gandak 132/33 kV transformer has decreased from 80% to 40.1%, Kawaswoti 132/33 kV transformer decreased from 35.8% to 25.8% and New Butwal decreased from 13.7% to 4.9%. Hence the loading of the branch improves upon interconnection of the PV System.

3) Losses in Transmission Line

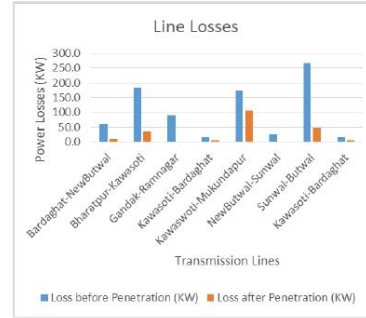


FIGURE 9: LINE LOSSES

Integrating distributed energy sources, such as photovoltaic (PV) plants, can significantly reduce these losses. Figure 9 shows losses in line before and after penetration of the PV into the grid. For example, losses in the Kawaswoti-Mukundapur Transmission Line were reduced from 172.8 kW to 106.4 kW. In the New-Butwal to Sunwal Transmission Line, losses dropped from 25.7 kW to 1.0 kW, while the Sunwal-Butwal Transmission Line saw a reduction from 266.1 kW to 48.4 kW. Hence the losses in the transmission line network reduced significantly upon interconnection of the PV Plant into the grid.

B. Short Circuit Analysis

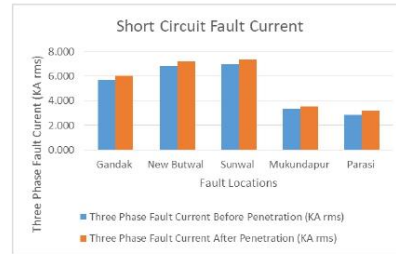


FIGURE 10: THREE PHASE SHORT CIRCUIT CURRENT

The PV penetration to the grid increases the fault current which may affect the interrupting duty of the Protective device. The three phase fault current has increases slightly upon interconnection of PV Power Plant. The maximum increment is seen in Parasi Substation bus bar with greater than 10% increment. However the short circuit current does not exceed 87.5% of the interrupting capacity of protective devices. So the interconnection of PV Power Plant does not have serious impact on fault duty.

C. Voltage Flicker Analysis

Excessive flicker can cause eye strain and headaches. Most electric device may not work under voltage fluctuations. Since PV Power is intermittent in nature, the voltage Flicker analysis must be done. At point of Interconnection, the Voltage Flicker should not cross 3% [9].

1) Voltage Flicker at Mukundapur and Parasi Substation

For voltage flicker analysis, an event was created. For the simulation of 30s, the circuit breaker associated to the PV Plant is disconnected after 5 sec and the voltage deviation is observed.

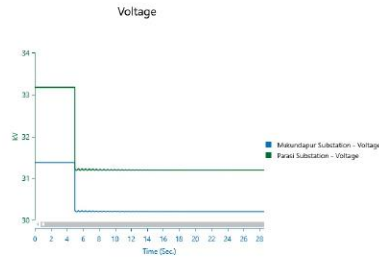


FIGURE 11: VOLTAGE CHANGE IN MUKUNDAPUR AND PARASI SUBSTATION

Figure 11 shows the voltage variation after the disconnection of PV Plant after 5 sec of simulation time. When the circuit breaker of respective PV Plant opens, the voltage dropped from 31.35 kV to 30.6 kV resulting in 2.39% in Mukundapur and 33.2 kV to 31.5 kV resulting in 5.12% reduction in Parasi Substation at POI. The voltage flicker at Mukundapur Substation is within the range, however the voltage flicker at Parasi Substation is greater than 3%.

2) Voltage Flicker at Gandak, Sunwal and New-Butwal Substation

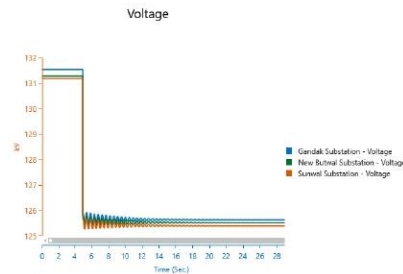


FIGURE 12: VOLTAGE CHANGE IN GANDAK, SUNWAL AND NEW BUTWAL SUBSTATION

After 5 seconds, the circuit breaker of the PV power plant was opened, leading to voltage fluctuations, as shown in Fig 12. The voltage dropped from 131.6 kV to 129.3 kV at Gandak Substation, a 1.75% decrease. At Sunwal Substation, the voltage declined from 131.5 kV to 127.1 kV, resulting in a 3.346% reduction. Meanwhile, at New-Butwal Substation, the voltage decreased from 131.3 kV to 129.8 kV, reflecting a 1.142% drop. The voltage flicker at Sunwal Substation exceeds 3%, whereas at Gandak and New-Butwal Substations, it remains within acceptable limits.

D. Transient Frequency Response

The transient frequency was analyzed in the simulation. The PV Plants was made to disconnect in 5 sec and the base model was check whether the system do have capacity to maintain the frequency within the limit or not.

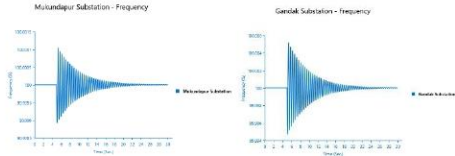


FIGURE 13: FREQUENCY RESPONSE OF MUKUNDAPUR AND GANDAK SUBSTATION

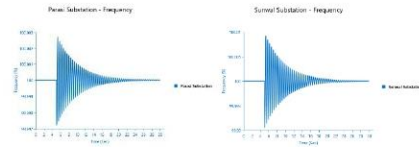


FIGURE 14: FREQUENCY RESPONSE OF PARASI AND SUNWAL SUBSTATION

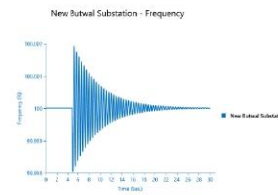


FIGURE 15: FREQUENCY RESPONSE OF NEW-BUTWAL SUBSTATION

Fig 13, 14 and 15 shows that the transient frequency response of the system is stable. The system can maintain the frequency within the limit upon disconnection of the PV Power Plants.

V. CONCLUSIONS

The system was analyzed before and after the integration of the Photovoltaic (PV) power plants. During the load flow analysis, it was noted that the voltage profile at the point of interconnection (POI) improved, while transformer loading and transmission line losses decreased following the interconnection of the PV Power Plants. Although PV penetration increased the fault current within the system, the increment remained within 10% threshold, with the exception of the Parasi Substation. Notably the fault current at the Parasi Substation is less than 87.5% of the rating of the protective equipment. When the PV power plants were disconnected, the voltage fluctuations at Mukundapur, Gandak and New-Butwal Substations were below 3 % at POI, except for the Parasi and Sunwal Substations, which experienced fluctuations slightly above 3%. To address issues related to voltage flicker, it is recommended that the PV plants at Parasi and Sunwal operate with a non-unity power factor. The transient frequency response of the system remained stable upon the shutdown of PV power plants. As a result, the grid parameters are stable following the interconnection of these plants. This study was conducted considering peak load conditions, however the utility should remain vigilant for potential violations that may arise during integration of PV plants under varying loading conditions.

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Appendix C: Power System Network Details

C.1 Transmission Line Details

S.N	Transmission Line	Voltage (kV)	Length (km)	Conductor	Circuit	Cross-Sectional Area (sq.mm)	Config.
1.	Bharatpur-Kawaswoti	132	36	Panther	Single	200	Triangular
2.	Kawaswoti-Bardaghat	132	34	Panther	Single	200	Triangular
3.	Bardaghat-Gandak	132	14	Panther	Double	250	Vertical
4.	Gandak-Ramnagar	132	10	Panther	Single	200	Triangular
5.	Bardaghat-New Butwal	132	14	Bear	Double	250	Triangular
6.	New Butwal-Sunwal	132	12	Bear	Double	250	Triangular
7.	Sunwal-Butwal	132	16	Bear	Double	250	Triangular
8.	Kaligandaki Corridor TL- New Butwal	220	44	ACCC Drake	Double	520	Vertical
9.	Kawaswoti S/S-Bhojpokhari	66	14	Dog	Single	100	Horizontal
10.	Kawaswoti S/S-Mukundapur	66	14	Dog	Single	100	Horizontal
11.	Kawaswoti S/S-Kawaswoti DCS	66	7	Dog	Single	100	Horizontal
12.	Gandak-Parasi	66	20	Dog	Single	100	Horizontal
13.	Bardaghat-Sardi	132	23	Bear	Single	250	Traingular

C.2 Load Data Details

S.N.	Substations	Voltage Level (kV)	Capacity (MVA)
1.	Bharatpur	11	44.575
2.	Bharatpur	33	42.991
3.	BhojPokhari	11	0.155
4.	Mukundapur	11	8
5.	Kawaswoti DCS	11	7.14
6.	Kawaswoti S/S	11	5.5
7.	Sardi	33	23.324
8.	Bardaghat S/S	11	15.25
9.	Gandak S/S	33	4.5

10.	Gandak S/S	11	11.43
11.	Parasi S/S	33	9.177
12.	Sunwal S/S	33	50
13.	Sunwal S/S	11	2
14.	Butwal S/S	33	56.87
15.	Butwal S/S	11	23.56

C.3 Substation Capacity

S.N.	Substations	Voltage Ratio kV	Capacity MVA(080-081)
1.	Butwal	132/33	63
		132/33	63
		132/33	63
		33/11	24
		33/11	16.6
		33/11	16.6
2.	Bardaghat	132/11	22.5
		132/11	22.5
3.	Kawaswoti	132/33	30
		132/33	30
		33/11	16.6
4.	Gandak	132/33	30
		132/33	30
		33/11	16.6
		33/11	16.6
5.	New Butwal	220/132	100
6.	Sunwal	132/33	63
		132/33	63
		132/11	22.5

Appendix D: Load Flow Results

D.1 Load Flow Study without PV Interconnection

Bus		Voltage		Generation		Load		Load Flow				XFMR	
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bardaghat Load Bus	11.000	99.545	-2.9	0.000	0.000	12.963	-2.868	Bardaghat Substation	-12.963	2.868	700.0	-97.6	
Bardaghat Substation	132.000	99.092	-1.4	0.000	0.000	0.000	0.000	Gandak Substation	8.118	-13.904	71.1	-50.4	
								New Butwal Substation	-36.909	0.442	162.9	100.0	
								Sardi Bus	20.081	11.178	101.4	87.4	
								Kawaswoti Substation	-4.265	4.796	28.3	-66.5	
								Bardaghat Load Bus	12.975	-2.512	58.3	-98.2	
Bharatpur 11kV Bus	11.000	97.554	-4.4	0.000	0.000	37.890	9.205	Bharatpur Substation	-37.890	-9.205	2097.9	97.2	
Bharatpur 33kV Bus	33.000	97.979	-3.2	0.000	0.000	36.540	11.130	Bharatpur Substation	-36.540	-11.130	682.1	95.7	
* Bharatpur Substation	132.000	100.000	0.0	97.029	30.483	0.000	0.000	Kawaswoti Substation	22.424	4.676	100.2	97.9	
								Bharatpur 11kV Bus	37.998	12.398	174.8	95.1	
								Bharatpur 33kV Bus	36.607	13.409	170.5	93.9	
BhojaPokhari Feeder	11.000	96.502	-2.9	0.000	0.000	0.132	0.082	BhojaPokhari S/S	-0.132	-0.082	8.4	85.0	
BhojaPokhari S/S	33.000	96.729	-2.7	0.000	0.000	0.000	0.000	Kawaswoti 33 kV Bus	-0.132	-0.082	2.8	84.8	
								BhojaPokhari Feeder	0.132	0.082	2.8	84.8	
Butwal 11 kV Bus	11.000	98.360	-3.8	0.000	0.000	20.026	12.411	Butwal 33 kV Bus	-20.026	-12.411	1257.2	85.0	
Butwal 33 kV Bus	33.000	100.697	-1.9	0.000	0.000	48.340	-30.881	Butwal 11 kV Bus	20.055	13.400	419.1	83.1	
								Butwal Substation	-68.394	17.481	1226.5	-96.9	
* Butwal Substation	132.000	100.000	0.0	137.486	5.307	0.000	0.000	Sunwal Substation	69.036	20.448	314.9	95.9	
								Butwal 33 kV Bus	68.450	-15.141	306.6	-97.6	
Gandak 11 kV Bus	11.000	99.422	-7.5	0.000	0.000	9.716	6.021	Gandak 33kV Bus	-9.716	-6.021	603.4	85.0	
Gandak 33kV Bus	33.000	102.271	-5.3	0.000	0.000	3.825	-23.778	Parasi Substation	8.092	5.297	165.4	83.7	
								Gandak 11 kV Bus	9.745	6.578	201.1	82.9	
								Gandak Substation	-21.662	11.904	422.8	-87.6	
* Gandak Powerhouse Bus	6.600	100.000	0.5	4.000	0.633	0.000	0.000	Gandak Substation	4.000	0.633	354.3	98.8	
Gandak Substation	132.000	99.263	-1.5	0.000	0.000	0.000	0.000	Bardaghat Substation	-8.109	12.320	65.0	-55.0	
								Ramnagar Substation	-9.637	-1.681	43.1	98.5	
								Gandak 33kV Bus	21.736	-10.153	105.7	-90.6	
								Gandak Powerhouse Bus	-3.990	-0.486	17.7	99.3	
* Kaligandaki Corridor Bus	220.000	100.000	0.0	12.483	-0.252	0.000	0.000	New Butwal Bus	12.483	-0.252	32.8	-100.0	
Kawasoti DCs 11 kV Bus	11.000	93.942	-4.3	0.000	0.000	6.069	3.761	Kawaswoti DCs	-6.069	-3.761	398.9	85.0	
Kawaswoti 11 kV Bus	11.000	95.375	-3.9	0.000	0.000	4.675	2.897	Kawaswoti 33 kV Bus	-4.675	-2.897	302.7	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Kawaswoti 33 kV Bus	33.000	96.786	-2.7	0.000	0.000	0.000	0.000	Kawaswoti DCs	6.142	4.026	132.8	83.6	
								BhojaPokhari S/S	0.132	0.037	2.5	96.3	
								Mukundapur Substation	6.982	4.706	152.2	82.9	
								Kawaswoti 11 kV Bus	4.683	3.037	100.9	83.9	
								Kawaswoti Substation	-17.938	-11.807	388.2	83.5	
Kawaswoti DCs	33.000	95.205	-3.2	0.000	0.000	0.000	0.000	Kawaswoti 33 kV Bus	-6.076	-3.930	133.0	84.0	
								Kawasoti DCs 11 kV Bus	6.076	3.930	133.0	84.0	
Kawaswoti Substation	132.000	98.734	-1.1	0.000	0.000	0.000	0.000	Bharatpur Substation	-22.242	-6.048	102.1	96.5	
								Bardaghat Substation	4.282	-6.497	34.5	-55.0	
								Kawaswoti 33 kV Bus	17.960	12.545	97.0	82.0	
Mukundapur S/S Feeder	11.000	91.690	-5.1	0.000	0.000	6.800	4.214	Mukundapur Substation	-6.800	-4.214	457.9	85.0	
Mukundapur Substation	33.000	93.144	-3.8	0.000	0.000	0.000	0.000	Kawaswoti 33 kV Bus	-6.809	-4.436	152.6	83.8	
								Mukundapur S/S Feeder	6.809	4.436	152.6	83.8	
New Butwal Bus	220.000	99.843	-0.3	0.000	0.000	0.000	0.000	Kaligandaki Corridor Bus	-12.478	-5.744	36.1	90.8	
								New Butwal Substation	12.478	5.744	36.1	90.8	
New Butwal Substation	132.000	99.239	-1.0	0.000	0.000	0.000	0.000	Bardaghat Substation	36.971	-1.619	163.1	-99.9	
								Sunwal Substation	-24.498	7.174	112.5	-96.0	
								New Butwal Bus	-12.473	-5.555	60.2	91.4	
Parasi Substation	33.000	96.667	-7.0	0.000	0.000	7.800	4.835	Gandak 33kV Bus	-7.800	-4.835	166.1	85.0	
* Ramnagar Substation	132.000	100.000	0.0	9.727	-3.112	0.000	0.000	Gandak Substation	9.727	-3.112	44.7	-95.2	
Sardi Bus	132.000	98.079	-2.0	0.000	0.000	20.000	12.000	Bardaghat Substation	-20.000	-12.000	104.0	85.7	
Sunwal 11 kV Bus	11.000	98.753	-1.2	0.000	0.000	1.700	1.054	Sunwal Substation	-1.700	-1.054	106.3	85.0	
Sunwal 33 kV Bus	33.000	97.153	-2.6	0.000	0.000	42.500	26.340	Sunwal Substation	-42.500	-26.340	900.4	85.0	
Sunwal Substation	132.000	99.211	-0.8	0.000	0.000	0.000	0.000	New Butwal Substation	24.524	-8.298	114.1	-94.7	
								Butwal Substation	-68.770	-21.004	317.0	95.6	
								Sunwal 11 kV Bus	1.701	1.070	8.9	84.6	
								Sunwal 33 kV Bus	42.545	28.231	225.1	83.3	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

Indicates a bus with a load mismatch of more than 0.1 MVA

Branch Loading Summary Report

CKT / Branch		Busway / Cable & Reactor			Transformer				
					Capability (MVA)	Loading (input)		Loading (output)	
ID	Type	Ampacity (Amp)	Loading Amp	%		MVA	%	MVA	%
Bardaghat 132/11 kV Tx	Transformer				45.000	13.277	29.5	13.216	29.4
Bharatpur 132/11 Tx	Transformer				45.000	39.970	88.8	38.992	86.6
Bharatpur 132/33 Tx	Transformer				60.000	38.985	65.0	38.198	63.7
BhojaPokhari Tx	Transformer				3.000	0.155	5.2	0.155	5.2
Butwal 33/11 kV Tx	Transformer				40.600	24.120	59.4	23.560	58.0
Butwal 132/33 kV Tx	Transformer				189.000	70.593	37.4	70.105	37.1
Gandak 33/11 kV Tx	Transformer				16.600	11.758	70.8	11.430	68.9
Gandak 132/33 kV Tx	Transformer				30.000	24.718	82.4	23.991	80.0
Gandak Hydro Tx	Transformer				10.000	4.050	40.5	4.020	40.2
Kawaswoti 33/11 Tx	Transformer				16.600	5.581	33.6	5.500	33.1
Kawaswoti 132/33 Tx	Transformer				60.000	21.907	36.5	21.475	35.8
Kawaswoti DCs 33/11 Tx	Transformer				24.000	7.236	30.2	7.140	29.8
Mukundapur Tx	Transformer				24.000	8.127	33.9	8.000	33.3
New Butwal Tx	Transformer				100.000	13.737	13.7	13.654	13.7
Sunwal 132/11 Tx	Transformer				22.500	2.010	8.9	2.000	8.9
Sunwal 132/33 Tx	Transformer				126.000	51.060	40.5	50.000	39.7

* Indicates a branch with operating load exceeding the branch capability.

Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd
	MW	Mvar	MW	Mvar	kW	kvar	From	To	% Drop in Vmag
Bardaghat 132/11 kV Tx	-12.963	2.868	12.975	-2.512	12.1	355.6	99.5	99.1	0.45
Bardaghat-Gandak	8.118	-13.904	-8.109	12.320	9.4	-1583.6	99.1	99.3	0.17
Bardaghat-NewButwal	-36.909	0.442	36.971	-1.619	62.0	-1177.2	99.1	99.2	0.15
Bardaghat-Sardi	20.081	11.178	-20.000	-12.000	80.8	-821.9	99.1	98.1	1.01
Bharatpur 132/11 Tx	-37.890	-9.205	37.998	12.398	108.2	3193.3	97.6	100.0	2.45
Bharatpur 132/33 Tx	-36.540	-11.130	36.607	13.409	66.8	2278.8	98.0	100.0	2.02
Bharatpur-Kawasoti	22.424	4.676	-22.242	-6.048	182.5	-1372.5	100.0	98.7	1.27
BhojaPokhari Tx	-0.132	-0.082	0.132	0.082	0.1	0.6	96.5	96.7	0.23
Butwal 132/33 kV Tx	-68.394	17.481	68.450	-15.141	55.7	2339.7	100.7	100.0	0.70
Butwal 33/11 kV Tx	-20.026	-12.411	20.055	13.400	29.0	988.8	98.4	100.7	2.34
Gandak 132/33 kV Tx	-21.662	11.904	21.736	-10.153	73.9	1750.8	102.3	99.3	3.01
Gandak 33/11 kV Tx	-9.716	-6.021	9.745	6.578	29.9	556.5	99.4	102.3	2.85
Gandak Hydro Tx	4.000	0.633	-3.990	-0.486	9.5	147.3	100.0	99.3	0.74
Gandak-Parasi	8.092	5.297	-7.800	-4.835	291.9	461.5	102.3	96.7	5.60
Gandak-Ramnagar	-9.637	-1.681	9.727	-3.112	90.1	-4792.7	99.3	100.0	0.74
Kaligandagi-NewButwal	12.483	-0.252	-12.478	-5.744	5.0	-5996.4	100.0	99.8	0.16
Kawasoti-Bardaghat	-4.265	4.796	4.282	-6.497	16.5	-1700.8	99.1	98.7	0.36
Kawasoti 132/33 Tx	-17.938	-11.807	17.960	12.545	21.6	738.2	96.8	98.7	1.95
Kawasoti 33/11 Tx	-4.675	-2.897	4.683	3.037	7.5	140.0	95.4	96.8	1.41
Kawasoti DCs 33/11 Tx	-6.069	-3.761	6.076	3.930	7.1	168.3	93.9	95.2	1.26
Kawasoti Sub-Feeder	6.142	4.026	-6.076	-3.930	65.6	96.8	96.8	95.2	1.58
Kawasoti-BhojaPokhari	-0.132	-0.082	0.132	0.037	0.1	-45.2	96.7	96.8	0.06
Kawasoti-Mukundapur	6.982	4.706	-6.809	-4.436	172.8	270.0	96.8	93.1	3.64
Mukundapur Tx	-6.800	-4.214	6.809	4.436	9.4	221.8	91.7	93.1	1.45
New Butwal Tx	12.478	5.744	-12.473	-5.555	5.5	189.2	99.8	99.2	0.60
NewButwal-Sunwal	-24.498	7.174	24.524	-8.298	25.7	-1123.4	99.2	99.2	0.03
Sunwal 132/11 Tx	-1.700	-1.054	1.701	1.070	0.7	16.4	98.8	99.2	0.46
Sunwal 132/33 Tx	-42.500	-26.340	42.545	28.231	45.0	1891.4	97.2	99.2	2.06
Sunwal-Butwal	69.036	20.448	-68.770	-21.004	266.1	-556.5	100.0	99.2	0.79
					1750.6	-3365.1			

* This Transmission Line includes Series Capacitor.

D.2 Load Flow Study with PV Interconnection

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow				XFMR	
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bardaghat Load Bus	11.000	99.861	-1.6	0.000	0.000	12.963	-2.937	Bardaghat Substation	-12.963	2.937	698.6	-97.5	
Bardaghat Substation	132.000	99.396	-0.1	0.000	0.000	0.000	0.000	Gandak Substation	-20.794	-11.402	104.4	87.7	
								New Butwal Substation	-14.872	0.398	65.5	-100.0	
								Sardi Bus	20.080	11.169	101.1	87.4	
								Kawaswoti Substation	2.611	2.418	15.7	73.4	
								Bardaghat Load Bus	12.975	-2.583	58.2	-98.1	
Bharatpur 11kV Bus	11.000	97.554	-4.4	0.000	0.000	37.890	9.205	Bharatpur Substation	-37.890	-9.205	2097.9	97.2	
Bharatpur 33kV Bus	33.000	97.979	-3.2	0.000	0.000	36.540	11.130	Bharatpur Substation	-36.540	-11.130	682.1	95.7	
* Bharatpur Substation	132.000	100.000	0.0	80.275	33.374	0.000	0.000	Kawaswoti Substation	5.670	7.567	41.4	60.0	
								Bharatpur 11kV Bus	37.998	12.398	174.8	95.1	
								Bharatpur 33kV Bus	36.607	13.409	170.5	93.9	
BhojaPokhari Feeder	11.000	96.666	-1.0	0.000	0.000	0.132	0.082	BhojaPokhari S/S	-0.132	-0.082	8.4	85.0	
BhojaPokhari S/S	33.000	96.892	-0.9	0.000	0.000	0.000	0.000	Kawaswoti 33 kV Bus	-0.132	-0.082	2.8	84.8	
								BhojaPokhari Feeder	0.132	0.082	2.8	84.8	
Bus2	0.400	100.521	9.8	4.874	0.000	0.000	0.000	Parasi PV Bus	4.874	0.000	6999.1	100.0	
Bus4	0.400	100.521	9.8	4.874	0.000	0.000	0.000	Parasi PV Bus	4.874	0.000	6999.1	100.0	
Bus5	0.400	100.521	9.8	4.874	0.000	0.000	0.000	Parasi PV Bus	4.874	0.000	6999.1	100.0	
Bus10	0.400	99.256	9.0	4.874	0.000	0.000	0.000	New Butwal PV Bus	4.874	0.000	7088.3	100.0	
Bus12	0.400	99.256	9.0	4.874	0.000	0.000	0.000	New Butwal PV Bus	4.874	0.000	7088.3	100.0	
Bus13	0.400	99.256	9.0	4.874	0.000	0.000	0.000	New Butwal PV Bus	4.874	0.000	7088.3	100.0	
Bus19	0.400	95.033	9.2	4.874	0.000	0.000	0.000	Mukundapur PV Bus	4.874	0.000	7403.3	100.0	
Bus21	0.400	95.033	9.2	4.874	0.000	0.000	0.000	Mukundapur PV Bus	4.874	0.000	7403.3	100.0	
Bus28	0.400	99.356	9.0	4.874	0.000	0.000	0.000	Gandak PV Bus	4.874	0.000	7081.2	100.0	
Bus29	0.400	99.356	9.0	4.874	0.000	0.000	0.000	Gandak PV Bus	4.874	0.000	7081.2	100.0	
Bus30	0.400	99.356	9.0	4.874	0.000	0.000	0.000	Gandak PV Bus	4.874	0.000	7081.2	100.0	
Bus37	0.400	99.356	9.0	4.874	0.000	0.000	0.000	Gandak PV Bus	4.874	0.000	7081.2	100.0	
Bus38	0.400	99.356	9.0	4.874	0.000	0.000	0.000	Gandak PV Bus	4.874	0.000	7081.2	100.0	
Bus45	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus46	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus47	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus48	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	

Bus		Voltage		Generation		Load		Load Flow				XFMR	
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus49	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus56	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus57	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus58	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus59	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Bus60	0.400	99.002	9.1	4.874	0.000	0.000	0.000	Sunwal PV Bus	4.874	0.000	7106.5	100.0	
Butwal 11 kV Bus	11.000	98.360	-3.8	0.000	0.000	20.026	12.411	Butwal 33 kV Bus	-20.026	-12.411	1257.2	85.0	
Butwal 33 kV Bus	33.000	100.697	-1.9	0.000	0.000	48.340	-30.881	Butwal 11 kV Bus	20.055	13.400	419.1	83.1	
								Butwal Substation	-68.394	17.481	1226.5	-96.9	
* Butwal Substation	132.000	100.000	0.0	65.870	14.741	0.000	0.000	Sunwal Substation	-2.580	29.882	131.2	-8.6	
								Butwal 33 kV Bus	68.450	-15.141	306.6	-97.6	
Gandak 11 kV Bus	11.000	99.634	-3.4	0.000	0.000	9.716	6.021	Gandak 33kV Bus	-9.716	-6.021	602.1	85.0	
Gandak 33kV Bus	33.000	102.477	-1.2	0.000	0.000	3.825	-23.883	Parasi Substation	-6.402	7.226	164.8	-66.3	
								Gandak 11 kV Bus	9.745	6.575	200.7	82.9	
								Gandak Substation	-7.169	10.082	211.2	-57.9	
* Gandak Powerhouse Bus	6.600	100.000	2.2	4.000	0.213	0.000	0.000	Gandak Substation	4.000	0.213	350.4	99.9	
Gandak PV Bus	11.000	99.033	5.2	0.000	0.000	0.000	0.000	Bus28	-4.848	0.324	257.5	-99.8	
								Bus29	-4.848	0.324	257.5	-99.8	
								Bus30	-4.848	0.324	257.5	-99.8	
								Gandak Substation	24.239	-1.619	1287.5	-99.8	
								Bus37	-4.848	0.324	257.5	-99.8	
								Bus38	-4.848	0.324	257.5	-99.8	
Gandak Substation	132.000	99.641	0.1	0.000	0.000	0.000	0.000	Bardaghat Substation	20.816	9.855	101.1	90.4	
								Ramnagar Substation	0.135	-3.924	17.2	-3.4	
								Gandak 33kV Bus	7.187	-9.645	52.8	-59.7	
								Gandak Powerhouse Bus	-3.991	-0.069	17.5	100.0	
								Gandak PV Bus	-24.147	3.783	107.3	-98.8	
* Kaligandaki Corridor Bus	220.000	100.000	0.0	-1.042	-1.215	0.000	0.000	New Butwal Bus	-1.042	-1.215	4.2	65.1	
Kawasoti DCs 11 kV Bus	11.000	94.110	-2.4	0.000	0.000	6.069	3.761	Kawaswoti DCs	-6.069	-3.761	398.2	85.0	
Kawaswoti 11 kV Bus	11.000	95.540	-2.0	0.000	0.000	4.675	2.897	Kawaswoti 33 kV Bus	-4.675	-2.897	302.2	85.0	
Kawaswoti 33 kV Bus	33.000	96.948	-0.8	0.000	0.000	0.000	0.000	Kawaswoti DCs	6.141	4.025	132.5	83.6	
								BhojaPolchari S/S	0.132	0.037	2.5	96.3	
								Mukundapur Substation	-2.728	6.019	119.2	-41.3	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
								Kawaswoti 11 kV Bus	4.683	3.037	100.7	83.9	
								Kawaswoti Substation	-8.228	-13.118	279.4	53.1	
Kawaswoti DCs	33.000	95.371	-1.3	0.000	0.000	0.000	0.000	Kawaswoti 33 kV Bus	-6.076	-3.929	132.7	84.0	
								Kawasoti DCs 11 kV Bus	6.076	3.929	132.7	84.0	
Kawaswoti Substation	132.000	99.022	-0.1	0.000	0.000	0.000	0.000	Bharatpur Substation	-5.634	-9.341	48.2	51.6	
								Bardaghat Substation	-2.605	-4.159	21.7	53.1	
								Kawaswoti 33 kV Bus	8.239	13.500	69.9	52.1	
Mukundapur PV Bus	11.000	94.716	5.1	0.000	0.000	0.000	0.000	Bus19	-4.845	0.354	269.2	-99.7	
								Bus21	-4.845	0.354	269.2	-99.7	
								Mukundapur Substation	9.690	-0.708	538.4	-99.7	
Mukundapur S/S Feeder	11.000	93.626	-0.5	0.000	0.000	6.800	4.214	Mukundapur Substation	-6.800	-4.214	448.5	85.0	
Mukundapur Substation	33.000	95.049	0.7	0.000	0.000	0.000	0.000	Kawaswoti 33 kV Bus	2.834	-5.870	120.0	-43.5	
								Mukundapur S/S Feeder	6.809	4.427	149.5	83.8	
								Mukundapur PV Bus	-9.643	1.443	179.5	-98.9	
New Butwal Bus	220.000	99.925	0.0	0.000	0.000	0.000	0.000	Kaligandaki Corridor Bus	1.042	-4.855	13.0	-21.0	
								New Butwal Substation	-1.042	4.855	13.0	-21.0	
New Butwal PV Bus	11.000	98.933	5.2	0.000	0.000	0.000	0.000	Bus10	-4.848	0.324	257.8	-99.8	
								Bus12	-4.848	0.324	257.8	-99.8	
								Bus13	-4.848	0.324	257.8	-99.8	
								New Butwal Substation	14.543	-0.973	773.3	-99.8	
New Butwal Substation	132.000	99.442	0.1	0.000	0.000	0.000	0.000	Bardaghat Substation	14.882	-1.796	65.9	-99.3	
								Sunwal Substation	-1.452	4.352	20.2	-31.6	
								New Butwal Bus	1.043	-4.830	21.7	-21.1	
								New Butwal PV Bus	-14.473	2.274	64.4	-98.8	
Parasi PV Bus	11.000	100.196	6.1	0.000	0.000	0.000	0.000	Parasi Substation	14.545	-0.949	763.5	-99.8	
								Bus2	-4.848	0.316	254.5	-99.8	
								Bus4	-4.848	0.316	254.5	-99.8	
								Bus5	-4.848	0.316	254.5	-99.8	
Parasi Substation	33.000	100.504	2.2	0.000	0.000	7.800	4.835	Gandak 33kV Bus	6.692	-6.770	165.7	-70.3	
								Parasi PV Bus	-14.492	1.935	254.5	-99.1	
* Ramnagar Substation	132.000	100.000	0.0	-0.133	-1.134	0.000	0.000	Gandak Substation	-0.133	-1.134	5.0	11.7	
Sardi Bus	132.000	98.386	-0.7	0.000	0.000	20.000	12.000	Bardaghat Substation	-20.000	-12.000	103.7	85.7	
Sunwal 11 kV Bus	11.000	98.912	-0.3	0.000	0.000	1.700	1.054	Sunwal Substation	-1.700	-1.054	106.1	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag	Ang	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Sunwal 33 kV Bus	33.000	97.315	-1.7	0.000	0.000	42.500	26.340	Sunwal Substation	-42.500	-26.340	898.9	85.0	
Sunwal PV Bus	11.000	98.679	5.2	0.000	0.000	0.000	0.000	Bus45	-4.848	0.326	258.4	-99.8	
								Bus46	-4.848	0.326	258.4	-99.8	
								Bus47	-4.848	0.326	258.4	-99.8	
								Bus48	-4.848	0.326	258.4	-99.8	
								Bus49	-4.848	0.326	258.4	-99.8	
								Sunwal Substation	48.475	-3.262	2584.2	-99.8	
								Bus56	-4.848	0.326	258.4	-99.8	
								Bus57	-4.848	0.326	258.4	-99.8	
								Bus58	-4.848	0.326	258.4	-99.8	
								Bus59	-4.848	0.326	258.4	-99.8	
								Bus60	-4.848	0.326	258.4	-99.8	
Sunwal Substation	132.000	99.369	0.1	0.000	0.000	0.000	0.000	New Butwal Substation	1.453	-5.582	25.4	-25.2	
								Butwal Substation	2.629	-31.336	138.4	-8.4	
								Sunwal 11 kV Bus	1.701	1.070	8.8	84.6	
								Sunwal 33 kV Bus	42.545	28.225	224.7	83.3	
								Sunwal PV Bus	-48.327	7.622	215.3	-98.8	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

Indicates a bus with a load mismatch of more than 0.1 MVA

Appendix E: Short Circuit Results

C.1 Short Circuit Analysis without PV Interconnection

Momentary Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Momentary Duty					Device Capability		
ID	kV	ID	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm. kA rms	Asymm. kA Peak
Gandak Substation	132.000	Gandak Substation	Bus	5.684	6.6	1.331	7.564	13.029			
Mukundapur Substation	33.000	Mukundapur Substation	Bus	3.317	4.2	1.204	3.993	6.914			
New Butwal Substation	132.000	New Butwal Substation	Bus	6.818	7.6	1.369	9.335	16.019			
Parasi Substation	33.000	Parasi Substation	Bus	2.864	5.1	1.259	3.605	6.239			
Sunwal Substation	132.000	Sunwal Substation	Bus	6.969	8.3	1.393	9.711	16.618			

- Method: IEEE - X/R is calculated from separate R & X networks.

- Generator protective device duty is calculated based on maximum through fault current. Other protective device duty is calculated based on total fault current.

- The multiplication factors for high voltage circuit-breaker and high voltage bus momentary duty (asymmetrical and crest values) are calculated based on system X/R.

* Indicates a device with momentary duty exceeding the device capability.

C.2 Short Circuit Analysis with PV Interconnection

Momentary Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Momentary Duty					Device Capability		
ID	kV	ID	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm. kA rms	Asymm. kA Peak
Gandak Substation	132.000	Gandak Substation	Bus	6.002	6.6	1.331	7.988	13.759			
Mukundapur Substation	33.000	Mukundapur Substation	Bus	3.526	4.2	1.204	4.245	7.350			
New Butwal Substation	132.000	New Butwal Substation	Bus	7.231	7.6	1.369	9.900	16.988			
Parasi Substation	33.000	Parasi Substation	Bus	3.183	5.1	1.259	4.007	6.935			
Sunwal Substation	132.000	Sunwal Substation	Bus	7.389	8.3	1.393	10.295	17.618			

- Method: IEEE - X/R is calculated from separate R & X networks.

- Generator protective device duty is calculated based on maximum through fault current. Other protective device duty is calculated based on total fault current.

- The multiplication factors for high voltage circuit-breaker and high voltage bus momentary duty (asymmetrical and crest values) are calculated based on system X/R.

* Indicates a device with momentary duty exceeding the device capability.