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# Optimal Placement of EV Charging Station with Randomly Distributed PV System in Bishnumati Distribution Feeder
## Kathmandu, Nepal

By
**Suman Paudel**

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

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# ABSTRACT

This thesis presents the optimal placement of EV charging stations with randomly distributed PV system. MATLAB software is used to analyze the load flow of distribution network using sweep algorithm. The Bishnumati feeder of Balaju DCS is used under analysis and IEE 33 bus system used for theoretical part for the load flow and EV stations. The 372 kW (mix of 60 kW and 42 kW) charging stations are considered and it is evaluated that the system loss increases and voltage regulation is found poor upto 0.732 pu at distribution secondary side voltage. This shows that EV charging capacity does not fulfilled by existing distribution network and transformer. The randomly distributed rooftop solar PV system is considered in this system as distributed generation and that allows the power to flow at day time. Genetic algorithm is used for the EV charging station location and size of PV. The total 1381.2 kW of PV system is used that improves the voltage to 0.84 pu. The system loss also decreases by using PV system and is reduced from 412.55 kW to 279.15 kW. The financial analysis shows the positive NPV and payback period of 12 years.

**Key words:** EVCS, Solar PV, Voltage profile, DCS, Feeder, Distribution System.

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| | |
|---|---|
| AEPC | Alternative Energy Promotion Center |
| BFA | Building Foot-print Area |
| CF | Capacity Factor |
| GIS | Geographical Information System |
| NEA | Nepal Electricity Authority |
| IC | Internal Combustion |
| PV | Photo Voltaic |
| PVA | Photo Voltaic Area |
| EVCS | Electric Vehicle Charging Station |
| EV | Electric Vehicle |
| AC | Alternating Current |
| FCS | Fast Charging Station |
| P | Active Power |
| Q | Reactive Power |
| Pu | Per unit |
| $V_{max}$ | Maximum Voltage |
| $V_{min}$ | Minimum Voltage |
| GA | Genetic Algorithm |
| R | Line Resistance |
| X | Line Reactance |
| HEV | Hybrid Electric Vehicle |
| ICE | Internal Combustion Engine |
| DG | Distributed Generation |
| GHG | Green House Gases |
| BEV | Battery Electric Vehicle |
| ANN | Artificial Neural Network |
| KVAR | Kilo Volt Ampere Reactive |

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Present-day power systems are undergoing swift changes owing to the integration of electric vehicle charging stations (EVCs) and solar PV systems. The global increase in the adoption of distributed PV is propelled by the diminishing costs of PV modules and their parts. The integration of PV systems and other distributed generation (DG) technologies into the grid has introduced the concept of prosumers, where electricity production and consumption happen simultaneously. In addition to its environmental advantages as a clean energy source, PV technology plays a role in reducing power losses and improving the voltage profile of electrical distribution networks. On the consumer (prosumer) side, the implementation of PV systems leads to decreased electricity expenses paid to supplier (Reiman et al., 2019).

Conversely, the significant surge in the electric vehicle (EV) population within the transportation sector is groundbreaking. Utilizing this technology in conjunction with distributed generation (DGs) stands out as the most effective approach to diminish reliance on petroleum products and mitigate greenhouse gas (GHG) emissions (Xie et al., 2018). Moreover, with the ongoing depletion of fossil fuels and increasing environmental concerns, the global future of petroleum-based vehicles is diverging from the ascendancy of electric vehicles (EVs). Additionally, EVs offer numerous benefits, including fuel efficiency, noise reduction, and emission-free operation. (Ejaz et al., 2017).

The widespread adoption of electric vehicles (EVs) hinges largely on the rapid expansion of charging infrastructure. EV chargers are categorized into three types: Level 1, Level 2, and Level 3, and they can be either onboard or off board. Of these, the first two are onboard chargers, with Level 2 being faster and exhibiting an average efficiency of 90%, surpassing that of other chargers. (Sears et al., 2014). Level 3 chargers are the fastest and are typically off-boarded, while level 1 and level 2 chargers are constrained by power density, weight, and size. A maximum current of 12–16 A is supplied to the EV by level 1 chargers, 32–70 A by level 2 chargers, and 167 A by level 3 chargers from the mains. The AC/DC power electronics conversion process is present in Level 3 chargers. Level 3 chargers provide rapid charging, but level 1 and level 2 chargers require a longer period to fully charge an EV (Ghahnavieh and Barzani, 2017). Electric vehicle battery swapping stations (EVBSS) are being developed to reduce the amount of time needed to charge EVs. When the EV's fully charged battery replaces the discharged one. EVBSS is a quick and easy alternative for EV customers to charge their vehicles compared to using charging stations because battery replacement may be completed there quickly and easily. Battery switching technology has been introduced by several electric vehicle (EV) manufacturers, such as Tesla. This process is quicker than refueling an IC-based vehicle. (Ahmad et al., 2020).

Similar to PV systems, the quick adoption of EVs in the transportation sector will aid the distribution system as well as the environment because they support frequency and voltage management for abrupt system load ups and downs. (Faddel et al., 2018). Because of the extremely congested network, installing an EV charging station in any feeder should be done carefully as there would be higher power loss. (Chukwu and Mahajan, 20 C.E.). Additionally possible problems include decreased power quality and increased voltage profile deviation above tolerance limits (Sadhukhan et al., 2019). The situation gets considerably trickier when photovoltaic (PV) systems are put randomly in a distribution feeder with EVCSs. To reduce EVCSs' detrimental effects on the voltage profile and power losses of the distribution feeder, it is necessary to optimize EVCSs in this configuration.

## 1.2 Problem Statement

The high price of crude oil and environmental impact of petroleum based vehicle, are being decreased day by day. Many countries have set target to phase out petroleum based vehicle which are being changed to electric vehicle. So that EVs will be mostly used in future transportation sector. These vehicle require charging facilities in transportation network as refueling place.

The word reliable and modern energy centers around renewable energy sources like as solar PV, wind, geo-thermal and others. Among them solar PV play the important role in country like Nepal because Nepal has 4 to 6 peak sun and around 300 sunshine day in a year (AEPC, 2021). Government of Nepal (GON) also focuses on the energy mix model to gain the sustainable development goals.

Bishnumati feeder has mixed type of consumer including commercial users. There are many commercial building which has probability of being EV users flow. By using PV module in roof of these buildings required power can be generate locally, which is beneficial to both users and NEA. Still this time there are no EV charging station in Bishnumati Feeder. To penetrate solar PV and installing EV charging station in feeder impact analysis is essential.

## 1.3 Objective

The main objective of this study is to find out the optimal location of EV charging station with randomly distributed rooftop solar PV system of Bishnumati Distribution Feeder Kathmandu, Nepal.

### 1.3.1 Specific Objective

1. To study the voltage profile of Bishnumati distribution feeder system using the sweep algorithm.
2. To study the impact on voltage profile, line loss with EV charging station.
3. To study the impact on distribution system voltage and loss with PV penetration and EV load station.

## 1.4 Scope and limitations of study

The number of electric vehicle users are increasing day by day in Nepal. It is necessary to prepare an effective charging station infrastructure to support the demand of EV charging in daily energy consumption.

- This study can give framework for planning EVs charging station in Bishnumati feeder.
- It helps to planner to find out the locations and capacity of solar PV to be installed for efficient operation.
- This study can give information to the utility company about the supply/demand trend of electricity and possibility of penetration locally generated power to the grid.

  The followings are the limitations of this study which are referred for further study.

- All the solar PV are considered to be directly connected to the distribution system without any storage system in itself.
- The EV charge efficiency shall be considered as 95%.
- Lower voltage limit for EV charging station is considered to 0.85pu. So charger of input voltage 230±15% is considered.
- Only active power load and active power generation by the distributed generators are considered.
- All the load and generators power are considered to be constant irrespective of bus voltage.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Electric Vehicle

Electric vehicle is a vehicle which is driven by electric motor energized from storage batteries system. Initially EVs used from last of nineteenth century, at that time source of power for conduct vehicle is electrical energy. Because electricity is clean and green energy. When used this in vehicle there is no problem which are created from petrol based vehicle. For over 100 years, internal combustion engines dominated the propulsion of automobiles, trucks, and Stint child transport and operator stand, while electric power remained prevalent in other vehicle types, such as railroads and smaller vehicles of all kinds. In the early 1900s, mass-produced electric cars first arrived in America. Although it also joined the market for petrol vehicles in 1904, the Studebaker Automobile Company entered the automobile industry in 1902 with electric vehicles. The popularity of electric vehicles, however, sharply decreased when Ford Motor Company introduced affordable assembly-line vehicles (Ganta and Malladi, 2020).

### 2.1.1 Pure Electric Vehicles

It is a vehicle which is driven by electrical motor. This electric motor can be operated by power from storage batteries and fuel cell or solar PV. These vehicle are better than other in terms of efficiency.

### 2.1.2 Hybrid EVs

It is a type of vehicle which is driven by internal combustion engine and electric motor engine. Electric motor uses power from storage batteries system. When power is exists in battery vehicle is driven by electric motor. After finishing charge of storage system vehicle is driven by IC engine. During vehicle running by IC engine, the storage system is also charged internally. There are many ways that vehicle can get power from the IC engine and electric motor engine. Parallel hybrid vehicle connect electric motor and engine by mechanical coupling. During this time wheel is directly drive by engine and electric motor The most common type is a parallel hybrid that connects the engine and the electric motor to the wheels through mechanical coupling. In this case the electric motor and the engine can drive the wheels directly. There are also series hybrid vehicle and series-parallel hybrid vehicle. These have own merits and demerits. Series hybrids only use the electric motor to drive the wheels and can often be referred to as range-extended electric vehicles (REEVs). There are also series-parallel hybrids vehicle where the vehicle can be powered by the engine working separately, the electric motor on its own or by working together (Smith and Matthew, 2022).

### 2.1.3 Plug-in hybrid electric Vehicle

This vehicle consists of both internal combustion engine and electric motor. Electric motor is powered from storage system. Storage batteries system is charged by external wall power socket not by internally within vehicle. Stored energy in battery system drive wheel. If there is no charge in the battery system then this vehicle is driven by internal combustion engine. PEV is a further type of electric vehicles that contains all conventional internal combustion engine vehicles, plug-in electric vehicles (PHEVs) and battery electric vehicles (BEVs) (Sandalow, 2009).

### 2.1.4 Fuel Cell Electric Vehicle

This is a type of electric vehicle in which electric energy is obtained from chemical energy which is converted by fuel cell. Hydrogen fuel cell electric vehicle are available.

## 2.2 Batteries

Battery is system of storing energy in the form of charge. Some battery are chargeable and some are non-chargeable. Battery used in electric vehicle most have high energy and power density. These electric vehicle batteries designed with high ampere hour capacity. These are used in electric bus, taxi, cycle, bike and other electric vehicle. Mainly lithium ion batteries are used in electric vehicle which has high energy and power density than others. (Seitz, 2022)

### 2.2.1 Lithium-Ion Battery

Nowadays most of the electric vehicle are powered from lithium ion batteries (Li-Ions or LIBs). These batteries have higher energy density, higher power density and long lifecycle than other batteries. Different factors of batteries include durability, safety, environmental impact, operating temperature range and cost. Efficiency of LIBs is 90 to 95%. The temperature range of this battery is -30 degree Celsius to 60 degree Celsius. Lifecycle is

1.5K to 7.5 K cycles. Maintenance cost is zero for lithium ion battery. Which is significant in other batteries. One main disadvantage of this battery is initial cost and per cycle cost. Which is greater than that of other batteries. Li-ion batteries should be used within safe temperature and voltage ranges in order to operate efficiently and safely. Few years ago, nickel cadmium and nickel metal hydride batteries were used in electric vehicle. Todays these batteries are not used because of their negative features of self-discharging when heated (Brian, 2017). These negative features of other batteries lithium ion batteries leading as mostly preferred battery for electric vehicle system (Asri et al., 2021). Different battery technologies with their features are shown in table below.

Table 2.1: Different Battery Technologies

| | Lead- Acid | NiCad | NiMH | Li-ion |
|---|---|---|---|---|
| Energy Density (wh/kg) | 30-35 | 50-60 | 60-70 | 60-150 |
| Power Density (W/kg) | 80-300 | 200-500 | 200-1500 | 80-2000 |

## 2.3 Solar PV

The solar PV is power obtained from sunlight through photovoltaic effect. Solar cell converts sunlight into electrical energy. Different solar PV technologies are used to convert sunlight into electricity. The current and voltage obtained from solar PV is the direct current and voltage. Due to geopolitics and problem of carbon production related to fossil fuel, use of fossil fuel is degraded. To overcome the problem fossil fuel and to manage the increasing demand of electrical energy is the use of solar PV energy. Solar PV the carbon free energy that means there is zero carbon emission during using time of this power (Charfi et al., 2018). The growing use of electric vehicle in the transportation system along with combination of DGs technology lower down the dependency on crude oil and helps to decrease the carbon emissions (Xie et al., 2018).

### 2.3.1 Solar PV potential determination

To find power production using solar PV, total rooftop area of building is necessary. Total possible solar PV power production calculation is needed for making energy related rules and regulation for further development of solar PV power generation (Izquierdo et al., 2008). The important way for calculating potential of solar PV is the deciding the required data sources, their accessibility and technology used (Sustainability, 2021). The potential of the roof-top solar PV is further divided into four sub-potentials as shown in Figure 2.1

Physical potential is the overall solar PV potential of the specific area by considering the area occupied by the selected region and climate data along with daily or monthly radiation data. Current study mainly focusses on finding the geographic potential of solar PV. For this rather than considering the area occupied by the selected region built in area of the structure within the region is consider. Actual solar PV installation area depend on the type and design of building also solar roof-top potential depend on the type of solar PV, solar irradiance, temperature, climate condition and solar photovoltaicarea (Singh and Banerjee, 2015).

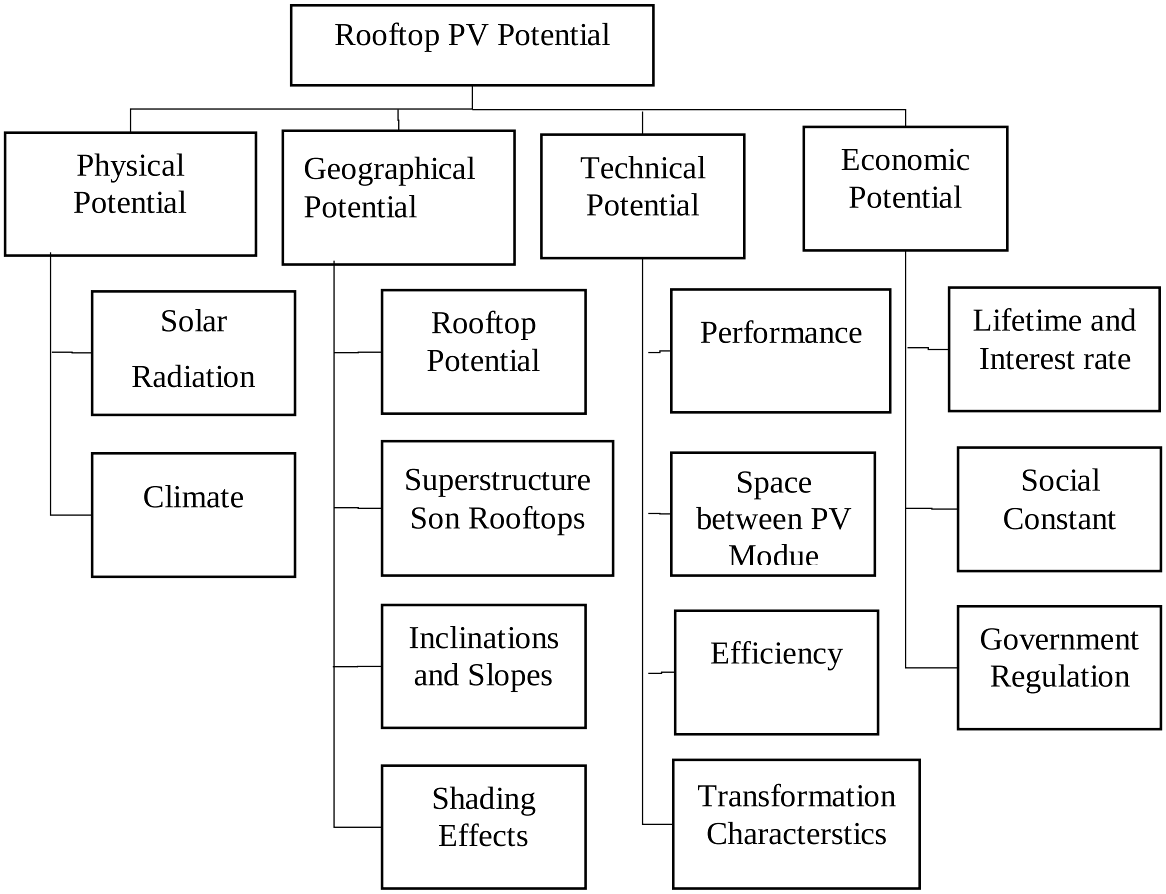


Figure 2.1: Types and factors affecting solar PV potential

(Singh and Banerjee, 2015)

The actual solar photovoltaic area from built in area can be determine as shown in Figure 2.2

. i.e., PVA = BFA*PVA ratio (Singh and Banerjee, 2015).

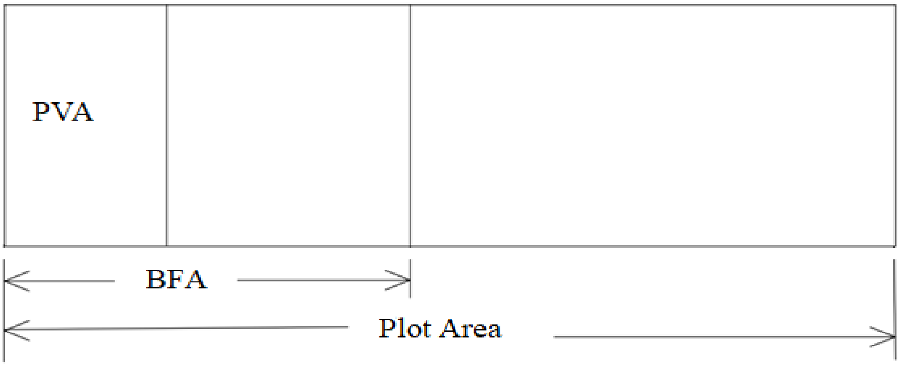


Figure 2.2: Correlation between PVA, BFA and Plot Area

(Singh and Banerjee, 2015)

### 2.3.2 Plot area

It is the area occupied by the building i.e., if any structure is built in 100 $m^2$, then 100 $m^2$ is the plot area of this building or structure as shown in Figure 2.2.

### 2.3.3 Building footprint area

It is common for building all plot area is not used for constructing the building some part of it left for parking and free space. The area used for construction of building is known as building footprint area (BFA) and ratio of BFA to plot area is BFA ratio (Singh and Banerjee, 2015) as shown in Figure 2.2.

$$i.e \quad BFA\,ratio = \frac{\text{BFA}}{\text{Plot Area}} \qquad \text{Equation 2.1}$$

### 2.3.4 Photovoltaic area

For installing the solar panel only certain area of rooftop is utilized because of shading, ventilation required in building, some essential structure in roof-top etc. after considering these factors the actual area available for solar PV installation is known as Photovoltaic area (Singh and Banerjee, 2015) i.e., mathematically

$$PVA\,ratio = \frac{\text{PVA}}{\text{BFA}} \qquad \text{Equation 2.2}$$

### 2.3.5 Performance analysis

Performance analysis is the very crucial parameter for to find actual energy yield, from this study investor can decide to invest or not. According to IEC 61724 standard, the final yield (Yf), array yield (Ya), reference yield (Yr), energy efficiency, and total power generated by the PV system EAC are the major consideration under performance analysis.

### 2.3.6 Array yield

The final yield is the ratio of AC energy delivered during a specific period to the rated power of the installation (Al-Otaibi, 2015) and given by

$$Y_A = \frac{\mathrm{Edc}}{PVrated} \qquad \text{Equation 2.3}$$

### 2.3.7 Final Yield

The final yield is the ratio of AC energy delivered during a specific period to the rated power of the installation (Al-Otaibi, 2015) and given by

$$Y_{f.\,d} = \frac{\mathrm{Eac}}{PVrated} \qquad \text{Equation 2.4}$$

### 2.3.8 Reference Yield

It the ratio of global solar radiation ($H_t$) in kwh/m$^2$ to PV's reference irradiance and given as (Kymakis et al, 2009).

$$Y_r = \frac{\mathrm{Ht}}{\mathrm{Hg}} \qquad \text{Equation 2.5}$$

Where Hg = 1 kw/m$^2$

### 2.3.9 Performance Ratio

Performance ratio depends on the total losses in the system resulting from conversion operations made by different compnents as PV modules, inverters, and cables. Weather conditions as ambient temperature are also impacting factors.

The performance ratio (PR) can be defined as the final yield divided by the reference yieldand is given as (Chaiyant et al., 2009)

$$PR = \frac{\mathrm{Yf}}{\mathrm{Yr}} \qquad \text{Equation 2.6}$$

### 2.3.10 Capacitor factor

The Capacity Factor (CF) during a specific period is the AC energy produced by the PV system divided by the AC energy that can be generated if the system operated withits nominal power during that same period. The annual capacity factor is given as (Kymakis et al., 2009: Sharma and Chandel, 2013: Singh and Banerjee, 2015)

$$C.F = \frac{Eac}{\mathrm{Ppvrated} * 24 * 365} \qquad \text{Equation 2.7}$$

## 2.4 Power Distribution System

Distribution system is the one of the most important component of power system. It is the system of providing electrical energy from substation to consumer terminal at the required voltage level. There may be any types of consumer like as: domestic, industrial, and commercial. There are mainly three types of configuration of distribution system. These are: radial, loop and network type configuration. These configuration have owns advantages and disadvantages (Humayd, 2011).

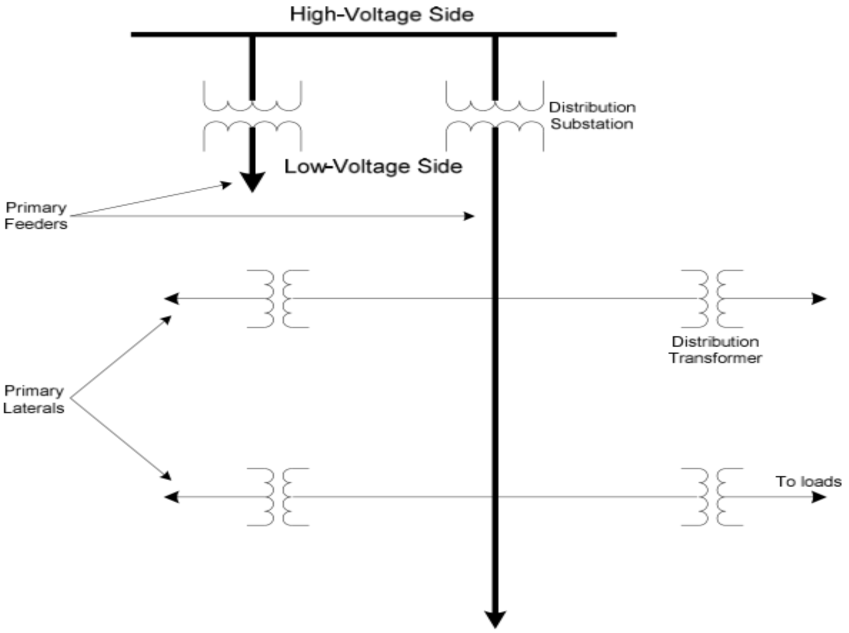


Figure 2.3: Radial configuration (Humayd, 2011)

### 2.4.1 Radial Distribution System (RDS)

Structure of radial network is shown in Figure 2.3. Main features of this structure are (Gönen, 1986) :

- One side power supply,
- Less expensive
- unreliable,

The structure in which only one substation for power feeding and there is only one way for power transfer to consumer from feeding station is known as radial structure of distribution system. The merits and demerits of radial structure are:

Merits

- Economical: This can be installed in lowest cost.
- Simple and easy maintenance
- Suitable in remote area.

Demerits

- Reliability is poor. Fault in any point, it disturb the whole supply of power after this fault point.

- Poor voltage regulation in end point of feeder.

In designing and planning of such structure level of reliability should be kept in mind without extra cost.

Sometimes structure is built in network form and conduct radially. Normally this types of structure are constructed in village area.

### 2.4.2 Network Distribution System

The structure of network type system is shown in Figure 2.4. Some features of this type of system are as follows (Gönen, 1986):

- More than one link between substation and consumer terminal,
- more than one path and some lines form loops within the system,
- reliability is more than radial
- Costly than radial system.

In this structure primary side of distribution transformers make a loop.

When feeder is supplied by two or more than two generating stations it is known as network system. Any area supplied from one substations at peak time can be supplied from another source also. This decrease extra backup source and improve the system efficiency

Merits:

- Highly reliable system
- Fault in any point will not disturb the whole system because there are more than one path for supply power.

Demerits:

- Complex structure
- Expensive

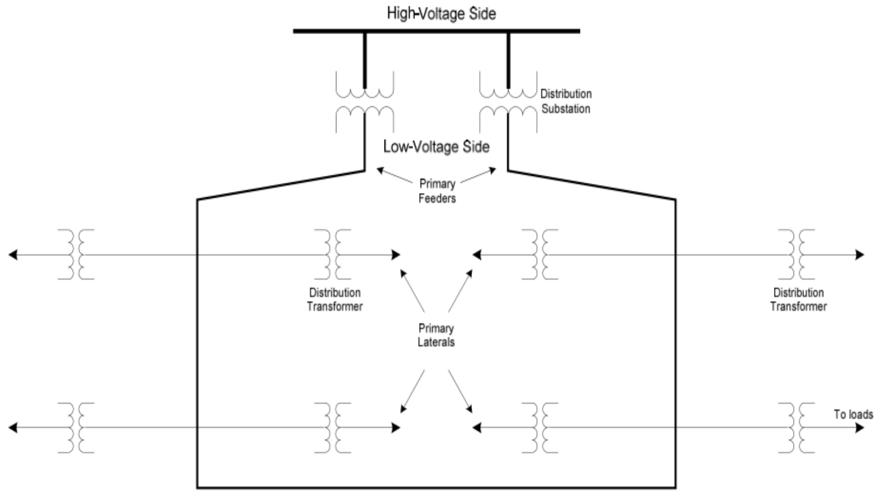


Figure 2.4: Network Distribution System(Humayd, 2011)

### 2.4.3 Loop Distribution System

The loop structure of power distribution is shown in Figure 2.5. And characteristics of this structure are as follows (Gönen, 1986):

- Reliability is more than radial structure but less than network
- Less costly than network and more than radial.
- NO switch is placed between two radial structure
- High reliability than radial system,

Disadvantages

- Structure is complex than radial structure
- Cost is more than radial
- Reliability is less than radial.

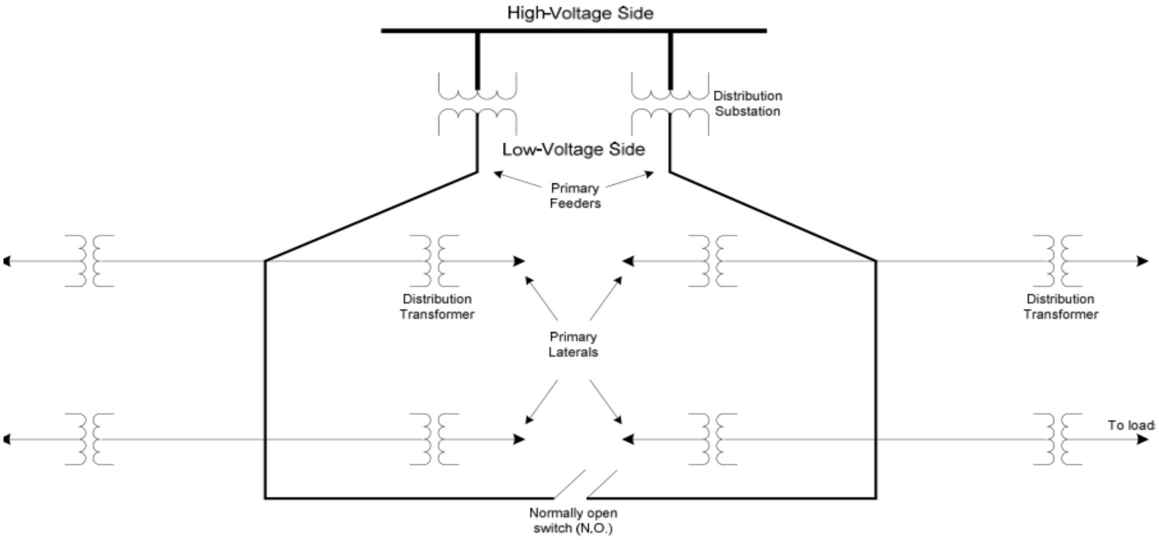


Figure 2.5: Loop Distribution System (Humayd, 2011)

## 2.5 Power System Losses

There are many losses in power system. Mainly they are technical and non-technical losses. Technical losses are the losses in transmission and distribution line such as $I^2$ R losses. These losses are cannot be minimized in given structure. But non- technical losses such as theft, neutral tampering etc. These losses can be minimized by taking related action. The losses except technical losses are not related to the operation of the power systems, such as faulty meter reading, non-payment of electricity bills, incorrect assessment of non-metered supply, and ineffective business and technology management systems. The distribution systems' many small parts are where the technical losses happen.(C. Daniel, 2005). The majority of losses occur at times of peak demand, when every resource is working at its full capacity to provide the end customer with the electricity they require. The copper losses become more significant as the load rises. Since copper losses are a function of the square of current flowing through the line, they account for the majority of the active power lost in the distribution system as shown in Equation 2.8.

$$P_{loss} = I^2R$$

Equation 2.8

Power loss equation shows that losses is depends upon resistance of line and resistance of line. Power loss is the product of square of the line current and resistance of line. Resistance is the nature of line which oppose the current flow. Magnitude of line current flowing through the line depends upon load of the circuit. Load includes total active and reactive load. Current flowing in the line based on total power supplied to the load. Current flow also based on voltage. The equation 2.9 gives the value of apparent power which is the product of voltage and current. This shows that for constant apparent power higher the voltage lesser the current flow.

$$\boldsymbol{S = V\,I}$$

Equation 2.9

.

### 2.5.1 Backward / Forward Sweep Algorithm

The primary advantage of the backward/forward sweep algorithm is the distinct route that each bus takes to return to the source in RDS (Zimmerman, 1995). The backward sweep and forward sweep basic phases of the sweep algorithm are iterated until convergence is reached. During backward sweep there is addition of current and in forward sweep determination of voltage drop is carried out. So that in forward sweep method node voltage is calculated. Where as in backward sweep branch current and power loss of each are calculated.(Zimmerman, 1995).

Table 2.2: Backward / Forward Sweep Algorithm

<table>
<tr><th colspan="2">Backward / Forward Sweep Algorithm</th></tr>
<tr><td colspan="2">Node voltage consideration</td></tr>
<tr><td>1</td><td>Backward Sweep: addition of current</td></tr>
<tr><td>2</td><td>Forward Sweep: Evaluate voltage drop</td></tr>
<tr><td colspan="2">Frequently calculate value until meet criteria</td></tr>
</table>

(Zimmerman, 1995)

The sweeping process in distribution systems uses a variety of techniques, some of these techniques are discuss in below (Teng, 2014).

### 2.5.2 Power Addition Method

Detailed information is provided about the sweep algorithm utilizing the power addition approach (Rupa & Ganesh, 2014) is explain in brief. Figure 2.6 shows that SLD of radial structure. Assuming real power ($P_n$) which passes from node ‘n’ to ‘n+1’ and imaginary part of apparent power ($Q_n$), which passes from node n to ‘n+1’..

At starting considering all bus as 1 pu.

### 2.5.3 Backward Sweep

In backward sweep approach branch power is evaluated starting from last node and toward first. Power calculation formula is shown in Equation 2.10.

$$P_n = P'_{n+1} + r_n \frac{\left(P'^2_{n+1} + Q'^2_{n+1}\right)}{V^2_{n+1}}$$

Equatin 2.10

where,

$$P'_{n+1} = P_{n+1} + P_{Ln+1}$$

$$Q'_{n+1} = Q_{n+1} + Q_{Ln+1}$$

$P_{n+1}$ is the real part of apparent power which passes from node ‘n+1’ and $Q_{n+1}$ is the imaginary part of apparent power which passes from node ‘n+1’. $P_{Ln+1}$ and $Q_{Ln+1}$ are loads joined at node ‘n+1’.

### 2.5.4 Forward Sweep

For potential drop calculation in each branch using equation 2.11.

$$V_{n+1} = V_n - Z_n I_n$$

Equation 2.11

Where, current passing is $I_n$ and value of impedance between node ‘n’ to ‘n+1’ is $Z_n$

Repeatedly determine value of node voltage, current and power loss until criteria is meet.

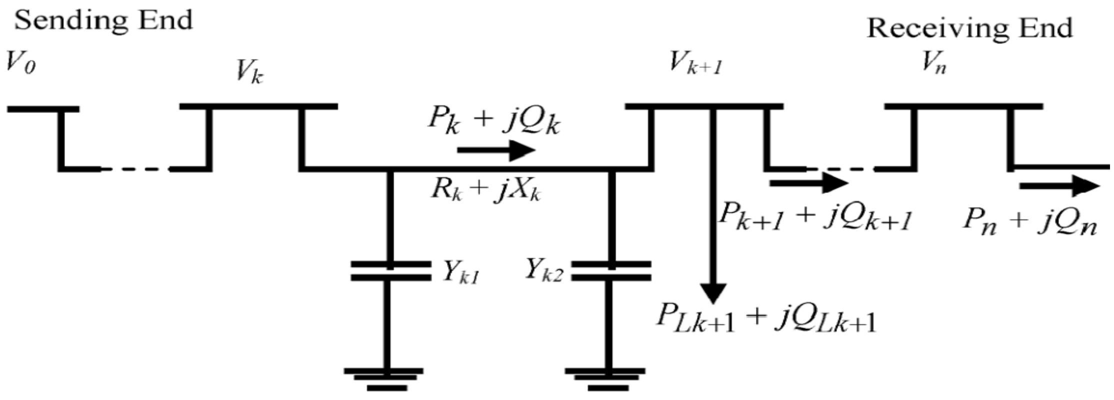


Figure 2.6: SLD of Radial structure

Steps for calculation:

**Step 1: Determination Node current**

For determination of node current, the equation 2.12 is used .

$$I_i^{(k)} = \left(\frac{S_i}{V_i^{(k)}}\right)^* - y_i V_i^{k-1}$$

Equation 2.12

Where,

*i = 1, 2, 3, ……., n.*

$S_i$ is the power at node i. $V_i$ is the voltage at node I and $y_i$ is the shunt admittance at node i.

**Step 2: Backward sweep:**

From end branch, branch current is evaluated using equation 2.13.

$$J_l^{(k)} = -I_{lr} + \sum J_{lr}$$

Equation 2.13

Where,

*l = b, b-1, ……,* 1.

$I_{lr}$ is node current and determined from first step and, $\sum J_r$ is the branch current.

**Step 3: Forward Sweep:**

Voltage and potential drop are evaluated from equation 2.14

$$V_{lr}^{(k)} = V_{ls}^{(k)} - Z_l J_l^{(k)}$$

Equation 2.14

Where,

$l$ =1, 2, ……., $b$.

$ls$ and $lr$ denote the sending and receiving end of branch $l$, $Z_l$ is the series impedance of branch $l$.

## 2.6 Optimization Techniques

Since it is a mathematical model, optimization's primary goal is to either maximize desired outcomes (e.g., profit, quality, efficiency, etc.) or minimize unwanted outcomes (e.g., cost, energy loss, errors, etc.). In all engineering professions, optimization is a mathematical issue that is frequently addressed. Finding the finest possible/desirable answer is what it literally means. Methods for tackling optimization problems are numerous and have a wide range. Traditional and contemporary optimization techniques, as well as other approaches, have all been created to address issues with power system operation, control, and planning. (Ayalew et al., 2019).

### 2.6.1 Traditional Method

Traditional approaches can be formulated to take use of the current scarcity techniques applicable to large-scale power systems, and some of their algorithms are optimality mathematically rigorous. These techniques are Unrestricted optimization strategies Programming techniques include nonlinear programming (NLP), linear programming (LP), quadratic programming (QP), the Newton method, the generalized reduced gradient method, mixed integer programming (MIP), interior point methods, and so on. (Ayalew et al., 2019).

### 2.6.2 Artificial Intelligent Techniques

Numerous power system issues were successfully solved using artificial intelligence (AI) techniques, and it has been shown that these techniques can be even more successful when appropriately combined with traditional mathematical methodologies. Artificial neural networks (ANN), fuzzy logic, intelligent optimization, genetic algorithms, particle swarm optimization, and more are some of these methods. Various PSSs were suggested using these AI approaches.

### 2.6.3 Hybrid AI Techniques

Power system issues may be successfully solved by the strengths and capabilities of AI or conform to its presumptions. Integrating two or more strategies in order to maximize their strengths and minimize their weaknesses to produce hybrid solutions is one method for handling these difficult real-world challenges. (Warwick et al., 1997). Those techniques are Fuzzy neural network systems Fuzzy/ neural/expert/genetic systems, simulated annealing with, fuzzy/genetic/expert systems and so on.

### 2.6.4 Genetic Algorithm

Genetic algorithm technique is the technique of solving optimization problem which are related to natural selection. A GA enables a population of many people to evolve to a state that maximizes "fitness" (i.e., minimizes the cost function) under predetermined selection procedures.

Due to its traits, genetic algorithms are especially well adapted to poorly structured optimization tasks. The binary status of switches in the distribution reconfiguration problem lends itself favorably to the encoded digital data of false strings employed by this method. Because the GA searches from a population of points rather than a single search point, this presents the prospect of finding an best result relatively quickly. Characteristics of this method are:

1. Rather of using the parameters themselves, GAs code the set parameters. Therefore, integer or discrete variables are simply handled by GAs.

2. GAs look within a population of points rather than just one. As a result, GAs can offer a globally ideal solution.

3. GAs don't employ derivatives or any other auxiliary information; they just use information about objective function. So this method uses the function which are discrete and infinite. These functions are found in real world.

4. This method does not employ deterministic criteria. We utilize GS because GA differs from other search algorithms in a number of ways from those other search approaches.

5. The algorithm seeks multiple peaks simultaneously, minimizing the possibility of local minimum trapping.

6. The genetic operator can develop the current state into the next state with the least amount of calculations if GA is used since it used encoded value.

**Advantages and Disadvantages of Genetic Algorithm Advantages**:

- GAs are capable of handling discrete or integer variables.
- They can offer a globally optimal solution.
- This method can handles discrete, rough, concave and uniform problem that are present in real world.
- convergence is fast, can evaluate many solutions by this method
- GAs are simple to code to work on parallel computers.
- GAs have the potential to find solutions in many areas of the search space simultaneously.

## 2.7 Selection Process

Charles Darwin's theory of evolution of living things is imitated by genetic algorithms (GA), which are direct, parallel, stochastic methods for global search and optimization. GAs are a subset of the class of evolutionary algorithms. The three major tenets of natural evolution are used by evolutionary algorithms: reproduction, natural selection, and species diversity, which is sustained by the variations between each generation and the one before it.

In nature, the survival of the fittest is used to choose individuals. The more an individual's environmental adaptation, the greater the likelihood that it will live, procreate, and pass on its genes to the next generation. Individuals with modest values of the fitness function will have a greater likelihood of recombination and, consequently, of producing offspring if the optimization problem is a minimization problem.

# CHAPTER THREE: METHODOLOGY

## 3.1 General

Complete work is divided into different parts, first part deals with site selection and data collection of Bishnumati feeder of Balaju DCS. Second stage is load flow analysis without EV load and then load flow analysis randomly generated EV load. In third, place PV using GA technique. In last stage includes determining of losses, voltage profile analysis and then find optimized solution. The overall workflow chart is shown in figure below.

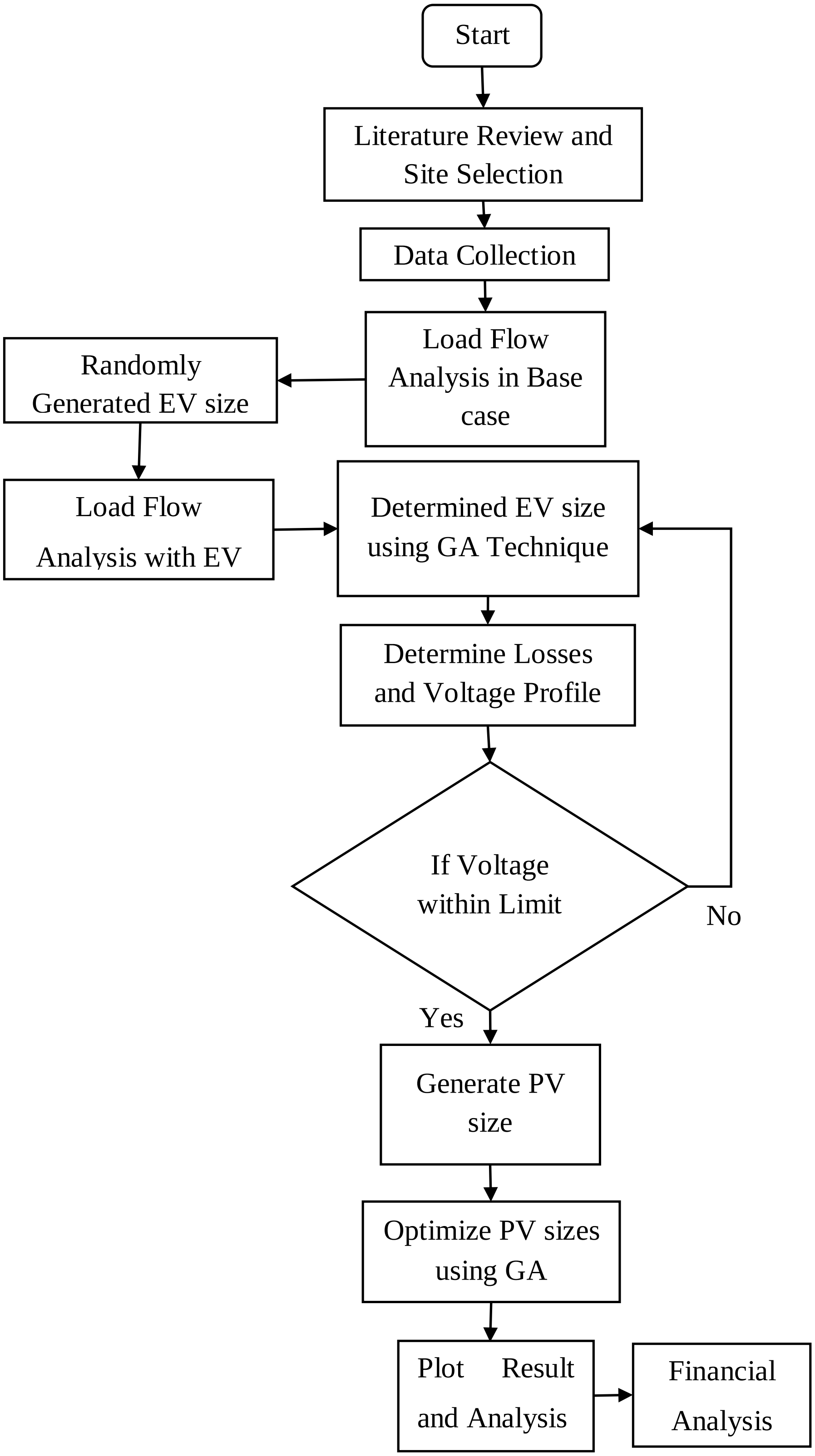


Figure 3.1: Flow Chart of Overall Thesis Work

## 3.2 Site Selection

For this research work Bishnumati feeder of Balaju substation is selected, which is located at Tarakeshwor municipality. Bishnumati feeder is feed by the Balaju substation. The satellite view of Tarakeshwor municipality is shown in Figure 3.2.The voltage drop at far end of Bishnumati feeder is high which cause the operational difficulty in end user devices, the voltage profile at daytime can be increase by injecting solar PV into a grid. There are many commercial buildings which has possibility of many EV users flow. Charging station required for EV which can be installed in any location of feeder. The impact of charging station in feeder that is voltage drop and power loss can be overcome by penetrating solar PV in feeder.

Figure 3.2: Sattelite View of Tarakeshwor Municipality

Tarakeshwor is municipality under Kathmandu district of Bagmati province. Which located in western part of Kathmandu district. It is formed after establishment of federialism in Nepal. It was established on December 2 of 2014 by combining the previous Dharmasthali, Futung, Goldhunga, Jitpurphedi, Kavresthali, Manmaiju and Sangla viage development committee before federalism in Nepal. It covers the area of 34.9 km$^2$, as information obtained from census 2011, total population of this municipality is 81,443. It is located in 27°47′12″ Northern latitude and 85°18′11″ Eastern longitude. According to information obtained from NEA, total number of consumers supplied by Balaju distribution feeder are 29,879. Different consumers of Bishnumati feeder are listed in Table 3.1.

Table 3.1: Types of consumers and their number

| S.N. | Type of Consumer | Number |
|---|---|---|
| 1. | Commercial | 237 |
| 2. | Domestic | 29,055 |
| 3. | Entertainment | 2 |
| 4. | Industrial | 335 |
| 5. | Internal Consumption | 4 |
| 6. | Irrigation | 4 |
| 7. | Non-Commercial | 102 |
| 8. | Non-Domestic | 40 |
| 9. | Religious and Cultural | 31 |
| 10. | Streetlight | 9 |
| 11. | Temp. Supply | 13 |
| 12. | TOD Industrial | 29 |
| 13. | Water Supply | 18 |
|  | Total | 29,879 |

There are total 57 buses in the Bishnumati feeder. Bishnumati feeder is radial distribution network supplied by the Balaju substation. Single line diagram of Bishnumati feeder is shown in figure below.

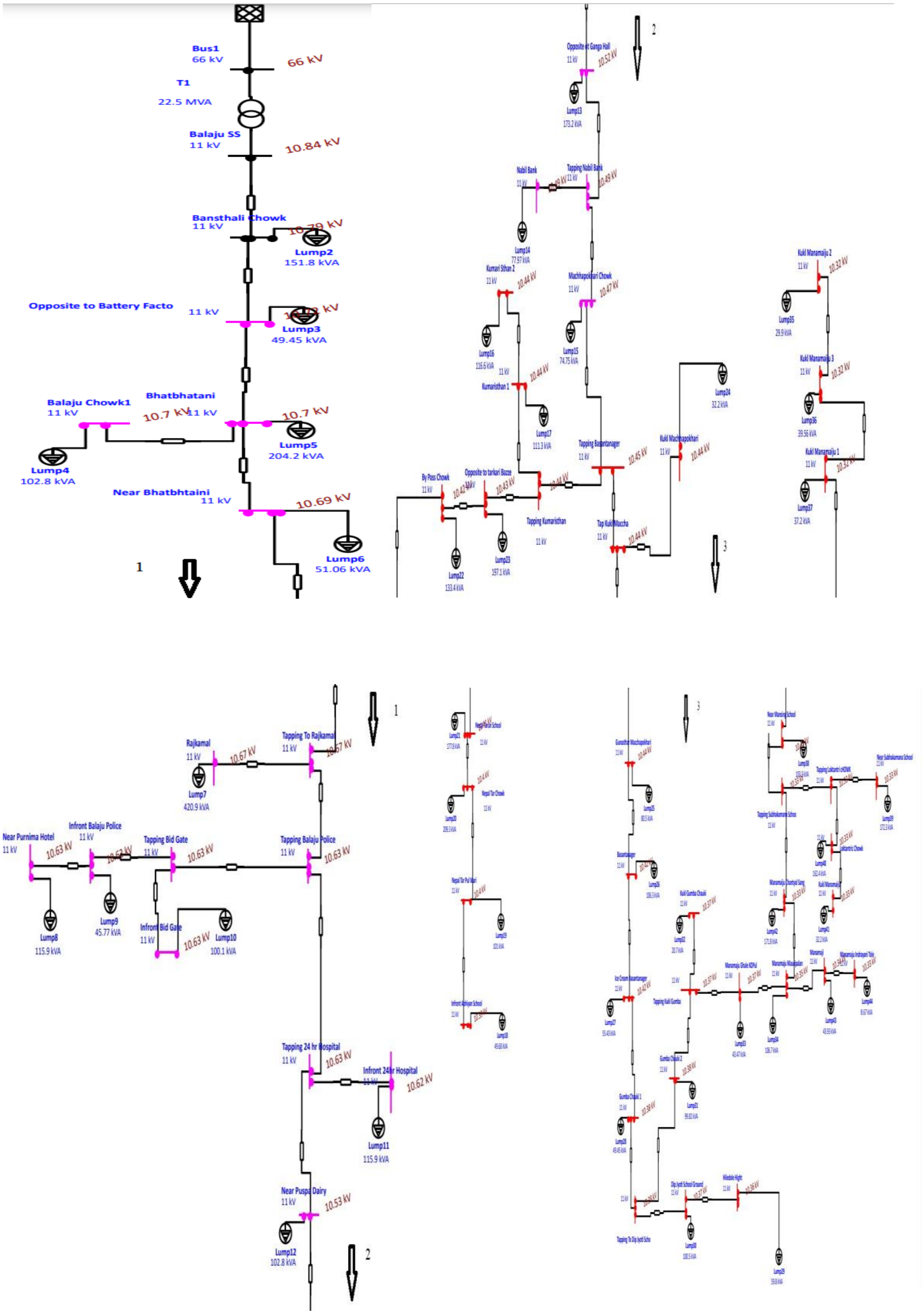


Figure 3.3: Single Line Diagram of Bishnumati Feeder

## 3.3 IEE-33 Bus Test Distribution Network System

IEEE-33 bus system is the standard test bus system. It consists of 33 buses and 32 lines. It is simulated in MATLAB. Starting bus of the system is considering substation which feeds power to the radial network. Which is shown in Figure 3.4. Since network is radial so there is using sectionalizing switches and tie switches to manipulate. Distribution networks are usually interconnected but sometimes there are radial network also used for economical aspects. Radial networks are normally built in remote area for power distribution. Fault in any point of the radial network disturb the power supply of whole network. So stability of radial network is poor.

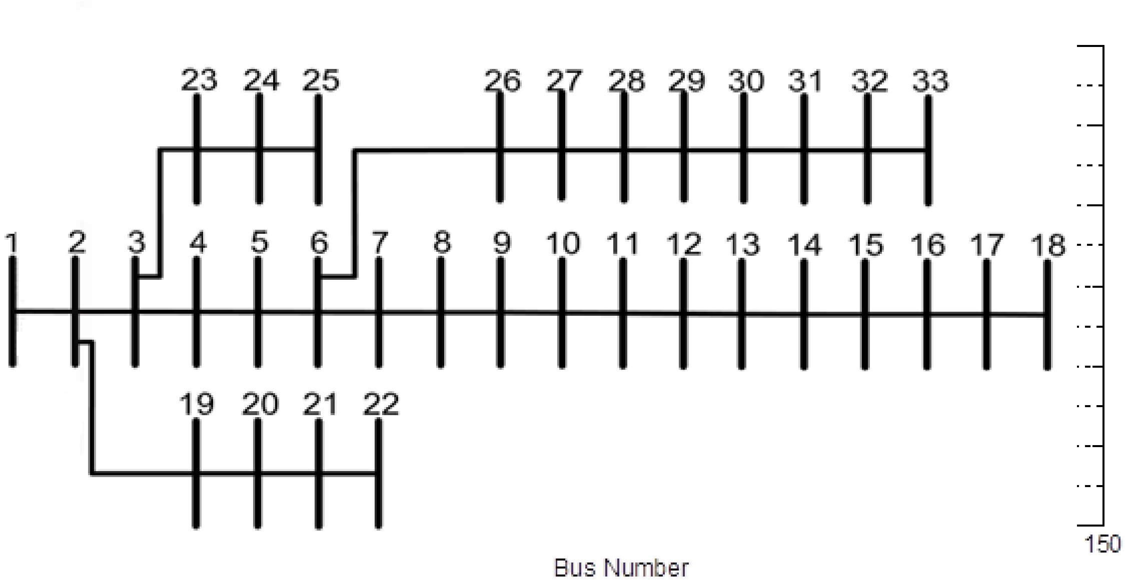


Figure 3.4: IEE 33 Test Bus System

Radial network consists of different switches like as normally open switches and normally closed switches. There is total active load of 3715 kW and reactive load of 2300 kVAR. In this system first bus is swing bus with votage 1 pu and there are no any load in this bus. The value of line data and load data of the network is presented in appendix below.

## 3.4 Line Loss Calculation

The complete paradigm for analysis of electric vehicle charging station and PV sizing is presented in figure below. The technical analysis performed for distribution system insights into the system power loss, and respective bus voltage and hence the integration planning process become decisive for the outcome.

The unique path from any stated bus backward to the source in power distribution system is the important feature used by the backward / forward sweep method. The sweep method of load flow analysis includes two fundamental steps, backward sweep and forward sweep, which are done again and again until result is converged.

Single line diagram of radial distribution network system which is used by power summation method of sweep algorithm. Assuming the watt full power ($P_k$) and reactive power ($Q_k$) which is flowing through branch from node ‘k’ to node ‘k+1’.

Firstly, all node voltage are assuming 1 pu.

**Backward Sweep**

The power pass through each line is determined in backward side from end node that is given by equation 3.1

$$P_k = P'_{k+1} + r_k \frac{\left({P'}^2_{k+1} + {Q'}^2_{k+1}\right)}{V^2_{k+1}}$$ Equation 3.1

where,

$$P'_{k+1} = P_{k+1} + P_{Lk+1}$$

$$Q'_{k+1} = Q_{k+1} + Q_{Lk+1}$$

$P_{k+1}$ and $Q_{k+1}$ are the impactful real and reactive power flowing from point ‘k+1’ and $P_{Lk+1}$ and $Q_{Lk+1}$ denote loads that are joined at point ‘k+1’.

**Forward Sweep**

The magnitude and phase angle of voltage at each node are determined by using equation 3.2.

$$V_{k+1} = V_k - Z_k I_k$$ Equation 3.2

where,

Current passes thorough branch is $I_k$ and the value of impedance between node k and k+1 is $Z_k$.

The backward and forward sweep equations are determined frequently until result reached acceptable limit.

The lower and upper limit of EV units and PV units are fixed and then the population of chromosomes are created within these lower and upper limit. The constraints assuming for calculation are mentioned in equation below

$$0 < P_{PV,size} \leq 1500\ kW$$

Equation 3.3

$$0 < P_{EV,size} \leq 400\ kW$$

Equation 3.4

$$0.85\ pu \leq V_{bus} \leq 1.03\ pu$$

Equation 3.5

Minimization of total real power loss under given imitations is the main objective function of our methodology. Summation of total real power losses of radial network is the fitness function which is also called objective function which is given in Equation 3.6

$$Fitness\ function = \sum_{i=1}^{total\ branches} P_{loss}$$

Equation 3.6

The objective function is calculated for every chromosomes of population and after the initialization. The chromosomes are created by using reproduction and mutation technique. Lagrangian equation of GA is used for production of new chromosomes.

The complete flow chart for load flow analysis of selected distribution system is shown in figure below.

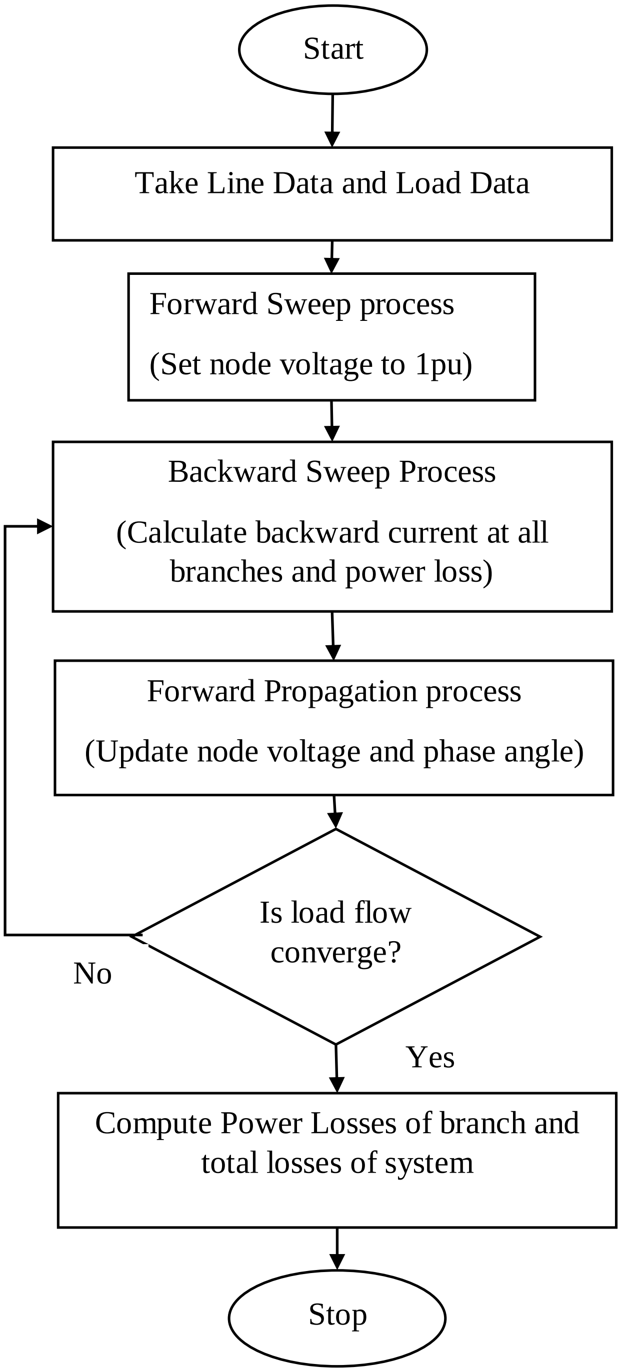


Figure 3.5: Flow Chart for Load Flow Analysis

The technical analysis completed for given system gives insights into the system's weaknesses and strengths parts with regard to power losses in each bus and the respective bus voltage, making the integration planning process crucial to the conclusion.

Following are the steps can be employed to describe the method for already above mentioned system power loss calculation.

Step 1: initializing from giving input of line data (R, X) and bus data (P,Q) of the system

Step 2: Voltage of each node is considered as 1 pu.

Step 3: Branch current values are determined by using equation of backward sweep method.

Step 4: In forward sweep method the value of voltage and phase angle is corrected.

Step5: The calculation in backward and forward propagation is done continuously until our criteria of result are reached.

Step6: Power losses is calculated by latest updated value of voltage and current after criteria met value obtained.

Step7: At last calculated power losses and voltage level are saved.

Step 8: Stop the process.

The above mentioned method is starts with the input of the system line and load data.1 pu is considered as voltage of each node of network and the branch currents are determined by using backward sweep method and magnitude of voltage are evaluated by using forward sweep method of load flow analysis. Calculation is done continuously until result met criteria. Iteration of backward and forward sweep propagation are repeated many times to obtained desired value. Firstly methodology used for line and load data of standard test bus system of IEEE. 33 test bus system is used in our study. Values of test bus system are given in appendix below. Then methodology is applied to our real system. Bishnumati distribution feeder under Balaju distribution center is taken as real system.

## 3.5 Detail Procedure for Optimization using GA

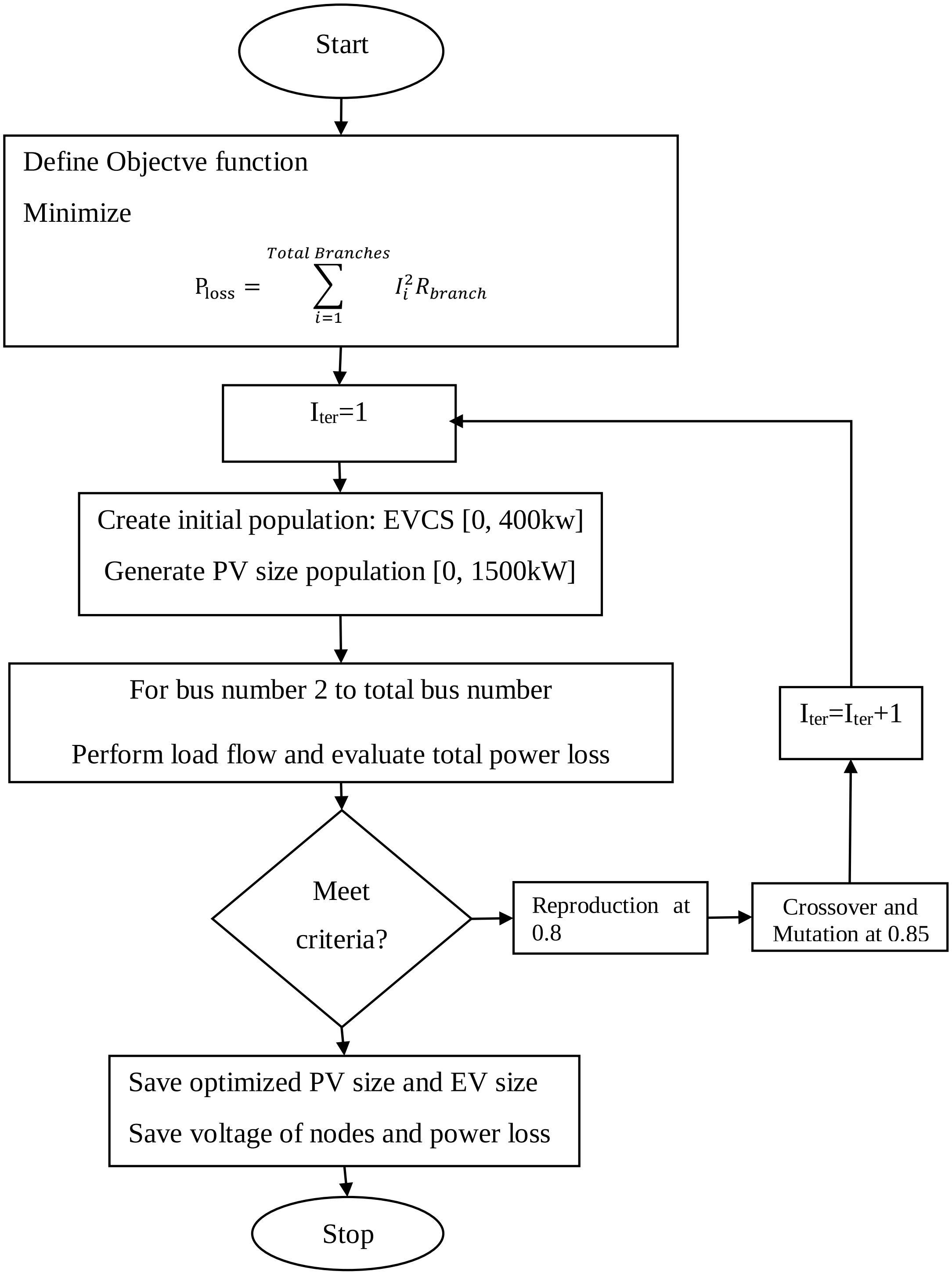


Figure 3.6: Flow chart of Genetic Algorithm used in Distribution System

Figure 3.6 depicts the entire process for analysis and planning of optimization in radial distribution systems as a flow diagram.

Optimal location of Charging Station using Genetic Algorithm based method takes the following steps.

**Step 1**: Describes objective function and each constraint

The objective function is the total active power loss of the distribution system which depicts from $P_{loss} = \sum_{i=1}^{total\ branches} I_i^2 R_{branch}$

**Step 2**: Set stopping criteria

The stopping criteria is either total number of iterations that converges to optimal solution or the consecutive losses of two iterations have negligible differences.

**Step 3**: Create initial population (number of length of chromosomes and number of population)

The initial populations of number of PV sizes under EV loads are considered. The total 10 numbers of solutions generated at each time during simulation.

**Step 4**: Evaluate fitness function

The power loss is defined as fitness function is evaluated using load flow analysis at each iteration by changing the PV locations for fixed EV stations.

**Step 5**: Perform Reproduction

The reproduction takes places inherently using MATLAB by standard formula with reproduction rate of 80%.

**Step 6**: Carry out crossover

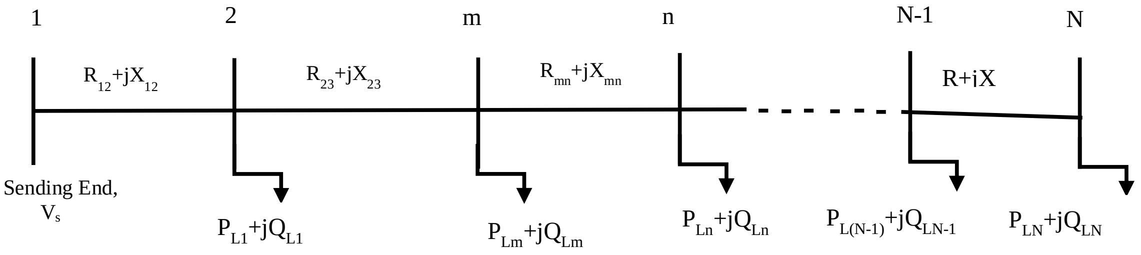
The Crossover and mutation take places inherently using MATLAB by standard formula with crossover using string bit and mutation rate of 85%.

**Step 8**: Increase number of iterations until stopping criteria

The total number of iterations carried out is 50 and 200. For both of iterations, the solutions converge within 50 iterations.

## 3.6 Calculation with base case

In this calculation, load flow analysis is carried by using collected line data and load data of Bishnumati feeder. The line data (resistance R and reactance X ) and load data(active power P and reactive power Q) of feeder are shown in appendix below. For load flow analysis backward-forward sweep method is used.



During load flow analysis the value of load data and line data are input parameters. Considering initially each node voltage as 1<0˚. Then calculate each load current by using formula:

$$I_j{}^k = \left(\frac{PL_j + QL_j}{V_j{}^{(k-1)}}\right)^* \quad for\ j = 2, 3, 4, \ldots N \qquad \text{Equation 3.7}$$

After calculating each load current, calculate branch current by using back-ward sweep method as

$$I_{mn}{}^k = I_n{}^k + \text{Sumation of all branch current after bus n.} \qquad \text{Equation 3.8}$$

Then by using forward sweep method all node voltages calculated as

$$V_n{}^k = V_m{}^k - I_{mn}{}^k Zmn \qquad \text{Equation 3.9}$$

The backward and forward sweep equations are evaluated iteratively until it converges. Then calculate branch power loss and total power loss as: $P_L = I^2R$

The final result of each node voltage and total power loss is obtained after load flow analysis in matlab.

## 3.7 Calculation in EV load connected case

In this calculation, considering minimum and maximum size of EV charging load as 0 and 400KW. Then random population is created Then load flow analysis is done within genetic algorithm where fitness function is minimization of total active power losses. i.e. $P_{loss} = \sum_{i=1}^{total\ branches} I_i^2 R_{branch}$

In genetic algorithm different 50 random population (EV sizes) are created. Then these population are kept in each bus of feeder and load flow analysis is done for each population in each bus, then fitness value is checked. If fitness value is within the criteria then stop iteration if not reproduction, crossover and mutation of population. Again total power loss is determined from load flow analysis. Then after meeting of criteria optimized value of loss and size is find out.

## 3.8 Calculation in PV and EV charging load case

In Bishnumati feeder total active load is 5572 kW. According to different paper, maximum PV power can be penetrate in distribution feeder is 30% of total load(Hoke et al., 2012). In our study, 26% of total load which is equivalent to 1381 kW PV power is connected to the feeder. PV power is distributed all bus by random distribution function. Then net injected power in each bus is power going through bus minus PV power penetrate into the bus. Then load flow is carried out as previous case. In genetic algorithm different 50 random population (PV sizes) are created from minimum and maximum range of size of PV (i.e. 0 -1500 kW) and check for fitness value in each bus with keeping constant EV sizes. When criteria of fitness is meet then optimized value is find out. If not, process of crossover and mutation of population and increase iteration until stopping criteria.

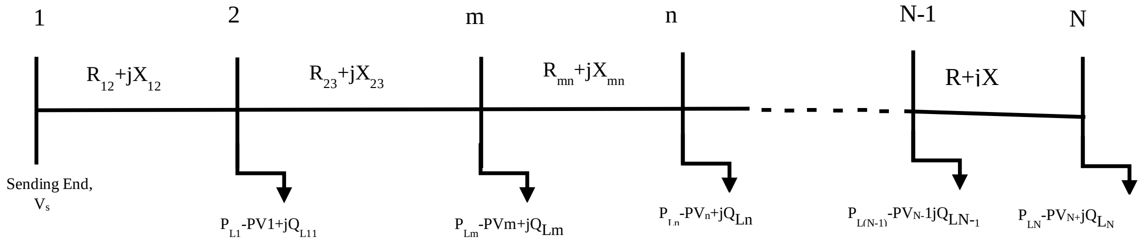


Figure 3.7: Radial bus network with PV injection and EV load

## 3.9 Methodological Tools

MATLAB (MATrix LABoratory), a multi-paradigm numerical computing environment that works directly with matrix and array mathematics, is the instrument utilized for the proposed methodology. It was developed by MathWorks. In MATLAB, all of the codes are just-in-time compiled, library cells are greatly optimized, and math operations are dispersed throughout the computer's cores(MATLAB Designed For Engineers and Scientists, 2016). The algorithm is coded in a MATLAB scripting language and processed for testing and debugging in PC with 64GB RAM, 2.54 GHz processor.

# CHAPTER FOUR: RESULTS AND DISCUSSION

The method used in this work to obtain optimum size and schedule along with location selection has been explained in the chapter 3. Here, in this chapter, the result obtained from application of this method is applied in IEEE 33 bus distribution feeder and then in a selected Nepalese distribution feeder is presented. For the analysis, the parameters considered are as follows:

a) The voltage at the substation bus is considered to be at always 1 pu.
b) Scenario for application of single EV station is considered.
c) All the solar PV are considered to be directly connected to the distribution system without any storage system in itself.
d) The EV charge efficiency shall be considered as 95%.
e) Allowable voltage for each bus is limited to fixed upper limit and is considered to be 1.05 pu.
f) Also, only active power generation by the distributed generators are considered.
g) All the load and generators power are considered to be constant irrespective of bus voltage.

And the obtained results are explained below

## 4.1 Load Flow of IEEE-33 BUS Radial Distribution System

Initially the load flow of the IEEE-33 bus radial distribution system was carried out. The voltage profile of the different buses of the test system is represented using graph shown in the figure.

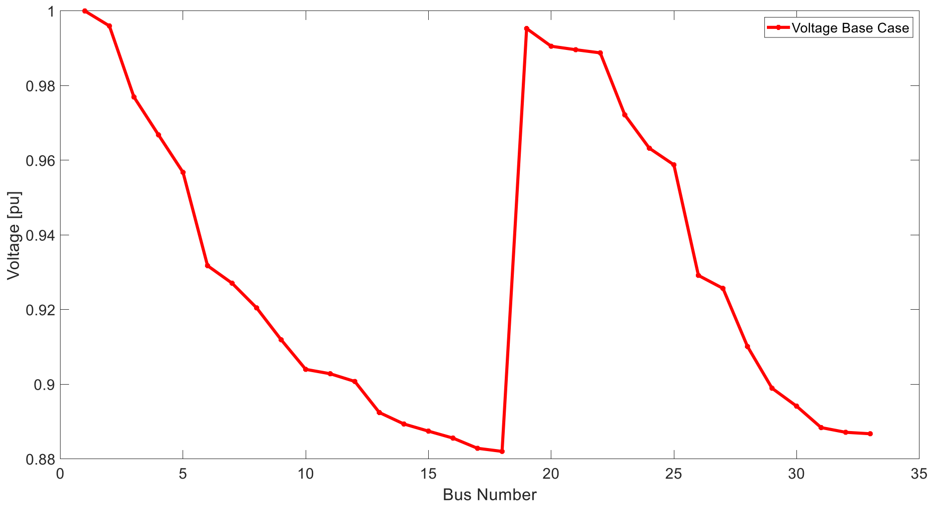


Figure 4.1: Voltage profile of IEEE-33 Bus Radial Distribution Network

The result of load flow indicates that the voltage of the end bus of laterals from bus 3 and bus 6 is below standard, i.e. the voltage at bus 18 is 0.8820 pu and at bus 33 is 0.8867 pu. The buses at the laterals from bus 6 are highly loaded. The voltage at the bus 6 is 0.95pu. As a result of which, the voltage at these buses (26, 27, 28, 29, 30, 31, 32, 33) i.e. lateral from bus 6 goes down below acceptable limit. Furthermore, the voltage at reference bus 1 is 1 pu. The maximum voltage of 0.9960 pu and minimum voltage of 0.8820 pu occurs at bus 2 and bus 18 respectively. The total loss of the system is found to be 281.58 kW.

## 4.2 Load flow results after EV charging station placement

The implementation of the EV charging stations at IEEE 33 bus system is located at buses 14, 15, 16, and 17 with the EV loads 102 kW (60 kW and 42 kW), 84 kW (two nos 42 kW), 84 kW (two nos 42 kW), and 102kW (60 kW and 42 kW), respectively. The total active power load is increased in the system. The load flow shows the voltage is decreased at this time and as shown in figure 4.2.

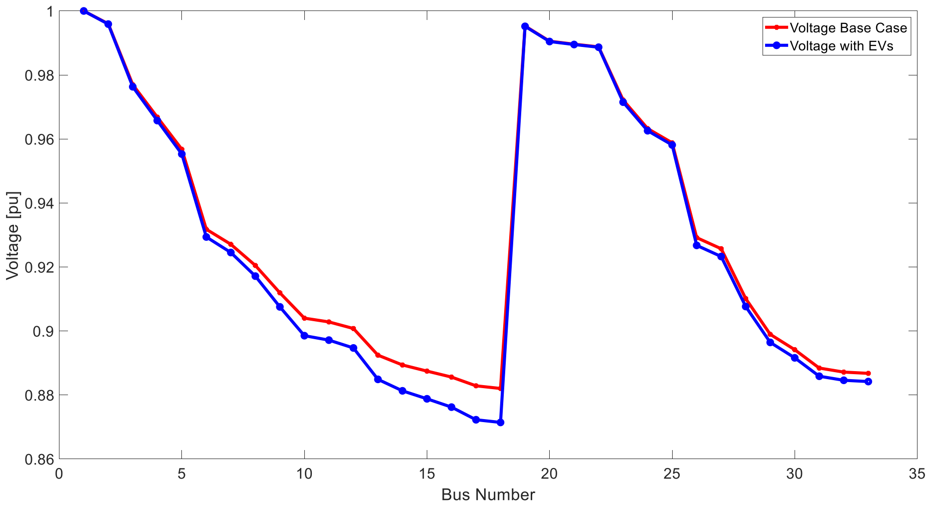


Figure 4.2: Voltage profile of IEEE-33 Bus with EVCS

## 4.3 Load Flow Results after EV charging station placement and PV penetration

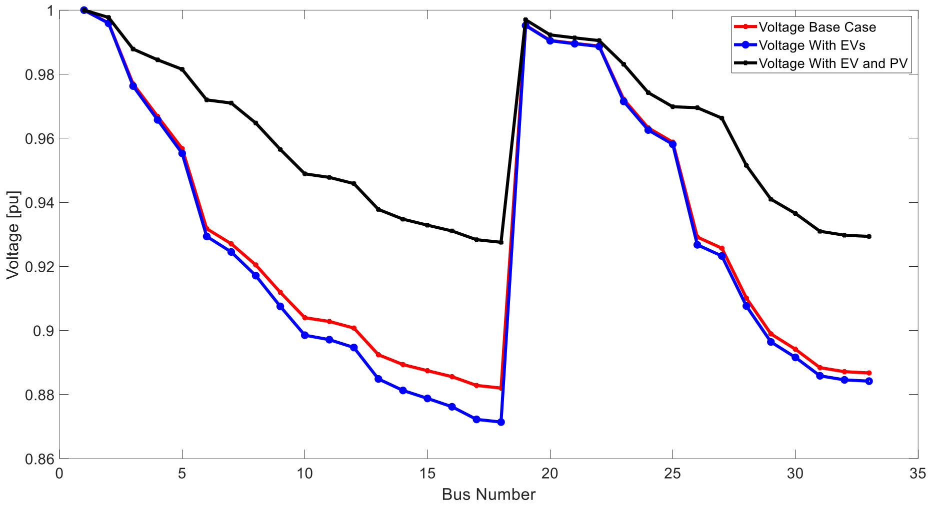


Figure 4.3: Voltage profile of IEEE-33 Bus with EVCS and PV

The rooftop solar PV generation is considered and the optimal flow with genetic algorithm is used for the PVs placement. The total capacity of PV system is required to 1975.2 kW which in results the total system loss of 146.22 kW. The PVs are considered distributed over all together 32 nodes. The random number distribution function is used for the distribution of PVs system in all nodes. The voltage profile for base case, and with EVCS and PV system is presented in figure 4.3. The total power loss is presented in figure 4.4

which shows that the losses of the system increases with the EV charging station and with PV generation system, the losses found to be reduced. It is considered that the charging station located in commercial buildings so that the charging of the vehicles took place at day time. At this time solar also generates the power and get efficient power balance.

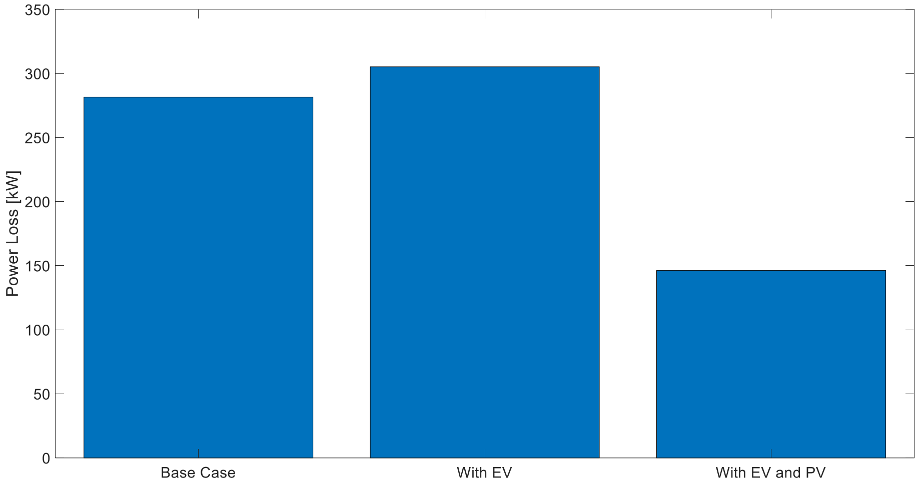


Figure 4.4: Power loss of IEEE-33 bus with EVCS and PV

## 4.4 Load Flow of Bishnumati 57 Bus Radial Distribution System

The load flow of the Bishnumati 57 bus radial distribution system was carried out. The voltage profile of the different buses of the test system is represented using graph shown in the figure.

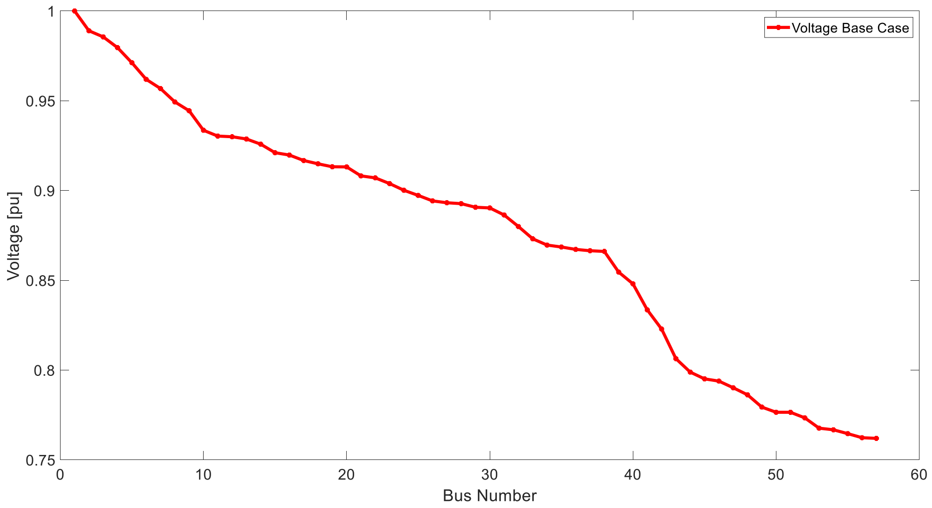


Figure 4.5: Voltage profile of Bishnumati 57 Bus Radial Distribution Network

The result of load flow indicates that the voltage of the end bus of laterals from starting bus. The voltage at the bus 57 is 0.7620 pu (equivalent to 180V AC of domestic users). The total loss of the system is found to be 412.55 kW. The total load of the feeder is 5572 kW and 4179 kVAR.

## 4.5 EV load Placement

Voltage of different bus after injecting different level of EV charging station load in feeder is shown in figure below. The level of EV charging station load is considering according to standard capacity of charging station (i.e. 60 kW or 42 kW as in NEA). In our base case minimum voltage of bus is 180 volt. In this study, I have consider minimum voltage limit of 160 volt with EV charging load. Then different level of EV charging load is increased from 60 kW (as 60 kw, 120 kW, 180 kW, 240 kW and so on). The impact of charging load on bus voltage is shown in figure. In figure lowest voltage is about 0.69 pu (which is equivalent to 160 volt) with EV load of 420 kW.

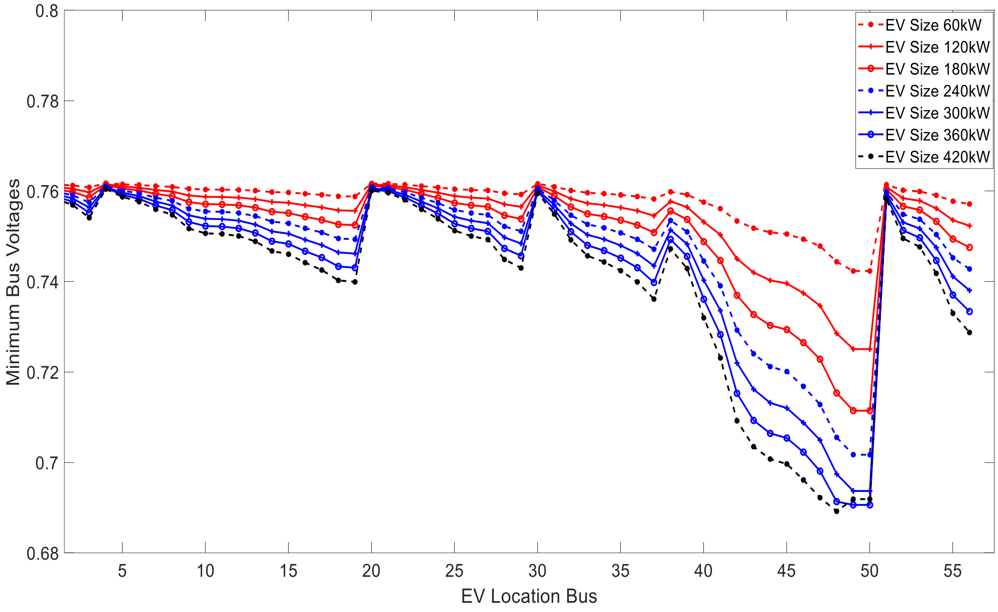


Figure 4.6: Minimum Bus Voltage after different level of EV load placement

## 4.6 Load Flow Results after EVCS Placement

The implementation of the EV charging stations at Bishnumati feeder system is located at buses 48, 49, 50, and 51 with the EV loads 102 kW (60 kW and 42 kW), 102 kW (60 kW and 42 kW), 84 kW (two nos 42 kW), and 84 kW (two numbers of 42 kW), respectively. The total active power load is increased in the system. The load flow shows the voltage is decreased at this time and as shown in figure 4.7.

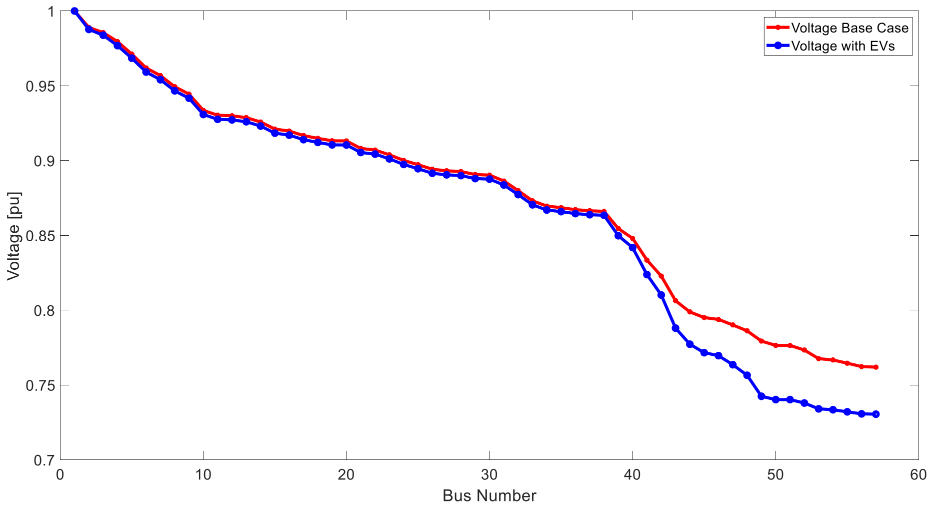


Figure 4.7: Voltage profile of Bishnumati 57 Bus Radial Distribution Network with EVCS

## 4.7 Penetration of PV in Distribution Feeder

According to many research paper normally maximum level of PV penetration in existing distribution system is 30 % of total load. So in our case total 1381 kW PV power is connected to the feeder. This PV is distributed to the different bus of feeder by creating random value. The distribution of PV to the feeder is shown in figure below.

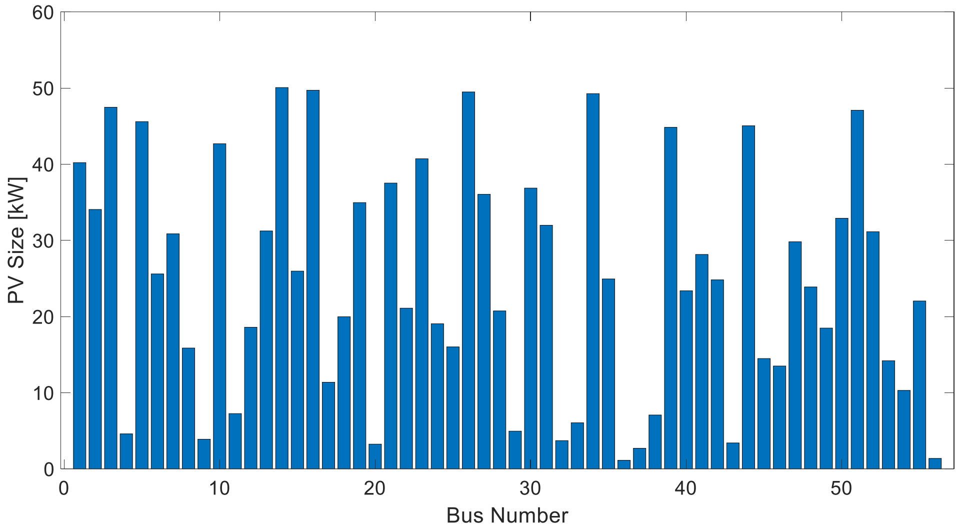


Figure 4.8: PV size distribution by randomly in different bus of feeder

## 4.8 Load Flow Results after EV Placement and PV Peneration

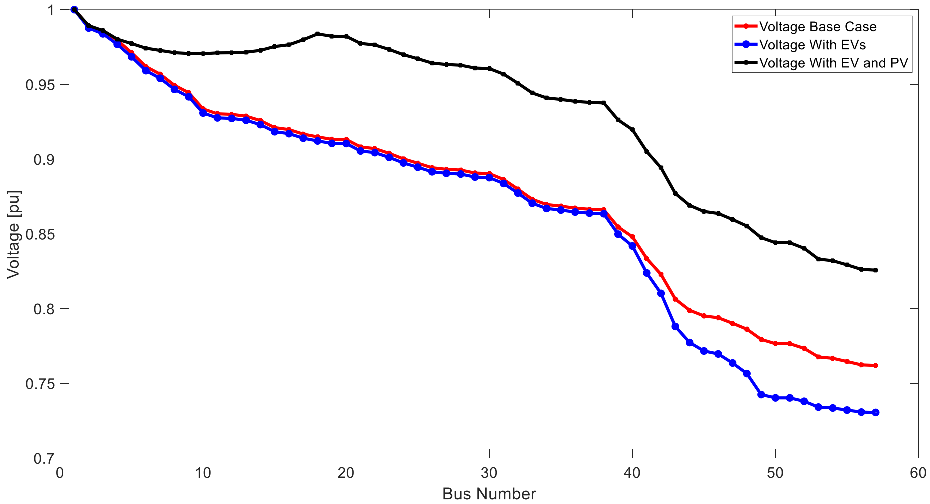


Figure 4.9: Voltage profile of Bishnumati 57 Bus with EVCS and PV

The rooftop solar PV generation is considered and the optimal flow with genetic algorithm is used for the PVs placement. The total capacity of PV system is required to 1381.5 kW which in results the total system loss of 279.15 kW. The PVs are considered distributed over all together 56 nodes. The random number distribution function is used for the distribution of PVs system in all nodes. The voltage profile for base case, with EV and with EV and PV system is presented in Figure 4.9. The total power loss is presented in Figure 4.10, which shows that the losses of the system increases with the EV charging station and with PV generation system, the losses found to be reduced. It is considered that the charging station located in commercial buildings so that the charging of the vehicles took place at day time. At this time solar also generates the power and get efficient power balance.

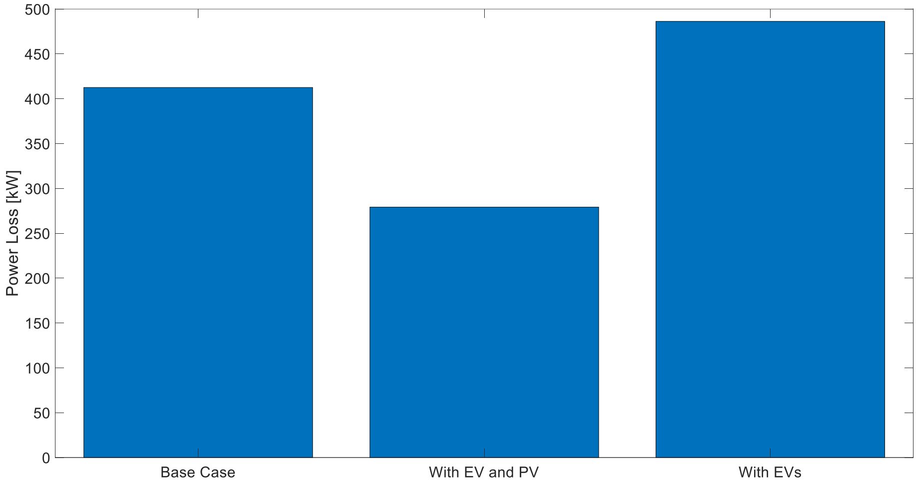


Figure 4.10: Power loss of Bishnumati 57 Bus with EVCS and PV

The voltage of different bus for base case, with EV and with EV and PV is shown in table below.

Table 4.1: Voltage profile of different buses

| Bus Number | Voltage | | |
|---|---|---|---|
| | Base Case | With EV | With EV and PV |
| 1 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 0.9890 | 0.9877 | 0.9893 |
| 3 | 0.9856 | 0.9838 | 0.9860 |
| 4 | 0.9796 | 0.9768 | 0.9802 |
| 5 | 0.9712 | 0.9685 | 0.9773 |
| 6 | 0.9619 | 0.9592 | 0.9742 |
| 7 | 0.9568 | 0.9541 | 0.9727 |
| 8 | 0.9494 | 0.9466 | 0.9712 |
| 9 | 0.9444 | 0.9417 | 0.9707 |
| 10 | 0.9336 | 0.9308 | 0.9705 |
| 11 | 0.9303 | 0.9276 | 0.9711 |
| 12 | 0.9299 | 0.9272 | 0.9711 |
| 13 | 0.9287 | 0.9260 | 0.9715 |
| 14 | 0.9258 | 0.9231 | 0.9727 |
| 15 | 0.9211 | 0.9183 | 0.9753 |
| 16 | 0.9198 | 0.9170 | 0.9765 |

| | | | |
|---|---|---|---|
| 17 | 0.9167 | 0.9140 | 0.9799 |
| 18 | 0.9149 | 0.9122 | 0.9837 |
| 19 | 0.9132 | 0.9105 | 0.9822 |
| 20 | 0.9132 | 0.9104 | 0.9821 |
| 21 | 0.9081 | 0.9054 | 0.9774 |
| 22 | 0.9071 | 0.9043 | 0.9764 |
| 23 | 0.9039 | 0.9012 | 0.9734 |
| 24 | 0.9001 | 0.8974 | 0.9699 |
| 25 | 0.8973 | 0.8946 | 0.9672 |
| 26 | 0.8942 | 0.8915 | 0.9643 |
| 27 | 0.8932 | 0.8905 | 0.9633 |
| 28 | 0.8927 | 0.8900 | 0.9628 |
| 29 | 0.8907 | 0.8880 | 0.9609 |
| 30 | 0.8903 | 0.8876 | 0.9606 |
| 31 | 0.8864 | 0.8837 | 0.9569 |
| 32 | 0.8799 | 0.8773 | 0.9507 |
| 33 | 0.8731 | 0.8705 | 0.9443 |
| 34 | 0.8696 | 0.8670 | 0.9409 |
| 35 | 0.8685 | 0.8659 | 0.9399 |
| 36 | 0.8672 | 0.8646 | 0.9386 |
| 37 | 0.8665 | 0.8638 | 0.9379 |
| 38 | 0.8661 | 0.8635 | 0.9376 |
| 39 | 0.8546 | 0.8498 | 0.9262 |
| 40 | 0.8480 | 0.8419 | 0.9197 |
| 41 | 0.8335 | 0.8238 | 0.9051 |
| 42 | 0.8229 | 0.8102 | 0.8942 |
| 43 | 0.8063 | 0.7880 | 0.8770 |
| 44 | 0.7989 | 0.7773 | 0.8690 |
| 45 | 0.7951 | 0.7716 | 0.8650 |
| 46 | 0.7939 | 0.7696 | 0.8636 |
| 47 | 0.7902 | 0.7636 | 0.8596 |
| 48 | 0.7862 | 0.7565 | 0.8552 |
| 49 | 0.7794 | 0.7425 | 0.8474 |
| 50 | 0.7765 | 0.7403 | 0.8441 |
| 51 | 0.7765 | 0.7403 | 0.8441 |
| 52 | 0.7734 | 0.7380 | 0.8403 |
| 53 | 0.7676 | 0.7341 | 0.8331 |
| 54 | 0.7667 | 0.7335 | 0.8320 |
| 55 | 0.7646 | 0.7321 | 0.8292 |
| 56 | 0.7623 | 0.7307 | 0.8262 |
| 57 | 0.7620 | 0.7305 | 0.8257 |

## 4.9 EV load in Bus 57

The 57 bus is the low voltage bus of Bishnumati feeder which has voltage 0.762 pu in base case. So bus number 57 is consider as worst case for EV charging load placement. Then EV charging load of 102 kW is considered and placed in that bus. Then bus voltage goes down to 0.7538 pu. To keep in original base case voltage there is required PV power of 60 Kw which maintain bus voltage at 0.7668 pu. The graph below shows the voltage level for different case.

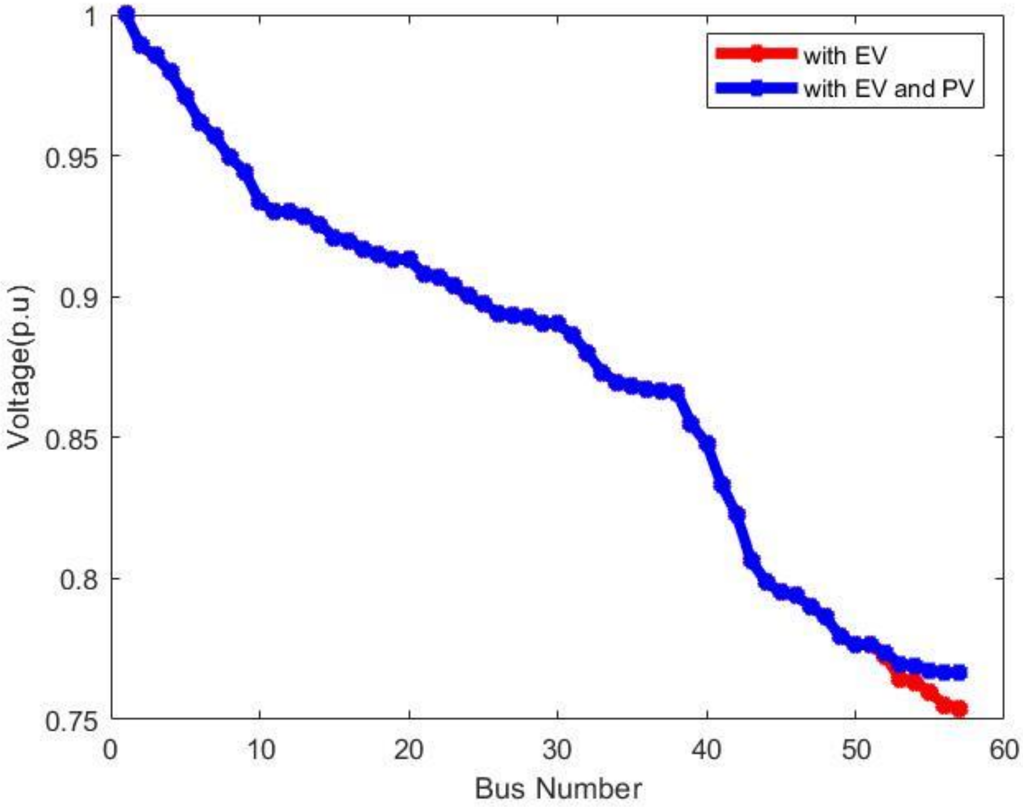


Figure 4.11: Voltage of 57 bus (worst case) with EV and PV

## 4.10 Financial Anaylysis

The cash flow curve is shown in figure below. The solar PV cost per watt is considered NPR 32.00, EV charging station cost is NPR 700,000 per station and the energy saving cost is NPR 8.00 per unit.

Different factors considered for financial analysis are as follows:

Table 4.2: Factors considered for financial analysis

| **Description** | **Value** | **Remarks** |
|---|---|---|
| **Solar PV Cost(Rs.)** | 1381.2*1000*32= 4,41,98,400 | Per watt 32 rupees. |
| **EV Charging Station Cost (Rs.)** | 8*700000 = 56,00,000 | 7 lakh per one charging station |
| **Subsidy from Nepal Government (per kw Rs.5600** | 1381.2*5600 = 77,34,720 | Per kw Rs.5600 |
| **O & M Cost(annual)NPR** | 56,00,000*10% = 5,60,000 | 10 % of charging station cost |
| **Annual Energy Saving Cost( Rs.)** | 72,62,040 | Energy Saving per day 188.4 kwh with loss factor 50% |
| **Interest rate** | 12% | |

Cumulative cash flow table is shown in appendix below. From above mentioned cash inflow and outflow the cash flow diagram is shown in Figure 4.12

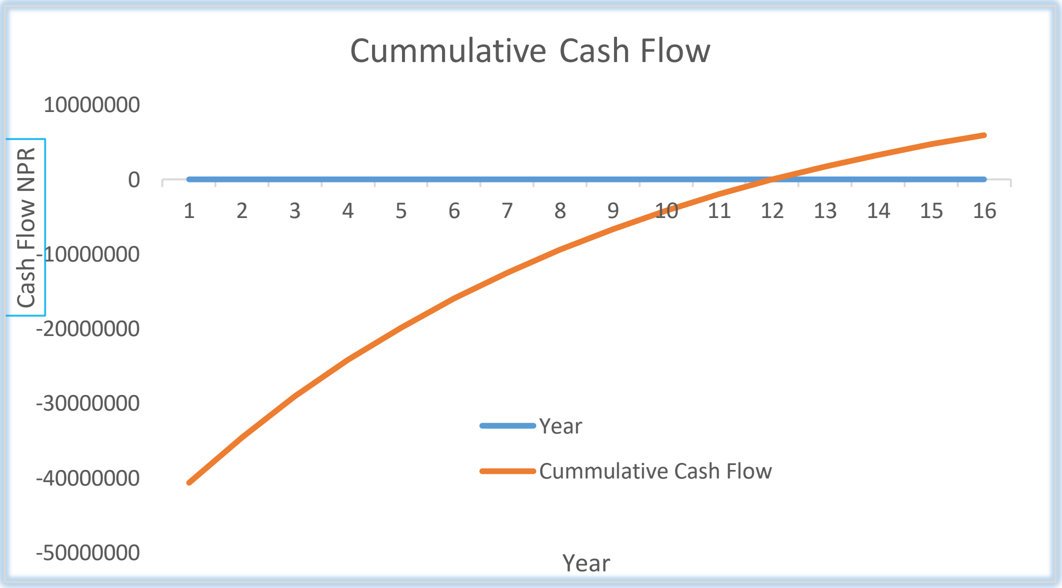


Figure 4.12: Cash flow diagram

Cash flow diagram shows that the payback period for the investment is 12 years with consideration of total investment, O&M cost and annual energy saving and charging income cost.

# CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Following conclusions have been drawn from the study:

- MATAB software is used for modelling of IEEE 33 bus system and Bishnumati feeder system. For loadflow analysis Balaju substation is taken as slack/reference bus and all other are taken as load bus. From load flow analysis it is found that there is a high line losses and voltage at far end of substation is lower around 0.7620 pu which is equivalent to 175V AC which doesn't maintain the IEEE standard. According to IEEE standard for distribution of electrical powervoltage should not be change ±5%.
- The EV charging station is considered in the system which behaves as load. The total capacity of charging station is 372 kW (8 numbers of charging station with different locations) which is connected to the system and the total load of Bishnumati feeder becomes 5944 kW. The voltage of the system decreases to 0.7305 pu. The voltage regulation at this case is very poor. The rooftop PV is considered for the system which allows the power to flow at day time. While considering 1381.5 kW PV system distributed over the 56 nodes, the system voltage is increased and goes upto 0.84 pu.
- The study from Bishnumati feeder shows that the EV station can be implemented with distributed generation. The voltage of the system shows it does not allowed to use EV charging station only with grid power. When implementing rooftop urban solar PV system, the system can be used up to limited value because of distribution system structure.
- In financial analysis, the payback period for the investment is 12 years with consideration of total investment, O&M cost and annual energy saving and charging income cost.

## 5.2 Recommendations

Following recommendations have been drawn from the study:

- After injecting the solar PV into the grid, the voltage profile and losses are reduced so practical implementation is recommended.
- It is recommended to use EV charging station with solar PV power which helps to improve voltage profile and reduces losses.
- In most of the cases there is voltage level around 0.85 pu after placement of charging station load and PV penetration. It is recommended to use EV charger which can be operate in voltage level 15% variation from rated voltage.

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# APPENDIX

Bus and Line Data for IEEE 33 Bus system

| Bus Number | Load kW | Load kVAR | Line Number | From Bus | To Bus | R (Ohm) | X (Ohm) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 2 | 0.0922 | 0.047 |
| 2 | 100 | 60 | 2 | 2 | 3 | 0.493 | 0.2511 |
| 3 | 90 | 40 | 3 | 3 | 4 | 0.366 | 0.1864 |
| 4 | 120 | 80 | 4 | 4 | 5 | 0.3811 | 0.1941 |
| 5 | 60 | 30 | 4 | 5 | 6 | 0.819 | 0.707 |
| 6 | 60 | 20 | 6 | 6 | 7 | 0.1872 | 0.6188 |
| 7 | 200 | 100 | 7 | 7 | 8 | 0.7114 | 0.2351 |
| 8 | 200 | 100 | 8 | 8 | 9 | 1.03 | 0.74 |
| 9 | 60 | 20 | 9 | 9 | 10 | 1.044 | 0.74 |
| 10 | 60 | 20 | 10 | 10 | 11 | 0.1966 | 0.065 |
| 11 | 45 | 30 | 11 | 11 | 12 | 0.3744 | 0.1238 |
| 12 | 60 | 35 | 12 | 12 | 13 | 1.468 | 1.155 |
| 13 | 60 | 35 | 13 | 13 | 14 | 0.5416 | 0.7129 |
| 14 | 120 | 80 | 14 | 14 | 15 | 0.591 | 0.526 |
| 15 | 60 | 10 | 15 | 15 | 16 | 0.7463 | 0.545 |
| 16 | 60 | 20 | 16 | 16 | 17 | 1.289 | 1.721 |
| 17 | 60 | 20 | 17 | 17 | 18 | 0.732 | 0.574 |
| 18 | 90 | 40 | 18 | 2 | 19 | 0.164 | 0.1565 |
| 19 | 90 | 40 | 19 | 19 | 20 | 1.5042 | 1.3554 |
| 20 | 90 | 40 | 20 | 20 | 21 | 0.4095 | 0.4784 |
| 21 | 90 | 40 | 21 | 21 | 22 | 0.7089 | 0.9373 |
| 22 | 90 | 40 | 22 | 3 | 23 | 0.4512 | 0.3083 |
| 23 | 90 | 50 | 23 | 23 | 24 | 0.898 | 0.7091 |
| 24 | 420 | 200 | 24 | 24 | 25 | 0.896 | 0.7011 |
| 25 | 420 | 200 | 25 | 6 | 26 | 0.203 | 0.1034 |
| 26 | 60 | 25 | 26 | 26 | 27 | 0.2842 | 0.1447 |
| 27 | 60 | 25 | 27 | 27 | 28 | 1.059 | 0.9337 |
| 28 | 60 | 20 | 28 | 28 | 29 | 0.8042 | 0.7006 |
| 29 | 120 | 70 | 29 | 29 | 30 | 0.5075 | 0.2585 |
| 30 | 200 | 600 | 30 | 30 | 31 | 0.9744 | 0.963 |
| 31 | 150 | 70 | 31 | 31 | 32 | 0.3105 | 0.3619 |
| 32 | 210 | 100 | 32 | 32 | 33 | 0.341 | 0.5302 |
| 33 | 60 | 40 |  |  |  |  |  |

### Bus and Line Data Bishnumati 57 Bus system

| Bus Number | Load kW | Load kVAR | Line Number | From Bus | To Bus | R (Ohm) | X (Ohm) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 2 | 1.0883 | 0.0983 |
| 2 | 160 | 120 | 2 | 2 | 3 | 0.3912 | 0.0382 |
| 3 | 160 | 120 | 3 | 3 | 4 | 0.8427 | 0.066 |
| 4 | 80 | 60 | 4 | 1 | 5 | 0.4375 | 0.0433 |
| 5 | 80 | 60 | 5 | 5 | 6 | 0.4983 | 0.056 |
| 6 | 160 | 120 | 6 | 6 | 7 | 0.2887 | 0.0466 |
| 7 | 160 | 120 | 7 | 7 | 8 | 0.4805 | 0.0499 |
| 8 | 160 | 120 | 8 | 8 | 9 | 0.3569 | 0.0321 |
| 9 | 160 | 120 | 9 | 9 | 10 | 0.8752 | 0.083 |
| 10 | 200 | 150 | 10 | 10 | 11 | 0.3103 | 0.0238 |
| 11 | 80 | 60 | 11 | 11 | 12 | 0.0374 | 0.0041 |
| 12 | 80 | 60 | 12 | 12 | 13 | 0.1329 | 0.0148 |
| 13 | 80 | 60 | 13 | 13 | 14 | 0.3372 | 0.0377 |
| 14 | 80 | 60 | 14 | 14 | 15 | 0.6052 | 0.0669 |
| 15 | 160 | 120 | 15 | 15 | 16 | 0.2062 | 0.0185 |
| 16 | 80 | 60 | 16 | 16 | 17 | 0.5344 | 0.0607 |
| 17 | 200 | 150 | 17 | 17 | 18 | 0.4815 | 0.0418 |
| 18 | 160 | 120 | 18 | 18 | 19 | 0.6712 | 0.0646 |
| 19 | 200 | 150 | 19 | 19 | 20 | 0.0977 | 0.0097 |
| 20 | 80 | 60 | 20 | 1 | 21 | 0.5562 | 0.0464 |
| 21 | 80 | 60 | 21 | 21 | 22 | 0.1295 | 0.0136 |
| 22 | 160 | 120 | 22 | 22 | 23 | 0.4564 | 0.0429 |
| 23 | 100 | 75 | 23 | 23 | 24 | 0.6179 | 0.0525 |
| 24 | 160 | 120 | 24 | 24 | 25 | 0.6179 | 0.0525 |
| 25 | 80 | 60 | 25 | 25 | 26 | 0.7726 | 0.0667 |
| 26 | 120 | 90 | 26 | 26 | 27 | 0.3467 | 0.036 |
| 27 | 80 | 60 | 27 | 27 | 28 | 0.2298 | 0.0173 |
| 28 | 80 | 60 | 28 | 28 | 29 | 1.3007 | 0.1128 |
| 29 | 100 | 75 | 29 | 29 | 30 | 0.5442 | 0.057 |
| 30 | 80 | 60 | 30 | 1 | 31 | 0.7171 | 0.0633 |
| 31 | 80 | 60 | 31 | 31 | 32 | 1.3689 | 0.1039 |
| 32 | 80 | 60 | 32 | 32 | 33 | 1.6931 | 0.1432 |
| 33 | 80 | 60 | 33 | 33 | 34 | 1.0257 | 0.103 |
| 34 | 80 | 60 | 34 | 34 | 35 | 0.4007 | 0.036 |
| 35 | 40 | 30 | 35 | 35 | 36 | 0.5663 | 0.0552 |
| 36 | 160 | 120 | 36 | 36 | 37 | 0.7274 | 0.0727 |
| 37 | 80 | 60 | 37 | 37 | 38 | 1.1242 | 0.1018 |
| 38 | 40 | 30 | 38 | 4 | 39 | 2.0642 | 0.1551 |
| 39 | 80 | 60 | 39 | 39 | 40 | 1.3279 | 0.1214 |
| 40 | 80 | 60 | 40 | 40 | 41 | 3.5917 | 0.2434 |
| 41 | 80 | 60 | 41 | 41 | 42 | 3.108 | 0.2796 |
| 42 | 80 | 60 | 42 | 42 | 43 | 6.0993 | 0.5488 |
| 43 | 80 | 60 | 43 | 43 | 44 | 3.6495 | 0.3283 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 44 | 40 | 30 | 44 | 44 | 45 | 2.1557 | 0.1939 |
| 45 | 40 | 30 | 45 | 45 | 46 | 0.8412 | 0.0756 |
| 46 | 12 | 9 | 46 | 46 | 47 | 2.6764 | 0.2408 |
| 47 | 40 | 30 | 47 | 47 | 48 | 3.5509 | 0.3118 |
| 48 | 40 | 30 | 48 | 48 | 49 | 8.4468 | 0.5807 |
| 49 | 40 | 30 | 49 | 49 | 50 | 4.9794 | 0.3345 |
| 50 | 40 | 30 | 50 | 50 | 51 | 0.0143 | 0.0012 |
| 51 | 80 | 60 | 51 | 1 | 52 | 1.0321 | 0.1069 |
| 52 | 80 | 60 | 52 | 52 | 53 | 2.4783 | 0.2017 |
| 53 | 160 | 120 | 53 | 53 | 54 | 0.5355 | 0.0554 |
| 54 | 80 | 60 | 54 | 54 | 55 | 1.6764 | 0.1657 |
| 55 | 80 | 60 | 55 | 55 | 56 | 2.6353 | 0.207 |
| 56 | 160 | 120 | 56 | 56 | 57 | 1.2109 | 0.1253 |
| 57 | 80 | 60 |  |  |  |  |  |

## Cumulative Cash flow

| Year | Cash Flow | Discounted Cash Flow | Cumulative Cash Flow |
|---|---|---|---|
| 0 | (40,663,680.00) | (40,663,680.00) | (40,663,680.00) |
| 1 | 6,842,040.00 | 6,108,964.29 | (34,554,715.71) |
| 2 | 6,842,040.00 | 5,454,432.40 | (29,100,283.32) |
| 3 | 6,842,040.00 | 4,870,028.93 | (24,230,254.39) |
| 4 | 6,842,040.00 | 4,348,240.11 | (19,882,014.28) |
| 5 | 6,842,040.00 | 3,882,357.24 | (15,999,657.03) |
| 6 | 6,842,040.00 | 3,466,390.40 | (12,533,266.64) |
| 7 | 6,842,040.00 | 3,094,991.43 | (9,438,275.21) |
| 8 | 6,842,040.00 | 2,763,385.20 | (6,674,890.01) |
| 9 | 6,842,040.00 | 2,467,308.22 | (4,207,581.79) |
| 10 | 6,842,040.00 | 2,202,953.76 | (2,004,628.03) |
| 11 | 6,842,040.00 | 1,966,923.00 | (37,705.03) |
| 12 | 6,842,040.00 | 1,756,181.25 | 1,718,476.23 |
| 13 | 6,842,040.00 | 1,568,018.98 | 3,286,495.20 |
| 14 | 6,842,040.00 | 1,400,016.94 | 4,686,512.14 |

| | | | |
|---|---|---|---|
| 15 | 6,842,040.00 | 1,250,015.13 | 5,936,527.27 |
| 16 | 6,842,040.00 | 1,116,084.94 | 7,052,612.21 |

## Matlab coding

```
%% base function
clear all;
clc;
LFa;
base_loss = totalloss;
save BaseLoss.mat totalloss voltage angle Plosskw
Qlosskw

%% Calculation with EV Station

clear all;
clc;


bus=load('loaddataPLbus.m');                         %
load bus data input

clear all;
clc;

options = optimoptions('ga','ConstraintTolerance',1e-
6,'PlotFcn', @gaplotbestf);
fun = @GA_with_EV;
bus=load('loaddataPLbus.m');
totalload=sum(bus(:,2));
nvar = 4;
[x,fval,exitflag,output,population,scores] =
ga(fun,nvar,[],[],[],[],0,400,[],options)
set(gca,'FontSize',20);
EV_station = x;
save resut_withEV.mat x fval exitflag output population
scores
```

```
%% GA with EV and PV
clear all;
clc;

options = optimoptions('ga','ConstraintTolerance',1e-
6,'PlotFcn', @gaplotbestf);
fun = @GA_with_PV;
bus=load('loaddataPLbus.m');
totalload=sum(bus(:,2));
nvar = 2;
[x,fval,exitflag,output,population,scores] =
ga(fun,nvar,[],[],[],[],0.15*totalload,0.6*totalload,[]
,options)
set(gca,'FontSize',20);
save GAresults.mat x fval exitflag output population
scores


%% Results for GA
clear all;
clc

load('BaseLoss.mat')
plot(voltage,'r-*','LineWidth',4)
hold on
xlabel('Bus Number')
ylabel('Voltage [pu]')


load('result_withEV.mat')
load('result_withEV.mat', 'totalloss_withEV')
plot(totalloss_withEV.voltage,'b-o','LineWidth',4)



load('GAresults.mat')

ga_result = optimumcalculation(x(1));

for i=2:length(ga_result)
    losses(i) = ga_result(i).Totalloss_kW;
end
[minval,index_min] = min(losses(2:length(ga_result)));
```

```
voltage = ga_result(index_min+1).Voltage;
plot(ga_result(index_min+1).Voltage,'k-
+','LineWidth',4)

legend('Voltage Base Case','Voltage With EVs','Voltage
With EV and PV')
set(gca,'Fontsize',20)


figure

c = categorical({'Base Case','With EVs','With EV and
PV'});
bar(c,[totalloss;totalloss_withEV.loss_f;ga_result(inde
x_min+1).Totalloss_kW])
set(gca,'Fontsize',20)
ylabel('Power Loss [kW]')
```

# Optimal Placement of EV Charging Station with Randomly Distributed PV System in Bishnumati Distribution Feeder Kathmandu, Nepal

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