OPTIMAL PLACEMENT OF SOLAR-POWERED ELECTRIC VEHICLE CHARGING STATION

A PROJECT REPORT
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS
FOR THE AWARD FOR THE DEGREE OF
BACHELOR OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING

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DEPARTMENT OF ELECTRICAL ENGINEERING

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CANDIDATE’S DECLARATION

We, **Chirag Prasad(2K21/EE/094), Dhairya Sharma(2K21/EE/100)**, and **Himanshu (2K21/EE/132)**, students of **B.Tech. (Electrical Engineering)**, hereby declare that our project dissertation titled “**Optimal Placement of Solar-Powered Electric Vehicle Charging Station**”, submitted to the Department of Electrical Engineering, Delhi Technological University (DTU), Delhi, is our original work.

We affirm that the content of the dissertation is not copied from any source without proper citation and acknowledgment. This work has been carried out under the guidance and supervision of **Prof. Uma Nangia**, and it has not been submitted previously for any degree or diploma at any other institute or university.

We understand that any breach of this declaration will result in the invalidation of the submitted work.

Chirag Prasad (2K21/EE/094)
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Date: 29/05/2025
Place: New Delhi

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CERTIFICATE

I hereby certify that the project Dissertation titled "**Optimal Placement of Solar-powered Electric Vehicle Charging Station**" which is submitted by **Chirag Prasad(2K21/EE/094)**, **Dhairya Sharma(2K21/EE/100)** and **Himanshu (2K21/EE/132)** Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of the Bachelor of Technology, is a record of the project work carried out under my guidance and supervision. The work is original and is not copied from any source without proper citation. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Supervisor:

Prof. Uma Nangia

ACKNOWLEDGEMENT

First and foremost, we express our heartfelt appreciation to **Prof. Uma Nangia**, our esteemed project mentor. Her unwavering commitment and insightful guidance have been instrumental in shaping the trajectory of this project. Our numerous consultations with her provided valuable perspectives, and her constructive feedback greatly contributed to the refinement of our report.

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ABSTRACT

This project focuses on the optimal allocation of Solar-Powered Electric Vehicle Charging Stations (SPEVCS) within a 33-bus radial distribution network. With the rise in electric vehicle usage and the shift toward sustainable energy, this study aims to position charging stations in a way that enhances system performance and supports environmental goals.

Load flow analysis, conducted using the Backward/Forward Sweep method, helped identify buses most sensitive to voltage and power loss variations by applying incremental loads of 0.1 MW. Based on these sensitivity results, analytical methods were employed to determine the optimal placement and size of distributed generation units, which act as the infrastructure for the charging stations.

The findings indicate that strategically placing DGs improves voltage stability and reduces active power losses, thereby boosting overall system reliability and efficiency. This study concludes that well-planned integration of solar-based EV charging stations can significantly enhance the sustainability and functionality of power distribution networks.

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LIST OF ABBREVIATIONS

1. **EVs:** Electric Vehicles
2. **SPEVCS:** Solar-Powered Electric Vehicle Charging Station
3. **EVCS:** Electric Vehicle Charging Stations
4. **EV:** Electric Vehicle
5. **DG:** Distributed Generation
6. **PV:** Photovoltaic
7. **MPPT:** Maximum Power Point Tracking

CONTENTS

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

The transport sector is experiencing a shift toward electrification, driven by environmental concerns and the urgency to reduce fossil fuel dependence. Electric Vehicles (EVs) have emerged as a cleaner alternative, but most EV charging infrastructure still relies on conventional power grids, which are predominantly powered by non-renewable sources. This undermines the environmental promise of EVs[1].

A more sustainable approach involves integrating solar energy into the EV charging ecosystem. With continual improvements in photovoltaic (PV) technology, solar-based solutions offer cost-effective and eco-friendly alternatives. Solar-Powered Electric Vehicle Charging Stations (SPEVCS) present a dual benefit—decarbonizing transport while promoting energy independence[6].

This project is motivated by the need to enhance EV infrastructure in a manner that aligns with clean energy objectives. By leveraging solar potential and applying engineering optimization methods, we aim to design a system that supports both technological advancement and environmental sustainability[6].

Figure 1.1 Modular Off-grid Solar EV Charger

Figure 1.2 Solar-Powered Electric Vehicle Charging Station

1.2 PROBLEM STATEMENT

• Heavy Reliance on Grid Electricity
Conventional EV charging stations often depend on power grids fueled by carbon-intensive sources, thereby increasing emissions and straining infrastructure[1].

• Uneven Utilization of Charging Stations
In many cases, charging stations are unevenly distributed—some experience high traffic while others are underused. This imbalance reduces system efficiency and user satisfaction[3].

• Insufficient Infrastructure in Underserved Regions
Rural and semi-urban zones often lack adequate charging networks. Expanding grid-based infrastructure in such areas can be economically and logistically challenging[5].

• Absence of Optimized, Green Planning
Many existing SPEVCS installations do not incorporate system-level optimization for voltage regulation and power loss minimization. This study aims to fill that gap through data-driven planning and modelling[15].

1.3 SIGNIFICANCE OF OPTIMAL CHARGING STATION PLACEMENT

Placing charging stations in optimal locations has both technical and practical implications:

• **Minimizes Stress on the Grid:** Solar-integrated stations, especially in off-grid or hybrid modes, reduce the burden on existing electrical networks[3].

• **Maximizes Energy Harvesting:** Strategic siting in areas with high solar radiation improves energy yield and station efficiency[3].

• **Improves Accessibility and Service Equity:** Well-placed stations expand coverage, reducing range anxiety and encouraging broader EV adoption[3][7].

• **Reduces Capital and Maintenance Costs:** Smart placement lowers land acquisition and installation costs, enhancing long-term economic viability[10].

• **Promotes Sustainable Urban Planning:** Aligning EV infrastructure with renewable energy contributes to climate-resilient urban development[10].

1.4 PROJECT OBJECTIVES:

This project is developed with the following goals:

- Reduce active power losses in the distribution network
- Enhance voltage profiles at critical nodes
- Identify optimal buses for Distributed Generation (DG) integration
- Estimate the ideal DG capacity to ensure energy-efficient operation

CHAPTER 2: LITERATURE REVIEW

2.1 ELECTRIC VEHICLE CHARGING SYSTEMS OVERVIEW

The ecosystem of EVs includes a network of EVCS enabling users to conveniently recharge their vehicle's battery. Therefore, charging units, commonly referred to as EV chargers, are classified into three distinct levels based on power availability and replenishment convenience:

• **Level 1 Charging**: Employs a standard household 120V outlet; the slowest option suitable for overnight use.
• **Level 2 Charging**: Pumping from 240V outlets, faster charging at residential, commercial, and public locations.
• **Level 3 Charging / DC Fast Charging:** Mainstay in public and commercial settings; accepts direct current for rapid charging.

Every category of EV charging infrastructure possesses distinct characteristics with regard to their economics, engineering, and technology. The most prominent conundrum related to grid-connected systems is that they are reliant on grid stability, electricity pricing, and environmental impacts. These restraints have furthered the exploration of integrating renewable energy sources, including solar, into the EV charging architecture[2][14][21].

2.2 SOLAR ENERGY INTEGRATION IN EV CHARGING

Due to its clean nature, renewability and abundance, solar energy is particularly well-suited to be integrate within the charger infrastructure as EV charging is usually sustainable. A SPEVCS typically includes PV panels, charge controllers, batteries for energy storage devices (optional), and converters for supplying electricity to EV charge ports.
These solar-enabled charging points are flexible and easier to set up in remote locations. As a result, they become an ideal candidate for surpassing the limitations of being off-grid and decuples areas.

- Some additional benefits are:
- Improved basic energy independence and preparedness
- Enhanced social responsibility for minimizing the emission of harmful gasses
- Reduced long-term costs
- Lowered dependency on the grid
- Strategic obelion approach

Ongoing research acts in a favorable way towards making SPEVCS more appealing by enhancing the efficiency of PV panels and MPPT (Maximum Power Point Tracking) solar batteries. However, some of the problems that require solutions include solar energy intermittency and high setup costs[6][16].

2.3 INFERENCES AND RESEARCH GAP

Inferences Taken from Literature Review: -

- The figure is growing with new electric vehicles annually, and so too is the requirement for charging infrastructure.
- The sustainability and potential for energy independence makes solar powered EV charging a promising alternative.
- Multiple optimization techniques, such as charge transport analysis and sensitivity-based placement, improve the effectiveness of EV charging station placement.
- Specific simulation testing confirms the technical assumptions and results of the SPEVCS models operate as intended in simulations.

Research Gap: -

- Absence of Optimized Load Centric EVCS Placement in Radial Topology of Distribution Networks.
- Notably, the lack of attention to power system modelling is prevalent in the literature. This research uniquely performs a load flow analysis and perturbative sensitivity analysis determining the best sites for distributed generation and electric vehicle charging stations within a 33-bus radial network.
- Less reliance on the grid for powering space EV charging stations.
- Many remain tethered to the grid, increasing the grid's load and carbon emissions. Little has been done on off-grid or solar-powered EV charging stations that pick up the voltage stability while reducing the grid dependency dynamic.
- Combination of outlying focus on voltage and loss reduction strategies and the placement of EVCS for optimal use.

CHAPTER 3: PROBLEM FORMULATION

This study explores how to best place and size DG units within a radial distribution system to reduce overall real power losses and improve voltage levels. The approach combines load flow analysis using the backward/forward sweep method, sensitivity-based techniques, and optimization strategies. By strategically allocating DG units, the goal is to support local power needs, ease the load on feeders, and enhance both the reliability and performance of the power system. The formulas used throughout the analysis are based on MATLAB implementations and are organized as follows :

1. System Inputs and Preprocessing

$$P_0(i) = P_L(i)/\ \text{BaseMVA} \tag{3.1}$$
$$Q_0(i) = Q_L(i)/\text{BaseMVA} \tag{3.2}$$

Where:

- $P_L(i)$ = actual active power demand at bus i (in kW or MW)
- $Q_L(i)$ = actual reactive power demand at bus i (in kVAR or MVAR)
- BaseMVA = system base power for per-unit conversion
- $P_0(i)$, $Q_0(i)$ = per-unit active and reactive power demands at bus i

2. Voltage-Dependent Load Modeling

$$P_a(i) = P_0(i)\cdot|V_i|^{n_p(i)} \tag{3.3}$$
$$Q_a(i) = Q_0(i)\cdot|Vi|^{n_q(i)} \tag{3.4}$$
$$S(i) = P_a(i)+jQ_a(i) \tag{3.5}$$

Where:

- $P_a(i)$, $Q_a(i)$ = adjusted active/reactive power based on voltage
- $|Vi|$ = voltage magnitude at bus i
- $n_p(i)$, $n_q(i)$ = ZIP model exponents for active/reactive power
- $S(i)$ = complex load power at bus i

3. Current Injection Calculation

$$I(i) = \text{conj}((S(i)-S_g(i))/V(i)) \tag{3.6}$$

Where:

- $S_g(i)$ = complex power generated by DG at bus i
- $V(i)$ = voltage phasor at bus i
- conj() = complex conjugate

- I(i) = injected current at bus i

4. Load Flow Analysis: Backward/Forward Sweep Method

Branch current: $I_{branch} = BIBC \cdot I$ (3.7)

Voltage update: $V_{down} = V_{up} - Z_{branch} \cdot I_{branch}$ (3.8)

Polar form: $|V| = abs(V)$, $\angle V = arg(V) \cdot (180/\pi)$ (3.9)

Where:

- BIBC = Bus Injection to Branch Current matrix
- Z_{branch} = branch impedance
- I_{branch} = current through branches
- V_{up}, V_{down} = voltages at sending and receiving end of branches
- $|V|$ = voltage magnitude, $\angle V$ = voltage angle in degrees

5. Line Loss and Power Flow Calculations

Power flow: $S_{line} = V_{down} \cdot conj(I_{branch}) \cdot BaseMVA + Loss$ (3.10)

Line loss: $Loss_{line} = |I_{branch}|^2 \cdot (r+jx) \cdot BaseMVA$ (3.11)

Total real power loss: $P_{loss} = \sum Re(Loss)$ (3.12)

Where:

- r, x = resistance and reactance of the line
- S_{line} = complex power flow through the line
- Loss = power loss in the line
- Re() = real part of the complex quantity
- P_{loss} = total real power loss in the network

6. Network Admittance and Impedance Matrices

$Y_{ff} = Y_{ff} + y + j(b/2)$ (3.13)
$Y_{ft} = -y$ (3.14)
$Z_{bus} = Y_{bus}^{-1}$ (3.15)

Where:

- Y_{ff}, Y_{ft} = self and mutual admittance values
- y = line admittance (1/(r + jx))

- b = line charging susceptance
- Z_{bus} = bus impedance matrix

7. **Baseline Power Flow Without DG**

$$P(1) = -\sum(\mathrm{Re}(S_{load})+\mathrm{Re}(\text{Line Loss})) \tag{3.16}$$
$$Q(1) = -\sum(\mathrm{Im}(S_{load})+\mathrm{Im}(\text{Line Loss})) \tag{3.17}$$

Where:

- $P(1)$, $Q(1)$ = total real and reactive power supplied from the slack bus
- S_{load} = complex load demand
- Im() = imaginary part of complex quantity

8. **Analytical Expressions for DG Sensitivity**

$$\alpha_{di} = (\mathrm{Re}(Z_{di})/\mathrm{BaseMVA})\cdot(\cos(\theta_d-\theta_i)/|Vd||Vi|) \tag{3.18}$$
$$\beta_{di} = (\mathrm{Re}(Z_{di})/\mathrm{BaseMVA})\cdot(\sin(\theta_d-\theta_i)/|Vd||Vi|) \tag{3.19}$$
$$a_p(d) = \sum_i [\alpha_{di}P(i)-\beta_{di}Q(i)] \tag{3.20}$$
$$a_q(d) = \sum_i [\alpha_{di}Q(i)+\beta_{di}P(i)] \tag{3.21}$$

Where:

- Z_{di} = element of Z_{bus} between bus d and i
- θ_d, θ_i = voltage angles at bus d and i
- $a_p(d)$, $a_q(d)$ = sensitivity coefficients with respect to real/reactive power
- $P(i)$, $Q(i)$ = real/reactive power load at bus i

9. **Optimal DG Sizing**

$$P_{DG}^{opt}(d) = -(a_p(d)/\ \alpha_{dd}) \tag{3.22}$$
$$Q_{DG}^{opt}(d) = -(a_q(d)/\ \alpha_{dd}) \tag{3.23}$$

Where:

- α_{dd} = sensitivity factor at bus d
- $P_{DG}^{opt}(d)$, $Q_{DG}^{opt}(d)$ = optimal real/reactive power DG at bus d

10. Loss Calculation with DG

$$P_{loss}^{DG}(\mathrm{d}) = \sum_{\mathrm{i,j}}[\alpha_{ij}(P_iP_j+Q_iQ_j)+\beta_{ij}(Q_iP_j-P_iQ_j)] \tag{3.24}$$

Where:

- P_i, Q_i = active/reactive load power at bus i
- α_{ij}, β_{ij} = sensitivity coefficients between buses i and j
- P_{loss}^{DG}(d) = total loss with DG placed at bus d

11. Optimization Objective

Objective function: $\min_{\mathrm{d}} P_{loss}^{DG}(\mathrm{d})$ (3.25)

Subject to constraints: $V_i^{min} \leq |V_i| \leq V_i^{max}$ (3.26)

$0 \leq P_{DG}(\mathrm{d}) \leq P_{DG}^{max}$ (3.27)

$0 \leq Q_{DG}(\mathrm{d}) \leq Q_{DG}^{max}$ (3.28)

Where:

- V_i = voltage magnitude at bus i
- P_{DG}(d), Q_{DG}(d) = DG sizing at bus d
- P_{DG}^{max},Q_{DG}^{max} = maximum allowable DG size

CHAPTER 4: METHODOLOGY

4.1 DESCRIPTION OF TEST SYSTEM

The analysis is performed using a “standard” 33-bus radial distribution system with:

- Base Power: 100 MVA
- Base voltage: 12.66 kV
- No. of buses: 33
- No. of lines: 32

4.2 LOAD FLOW TECHNIQUE AND DG SIZING

The Load Flow Method developed on the basis of backward-forward sweep methodology, is adopted due to its effectiveness in radial distribution networks. This algorithm is implemented using MATLAB, within which active and reactive power values at each bus along with all line impedance values are included. For DG sizing Analytical Method is used.

4.3 PERTURBATION BASED SENSITIVITY ANALYSIS

The 0.1 MW active power is injected at each bus individually for the system response assessment. For each injection case, the minimum obtained bus voltage and total losses of the system are noted. This consideration helps to pinpoint the most critical buses associated with voltage levels and losses.

4.4 STRATEGY FOR OPTIMIZING DG

The predetermined methodology selects the appropriate bus through which the distributed generation DG capacity will connect. The aim of this optimization problem seeks to obtain the minimum active losses of the system while the bus voltages must not exceed the limits, also known as the operational constraints. After the optimal size and location are determined, it is necessary to re-run the load flow to see how it performs.

CHAPTER 5: RESULTS AND ANALYSIS

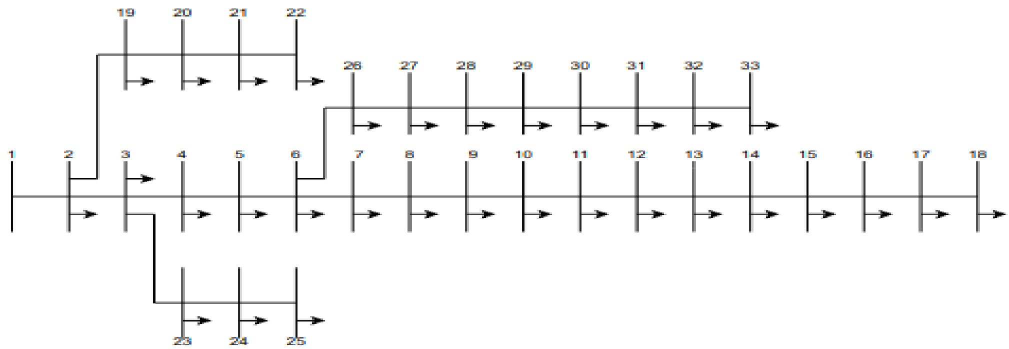

Figure 5.1 IEEE 33-bus radial distribution system

5.1 FLOWCHART FOR DG & EVCS PLACEMENT STRATEGY

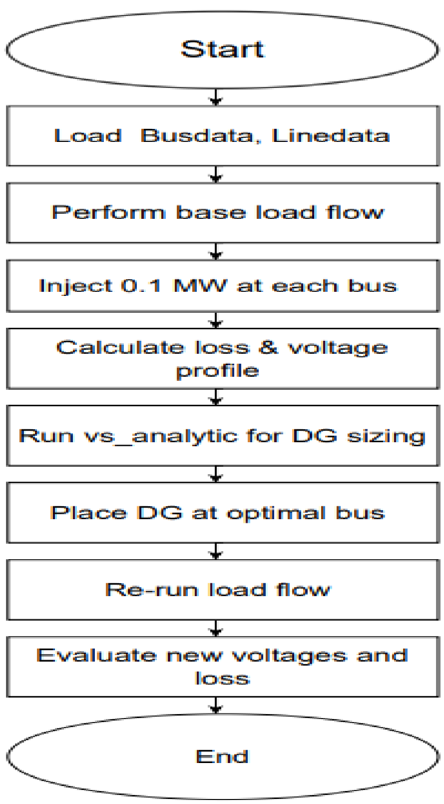

Figure 5.2 Flowchart for locating the optimal DG and EVCS positions using load flow analysis and sensitivity-based optimization

5.2 CASE STUDY-LOAD FLOW ANALYSIS

Case 1: Without adding any load and DG:
Active Losses is 0.21100 MW and Minimum Voltage is 0.90377 pu.

Case 2: Adding 0.1 MW load at all buses but not adding DG:
Active Losses is 0.220277 MW (By taking average of all the values of Case 2 Active Losses column from the table 5.1) and Minimum Voltage is mentioned in the table 5.1 in Case 2 Minimum Voltage column.

Case 3: Without adding 0.1 MW load but adding DG:
Active Losses is 0.11117 MW and Minimum Voltage is 0.94095 pu.

Case 4: Adding 0.1MW load at all buses and DG:
Active Losses is 0.114379 MW (By taking average of all the values of Case 4 Active Losses column from the table 5.1) and Minimum Voltage is mentioned in the table 5.1 in Case 4 Minimum Voltage column.

	Case 2		**Case 4**	
Bus	**Active Losses (MW)**	**Minimum Voltage (pu)**	**Active Losses (MW)**	**Minimum Voltage (pu)**
1	0.21100	0.90377	0.11117	0.94095
2	**0.21149**	**0.90371**	0.11133	0.94095
3	0.21385	0.90336	0.11190	0.94093
4	0.21512	0.90309	0.11181	0.94093
5	0.21641	0.90282	0.11165	0.94093
6	0.21921	0.90220	**0.11117**	0.94095
7	0.21960	0.90205	0.11210	**0.94227**
8	0.22230	0.90078	0.11438	0.94109
9	0.22362	0.90001	0.11549	0.94038
10	0.22487	0.89922	0.11654	0.93964
11	0.22509	0.89907	0.11671	0.93951
12	0.22546	0.89879	0.11703	0.93925
13	0.22684	0.89767	0.11818	0.93820
14	0.22731	0.89725	0.11857	0.93781
15	0.22768	0.89680	0.11888	0.93739
16	0.22805	0.89625	0.11919	0.93687
17	0.22858	0.89529	0.11963	0.93596
18	0.22878	0.89475	0.11979	0.93546
19	0.21157	**0.90371**	0.11142	0.94095
20	0.21219	**0.90371**	0.11203	0.94095
21	0.21231	**0.90371**	0.11215	0.94095

22	0.21244	**0.90371**	0.11228	0.94095
23	0.21446	0.90335	0.11248	0.94093
24	0.21558	0.90335	0.11356	0.94093
25	0.21618	0.90334	0.11413	0.94093
26	0.21953	0.90220	0.11145	0.94095
27	0.21953	0.90220	0.11145	0.94095
28	0.22152	0.90215	0.11313	0.94094
29	0.22264	0.90213	0.11408	0.94093
30	0.22324	0.90212	0.11458	0.94093
31	0.22408	0.90210	0.11529	0.94092
32	0.22427	0.90209	0.11545	0.94092
33	0.22434	0.90209	0.11551	0.94092

Table 5.1: Case Study – Load Flow

5.3 OBSERVATIONS

From the Table and the Cases, we observe that:

I. **Case 2: Adding 0.1 MW load at all buses but not adding DG:**

1. Bus 2 demonstrates the least losses at 0.21149 MW and the highest observed minimum voltage at 0.90371 pu.
2. Buses 19,20,21,22 suffers from losses but the voltage is same compared to bus 2.

II. **Case 4: Adding 0.1 MW load at all buses and DG:**

1. Bus 6 demonstrates the least losses at 0.11116 MW.
2. Bus 7 demonstrates the highest minimum voltage at 0.94227 pu.

III. DG’s optimum size at bus 6 is 2.59070 MW and at bus 7 is 2.47759 MW.

IV. Active Losses is minimum in Case 3 and maximum in Case 2.

V. On increasing load, the Active Losses increases and the Minimum Voltage decreases.

VI. With DG the Active Losses decreases and the Minimum Voltage increases.

5.4 GRAPHICAL RESULTS

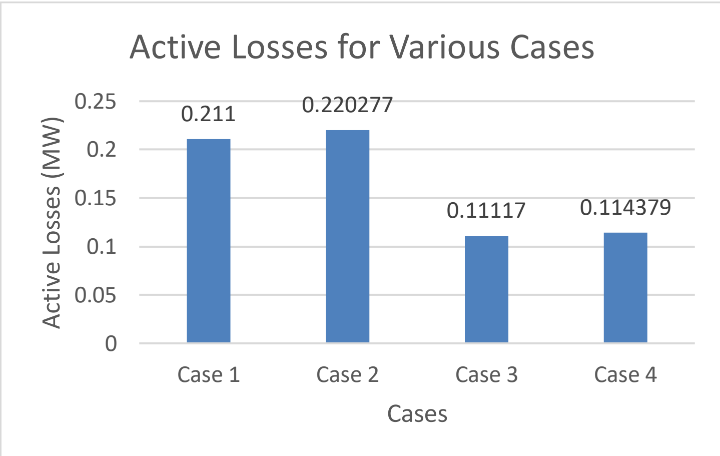

Figure 5.3 Active losses in MW for various cases

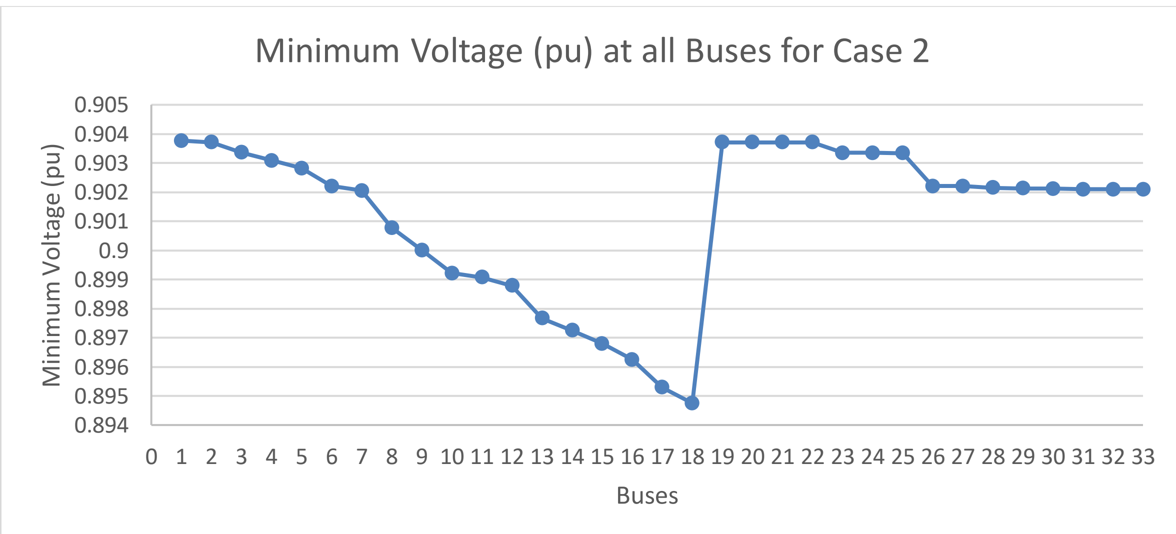

Figure 5.4 Minimum voltage (pu) at all Buses for Case 2

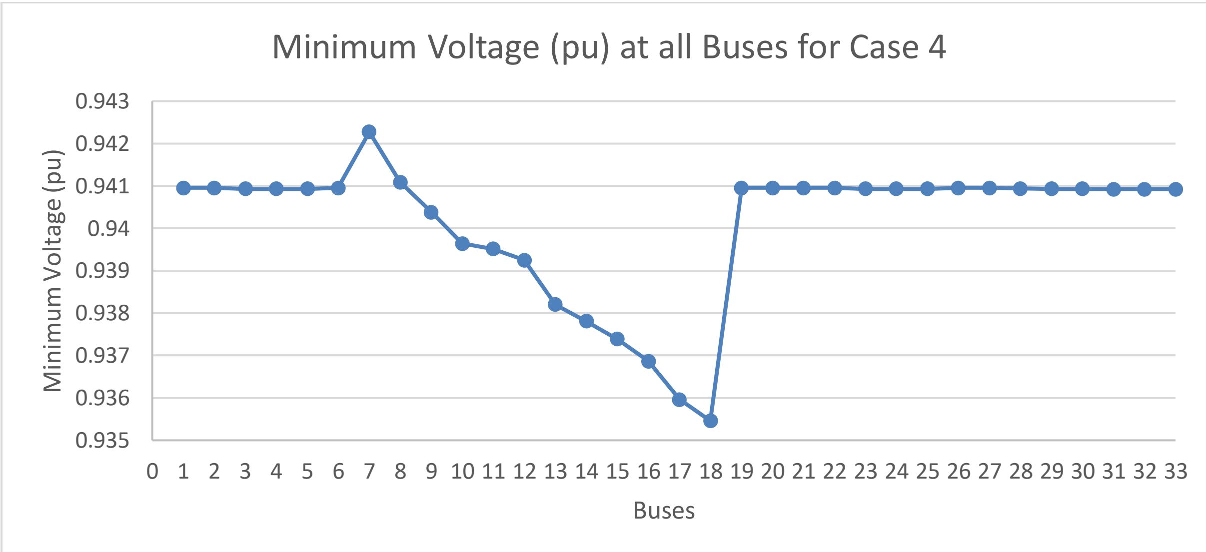

Figure 5.5 Minimum voltage (pu) at all buses for Case 4

1.Without adding 0.1 MW Load

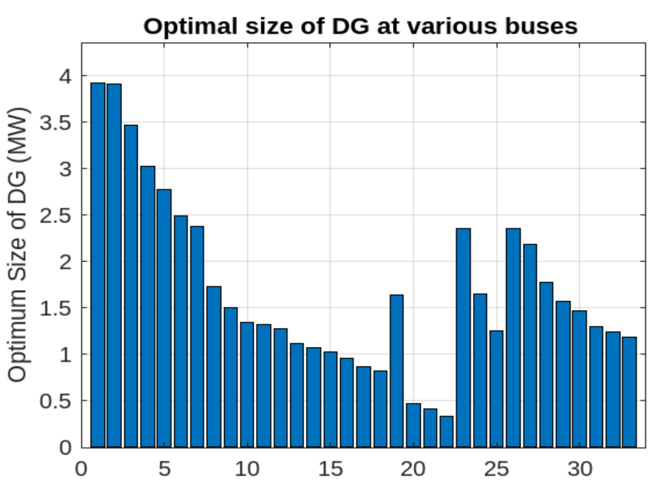

Figure 5.6 Optimal size of DG at various buses without adding 0.1 MW load

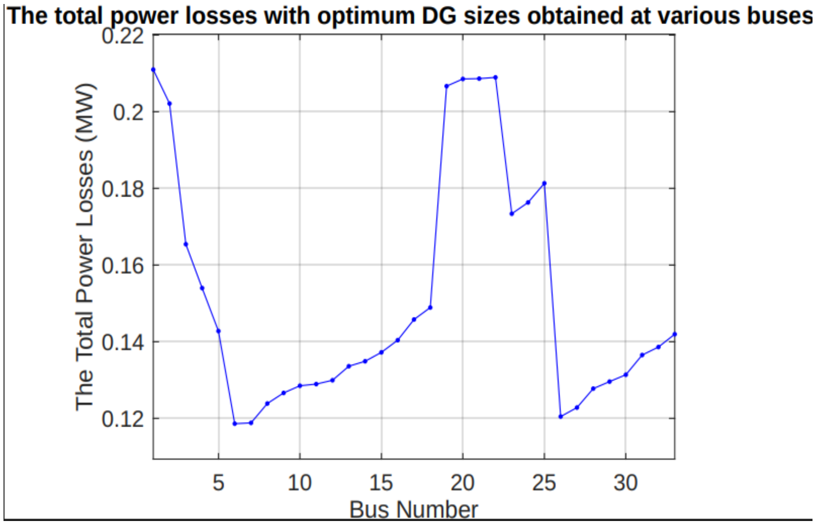

Figure 5.7 The total power losses with optimum DG sizes obtained at various buses without adding 0.1 MW Load

2. Adding 0.1 MW Load at bus 2

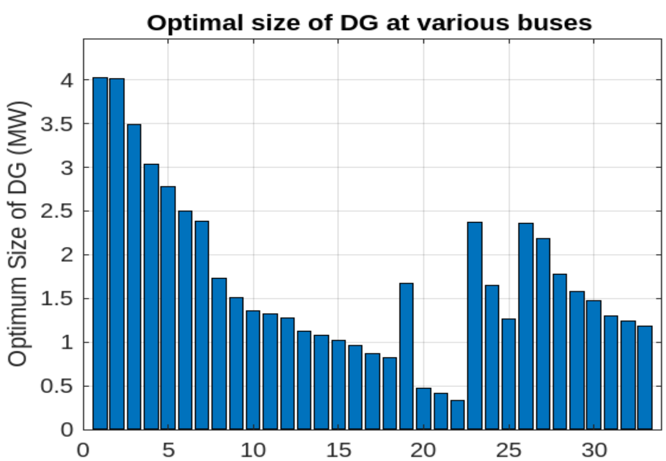

Figure 5.8 Optimal size of DG at various buses by adding 0.1 MW load at bus 2

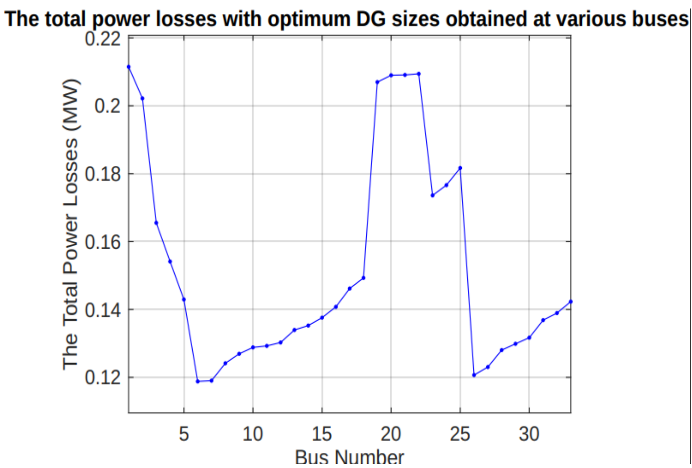

Figure 5.9 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 2

3.Adding 0.1 MW Load at bus 6

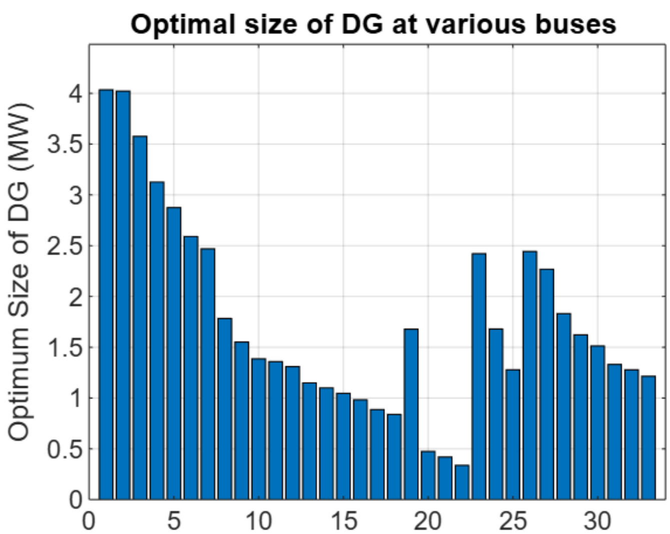

Figure 5.10 Optimal size of DG at various buses by adding 0.1 MW load at bus 6

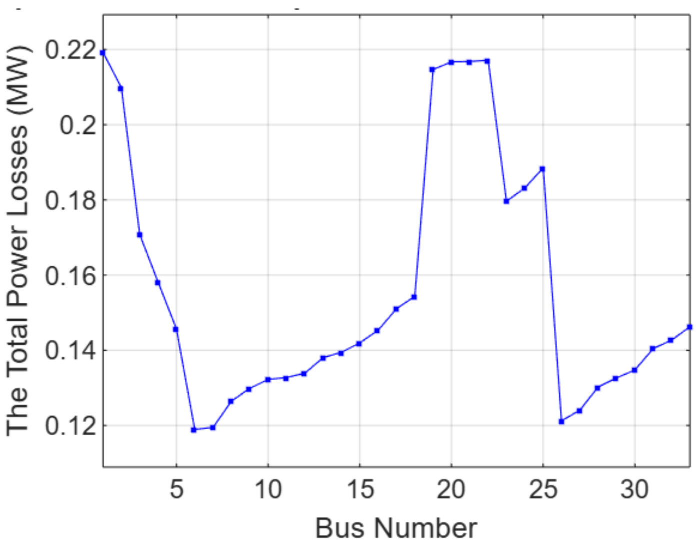

Figure 5.11 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 6

4.Adding 0.1 MW Load at bus 7

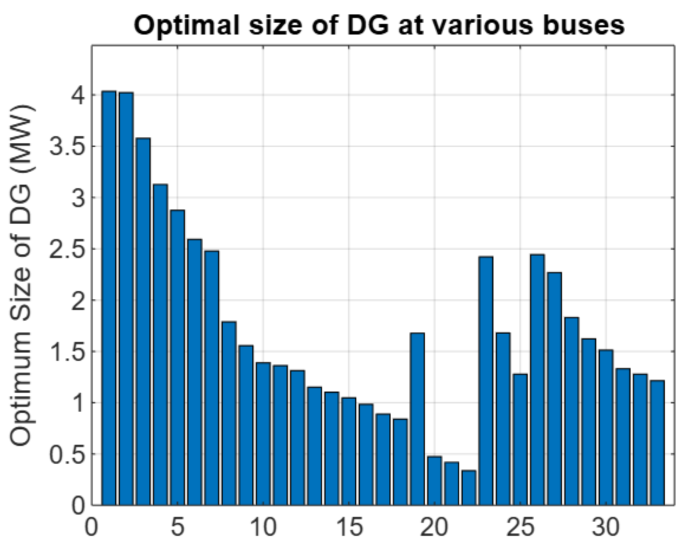

Figure 5.12 Optimal size of DG at various buses by adding 0.1 MW load at bus 7

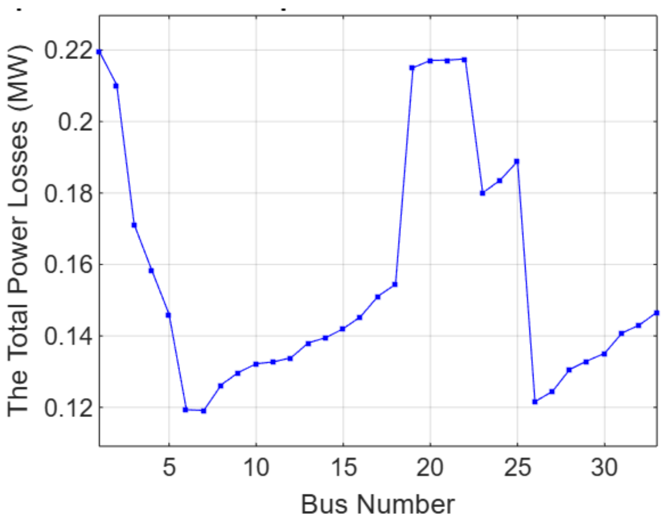

Figure 5.13 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 7

5.Adding 0.1 MW Load at bus 19

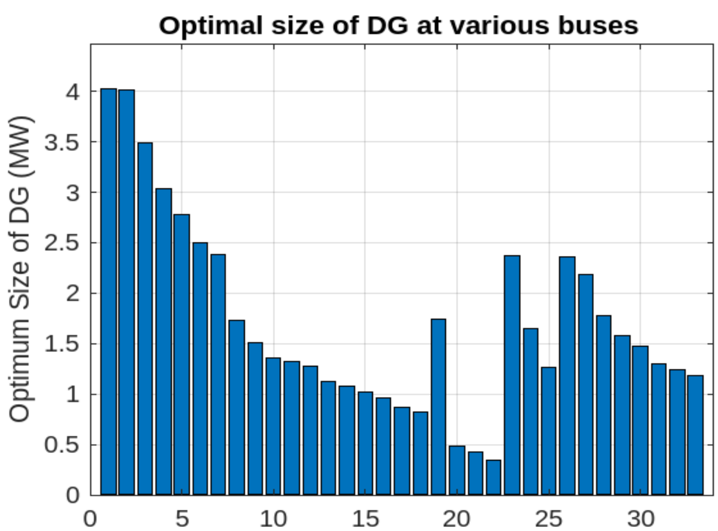

Figure 5.14 Optimal size of DG at various buses by adding 0.1 MW load at bus 19

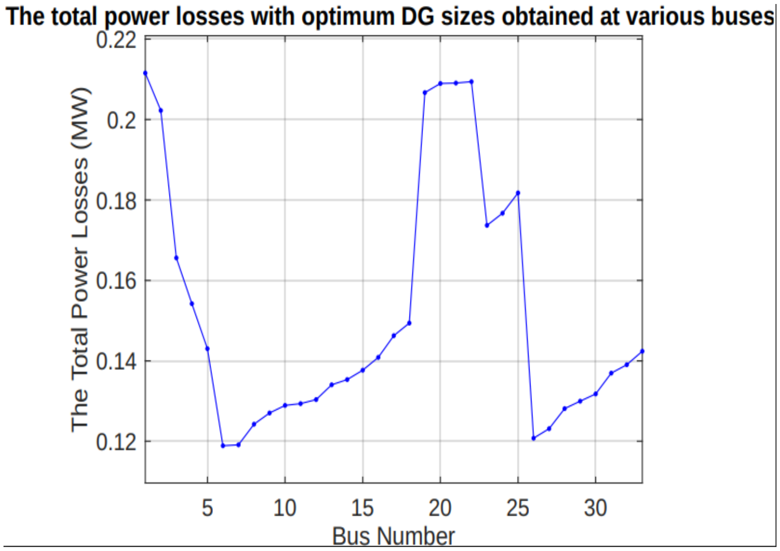

Figure 5.15 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 19

6.With adding 0.1 MW Load at bus 20

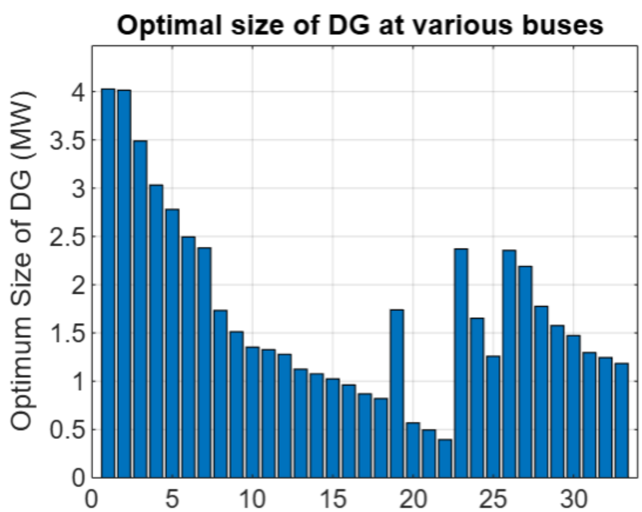

Figure 5.16 Optimal size of DG at various buses by adding 0.1 MW load at bus 20

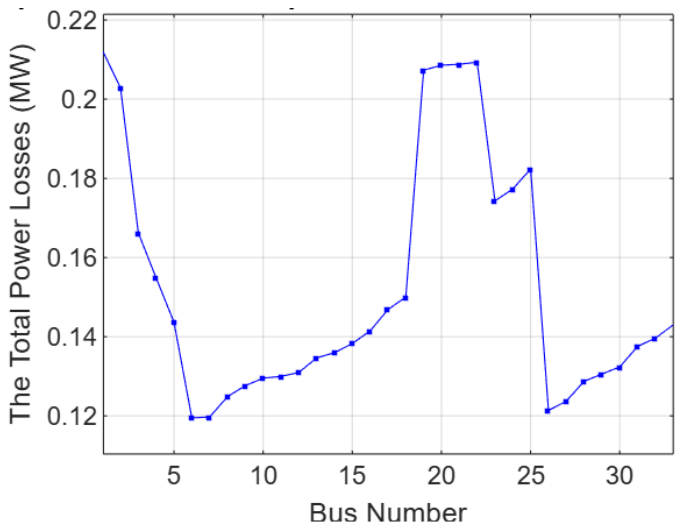

Figure 5.17 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 20

7.With adding 0.1 MW Load at bus 21

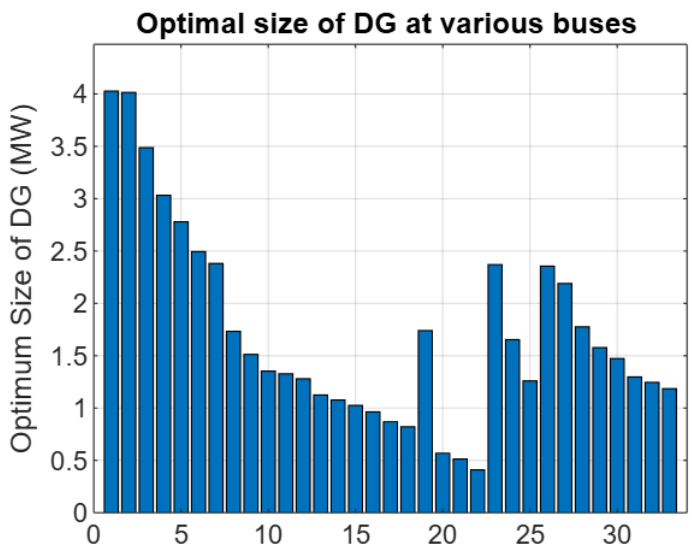

Figure 5.18 Optimal size of DG at various buses by adding 0.1 MW load at bus 21

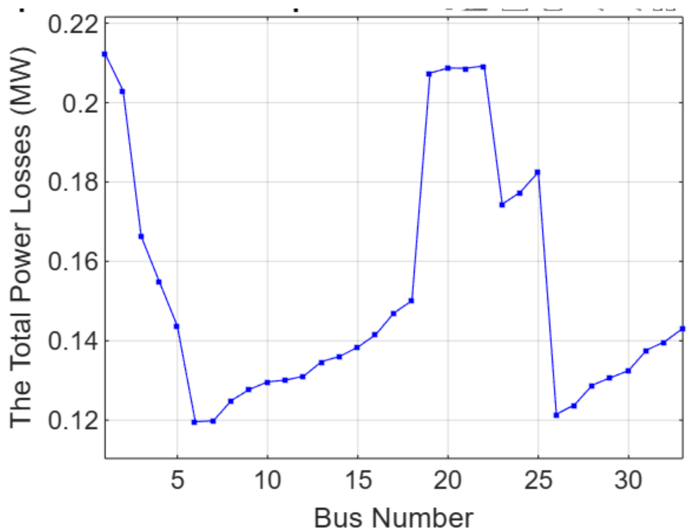

Figure 5.19 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 21

8.With adding 0.1 MW Load at bus 22

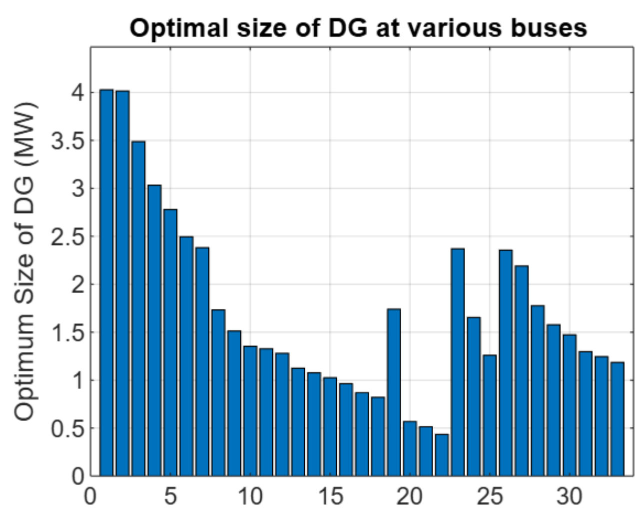

Figure 5.20 Optimal size of DG at various buses by adding 0.1 MW load at bus 22

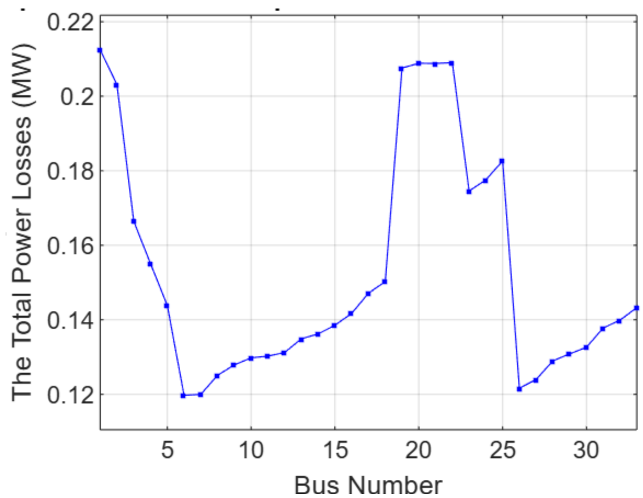

Figure 5.21 The total power losses with optimum DG sizes obtained at various buses by adding 0.1 MW at bus 22

CHAPTER 6: CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

- This project studied the optimal locations for Solar-Powered Electric Vehicle Charging Stations (SPEVCS) within a 33-bus radial distribution system.
- Load flow analysis demonstrated that the addition of Distributed Generation (DG) greatly enhances the voltage profiles and reduces power losses.
- Among the various tested buses, some locations (such as Bus 6 and Bus 7) exhibited the most favourable results with regard to losses and elevation of voltage levels.
- DG's optimum size at bus 6 is 2.59070 MW and at bus 7 is 2.47759 MW.
- The use of perturbation-based sensitivity (0.1 MW step increases in loading) was particularly useful for locating the most critical buses for allocation of DG.
- Simulation results undoubtedly indicated that system efficiency is improved with the addition of DG, particularly under conditions of higher system demand.
- The approach developed in this work enables the efficient and intelligent optimization of planning electric vehicle (EV) charging station locations in conjunction with high solar availability areas.
- This project enhances sustainable energy objectives by providing a solution for clean solar-powered EVs that directly integrates with solar energy charging stations.

6.2 FUTURE SCOPE

- Modeling dynamic load in real-time
- Multi-objective optimization problem of emissions, cost, and reliability.
- Involvement of reactive power support with distributed generation.
- Corporate renewable energy powered distributed generators with electric vehicle charging stations.

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