**Proceedings of 12th IOE Graduate Conference**
*Peer Reviewed*
**ISSN: 2350-8914 (Online), 2350-8906 (Print)**
**Year: 2022 Month: October Volume: 12**

# Study on Impacts of Photovoltaic Integration In Radial Distribution System

Hari Bhusal [a], Radhika Kumari Sah [b], Saubhagya Acharya [c], Shailendra Kumar Jha [d]

[a, b, c, d] *Kathmandu University, School of Engineering, Department of Electrical and Electronics Engineering*
[a] haribhusal49@gmail.com, [b] radhikasah67@gmail.com, [c] sauacharya06@gmail.com, [d] shailendra@ku.edu.np

**Abstract**

This paper presents the impact of integrating photovoltaic (PV) generation system on the distribution system in a radial distribution network. IEEE 33 radial bus system and modified 24 bus Dharan feeder of Dharan substation are selected as candidate system. Particle Swarm Optimization (PSO) is proposed for optimal location for PV penetration at different penetration level with minimum power loss as objective function. The results in terms of voltage profile improvement and power loss minimization are studied with PV integration. Also, a comparative analysis for the system with integration of Distributed Generation (DG), PV with capacitor bank for reactive power injection as well is conducted. Voltage profile improvement and significant decrease in power loss was observed in both the cases. Also, PV with capacitor bank used had shown effective results at lower penetration level than that with just PV.

**Keywords**

Backward-forward sweep, Distributed generation, Distribution system, Particle swarm optimization, Photovoltaic penetration

## 1. Introduction

The production of solar energy has increased significantly in recent years. The widespread usage of photovoltaic (PV) technology on a global scale is a result of its significance as a substantial component of the supply of renewable energy. [1]. It is challenging to integrate renewable energy resources into the electricity grid because they are intermittent in nature. [2]. PVs in particular provide additional difficulties for the electricity system because they are intermittent sources. Integration of PVs in power system results in issues like power quality, power imbalance between generation and load demand, voltage and frequency variation[3]. Small-scale generation units that are connected at the distribution level are known as distributed generation (DG). Electric power research institute (EPRI) defines distributed generation as generation ranging from a few kW to 50 MW [4]. DG technologies include renewable resources, such as PV, wind, micro- turbines, combustion gas turbines, and fuel cells etc. For producing electricity from solar energy, PV power generation is considered the most capable methods [5]. Solar PV is one of the sources of energy that has grown at the fastest rate over the previous ten years, increasing by 25 to 35 percent annually. In the past ten years, the market for solar PV has also changed from off-grid uses like lighting and water pumping to grid-connected uses.

For a long time, the distribution networks were constructed so that power was sent from a single, centralized generator to loads in a radial pattern. As this traditional pattern of power transmission, which tends to rely on limited fuel energy sources, has not proven sustainable, the scenario is now shifting to expanding DGs to include sustainable alternative energy sources. Once there are many DG sources connected to the grid, the power flow is reversed i.e, power flow from the DG unit to the main grid. The main difference during this method is the reverse power flow. Reactive power cannot be supplied by PV on its own, however most voltage source inverters now help by also supplying reactive power. The network's power flows and voltage profiles are more relevant to the feeder maximum load versus PV peak capacity approach. [6]. While PV alone doesn't supply reactive power to the system, the advancements in power electronics, smart inverters are being utilized widely for reactive power control and active power curtailment. [7]

There are several methods for finding the optimal sizing and location of PV in distribution system for loss minimization and voltage profile improvement. Among different approaches that are used for DG unit allocation study in radial distribution system, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are both populations based stochastic optimization [8]. As long as the size range is chosen as high as possible close to the whole load requirement, the PSO achieves the same optimal solution. [9]. Prior to installation, the best placement for the solar generator must be determined because it is not feasible to change the location of the system's power injection due to changing loads or congestion [10]. In [11] optimal placement and sizing of PV-battery-diesel hybrid systems to reduce the system cost and control the grid voltage has been proposed using PSO in two stage. [12] shows that employing PSO rather of GA for cycle charging techniques produces better outcomes in terms of DG, COE, pollutant emissions, reliability, and algorithm running time.

## 2. Problem Formulation

Voltage fluctuations and imbalance, current and voltage harmonics, grid landing protection, and other power quality issues, such as flicker and stress on distribution transformer, could be identified as the main effects of PV integration. The distribution system does not suffer any stability problems under balanced condition between load and supply side, but when one of the section lags or exceeds other, the stability issue arises. The issues arising by the power scarcity in a distribution system can be improved with integration of DG units [13]. In distribution system integrated with DG, the static DG or rotary type DG, both finally affect the voltage stability margin of the system [11]. The issue is figuring out the DG penetration limit by sizing and assigning DGs in a way that minimizes power losses and voltage deviation for the expanded distribution network.

### 2.1 Objective function

The main objective is to minimize the real power loss and the voltage deviation subject to different constraints. This can be expressed mathematically as in equation (1):

$$\text{Objective function} = \text{Minimum } \Sigma_{i=1}^{\text{total}} \text{ Pi,loss} \quad (1)$$

### 2.2 Constraints

The objective function is subjected to the following constraints:

#### 2.2.1 Branch capacity limit

$$I(i,j) \leq \text{ Irated} \quad (2)$$

#### 2.2.2 PV power rating constraints

The size of the DG in the expanded network should neither be less than 20% of the feeder load nor should it be greater than 60% of the feeder load value.

$$10\%L \leq PV \text{ rating } \leq x\%L \quad (3)$$

x = 60 for IEEE 33 bus and x = 40 for Dharan feeder. where; L is total feeder load

#### 2.2.3 Active and reactive power loss constraints

The losses after installing PV in the network should be less than or equal to the losses before installing PV.

$$PL_{withPV} \leq PL_{withoutPV} \quad (4)$$

$$QL_{withPV} \leq QL_{withoutPV} \quad (5)$$

## 3. Methodology

In the proposed methodology, initially the line and load data of distribution system are taken as input. The load flow of the initial condition is carried out using Backward Forward sweep method. Initially the voltages values are set to 1 per unit (p.u) at all nodes. Then using backward sweep prorogation, the analysis is started with end node and the node current is calculated using equation (6). The current flowing from node i towards node i+1 is calculated using equation (7). The voltage at ith node is computed using equation (8) taking into account the current from equation (7). This step is continued till the junction node is reached. At junction node the voltage computed is stored[14].

$$Ii = (Si/Vi)* \quad (6)$$

$$I(i,i+1) = I(i+1) + \sum \text{ currents } (i+1) \quad (7)$$

$$Vi = V(i+1) + (I(i,i+1) * Z(i,i+1)) \quad (8)$$

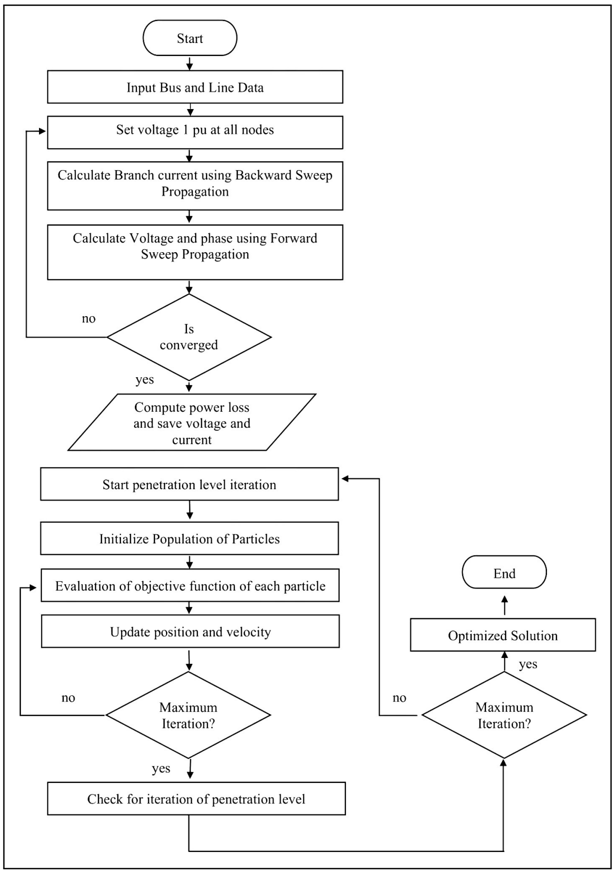


**Figure 1:** Proposed model for sizing and optimal location of DG units

Voltage and current are calculated for a different end node of the system. Equation (6) is used to compute the current after obtaining the most recent voltage at the junction node. Up until the reference node, the calculation is done, and the calculated magnitude of the rating voltage at the reference node is compared to the provided source voltage. If the voltage difference meets the given conditions, the analysis is stopped; otherwise, the forward sweep starts. When initiating a forward sweep, the reference node is set to its rated voltage, and equation (9) is used to compute the node voltage from the reference node to the end nodes in the forward direction. Similar to just how forward sweep was computed, backward sweep is initiated with updated bus voltage.

$$V(i+1) = Vi - (I(i,i+1) * Z(i,i+1)) \tag{9}$$

Line losses are determined following the standard backward-forward sweep algorithm calculations of node voltages and line currents. Equation (10) and (11) are used to compute the complex power, Sij from bus i to bus j and Sji from bus j to bus i.

$$S_{ij} = (V_i I_{ij})* \tag{10}$$

$$S_{ij} = (V_j I_{ji})* \tag{11}$$

After the computation of power loss and storing the values of current and voltage for each node, the penetration level iteration is set for penetration of PV in the system. The optimum location for the penetration is found by PSO. Initially it generates the population of solution, and objective function in equation (1) is evaluated for each swarm particle in population. These particles maintain a record of the positions in hyperspace where they found the ”Pbest” fittest solution. The ”Gbest” location and overall best value of the particles are both maintained by the particle swarm optimizer. With each cycle of the PSO, each particle’s position and velocity are changed. After defined number of iterations, the optimized results are presented[15]. For the proposed methodology, the size of population is taken 50 and the number of iterations is taken 100. The inertia and correction factor for updating velocity parameters are taken 1.0 and 2.0 respectively.

## 4. Results and Discussion

The proposed PSO method tests are simulated on MATLAB. The study is analyzed on IEEE 33 test bus system and 11 kV Dharan feeder.

### 4.1 IEEE 33 Bus Test System

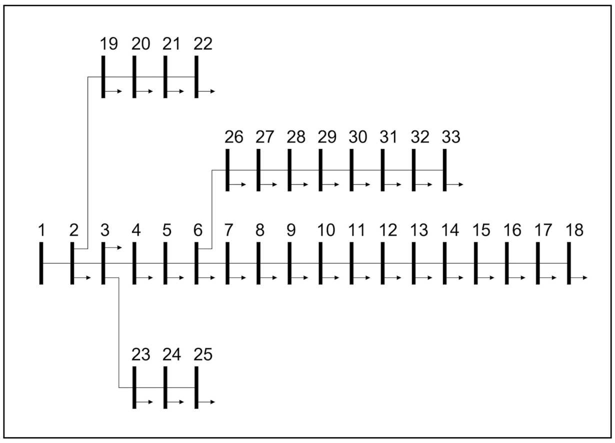


**Figure 2:** Single line diagram of IEEE 33 Bus RDS [16]

The test system, IEEE–33 bus radial distribution system (RDS), is taken into account for the proposed study. From the detailed data taken [17], system has a voltage of 12.66 kV, total loads 3715 kW and 2300 kVAR. The base power was taken as 100 MVA and base voltage as 12.66 kV for calculating per unit values. The active and reactive power loss of the system is found to be 201.99 kW and 134.74 kVAR without PV and DG integration. The maximum and minimum voltages are 1.0 p.u for reference bus 1 and 0.91 p.u for bus 18, respectively.

#### 4.1.1 With PV

At first, the PV was penetrated at different penetration levels in optimal location drawn by PSO and the optimum size is calculated. The voltage and power loss scenario when 1610.45 kW of PV is penetrated at bus 6 with power factor of 0.85 are as shown in figure (3) and (4). The voltage profile of the buses with lower voltage level has been improved. The active power and reactive power loss have been decreased to 85.99 KW which is 57.42% reduction in loss as compared to the case without PV integration. Buses 6 to 18 and buses 26 to 33 have voltage lower than 0.95 pu without PV unit and those are improved.

#### 4.1.2 With PV and Capacitor Bank

The voltage and power loss scenario when 2228.37 kVA of DG (PV with capacitor bank) is penetrated at bus 6 are as shown in figure (3) and (4). Buses 6 to 18 and buses 26 to 33 have voltage lower than 0.95 p.u without PV unit and those are improved. The active power and reactive power loss have been decreased to 78.96 kW which is 60.91% reduction in loss as compared to the case without DG integration.

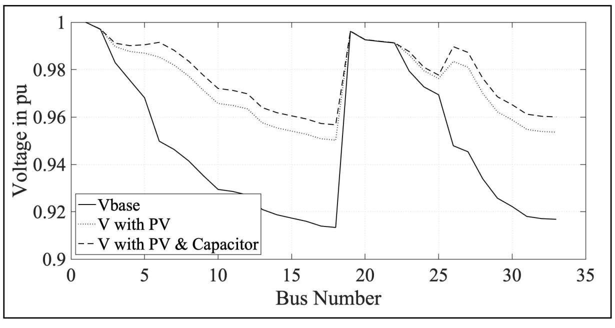


**Figure 3:** Voltage plot for base case, with integration of PV only and with PV and Capacitor, IEEE 33 Bus RDS.

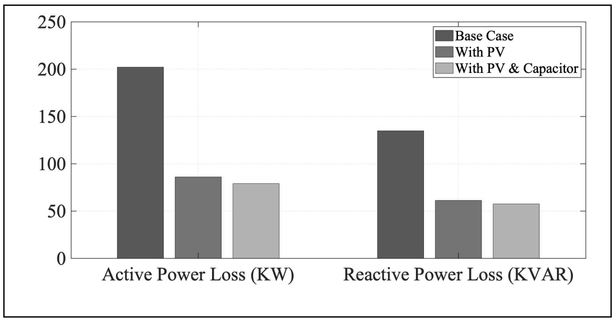


**Figure 4:** Power loss scenario for base case, with integration of PV only and with PV and Capacitor, IEEE 33 Bus RDS.

### 4.2 Dharan Feeder

Dharan Feeder is a radial distribution system of 19.92 km length which consist 47 transformers in total connected into11 kV primary distribution system. The main location of the feeder is Bhat-Bhateni super market, College road, Vijaypur hospital, NEA office. This system is modified to 24 bus system considering the transformers located within 100m radius to be a single bus with a load to be sum of the total transformer load. In this study, the peak load of a transformer is considered as a load of the bus at power factor 0.80 lagging. The total load of the modified Dharan feeder 24 bus system is 4288 kW and 3216 kVAR. The system is not lateral and has branches connected to it. The base power was taken 100 MVA and base voltage 11 kV for calculating p.u values. The active and reactive power loss of the system is found 434.77 kW and 445.43 kVAR without PV integration. The maximum and minimum voltages are 1.0 p.u of reference bus 1 and 0.86 pu of bus 24, respectively.

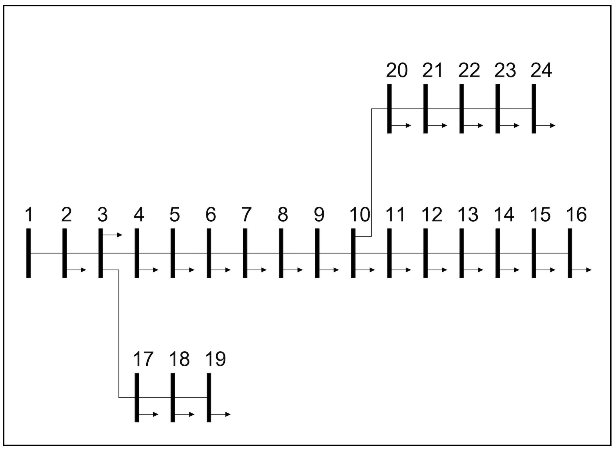

**Figure 5:** Single line diagram of Modified Dharan Feeder 24 Bus RDS.

**Table 1:** Active power loss reduction with different DG unit

| RDS | Types of DG | Size | Location Bus | Active power loss reduction |
|---|---|---|---|---|
| IEEE 33 | PV | 1610.45 KW | 6 | 57.43% |
| | PV and Capacitor | 2228.37 KVA | 6 | 60.90% |
| Dharan Feeder | PV | 1239.23 KW | 16 | 71.85% |
| | PV and Capacitor | 1822.40 KVA | 16 | 76.00% |

#### 4.2.1 With PV

The voltage and power loss scenario when 1239.23 kW of PV is penetrated at bus 16 with power factor of 0.85 are as shown in figure (6) and (7). The voltage profile of the buses with lower voltage level has been improved. The active power loss has been decreased to 122.40 kW which is 71.85% reduction in loss as compared to the case without PV integration. The penetration range for PV in Dharan feeder is selected between the range of 20-40% from equation (3), as higher penetration level would require plant of higher capacity which does not look feasible due to location and other factors. Within penetration level of 40% for PV, bus 16 has lowest voltage of 0.94 p.u.

#### 4.2.2 With PV and Capacitor Bank

The voltage and power loss scenario when 1822.40 kVA of DG (PV with capacitor bank) is penetrated at bus 16 are as shown in figure (6) and (7). All the bus voltages that were less than permissible limit are been improved. The active power loss has been decreased to 104.30 kW which is 76% reduction in loss as compared to the case without DG integration.

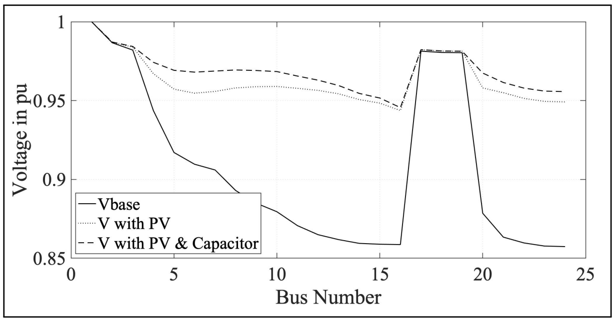


**Figure 6:** Voltage plot for base case, with integration of PV only and with PV and Capacitor, Modified Dharan Feeder 24 Bus RDS.

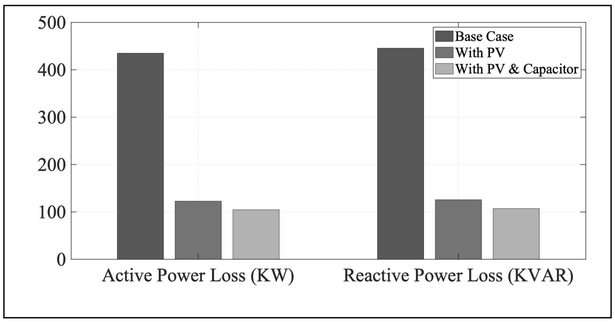


**Figure 7:** Power loss scenario for base case, with integration of PV only and with PV and Capacitor, Modified Dharan Feeder 24 Bus RDS.

## 5. Conclusion

The proposed model of PSO presented in this paper for finding optimal location for placement of PV for different level of penetration in radial distribution system is tested for two systems: IEEE-33 radial bus system and a modified Dharan feeder 24 bus system. Using minimum power loss as objective function, PSO allocated penetration location in both systems under a given iteration number. Voltage level improvement and significant loss in power is observed in both the cases.

## References

[1] M Karimi, H Mokhlis, K Naidu, S Uddin, and AH Abu Bakar. Photovoltaic penetration issues and impacts in distribution network–a review. *Renewable and Sustainable Energy Reviews*, 53:594–605, 2016.

[2] Andra Backhaus. *Analyzing the Application of Different Energy Cell Sizes as an Approach for the Integration of Decentralized Renewable Energy Sources.* PhD thesis, University of Freiburg.

[3] Sirine Essallah, Adel Bouallegue, and Adel Khedher. Optimal placement of pv-distributed generation units in radial distribution system based on sensitivity approaches. In *2015 16th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*, pages 513–520. IEEE, 2015.

[4] Francisco Gonzalez-Longatt and C Fortoul. Review of the distributed generation concept: Attempt

of unification. In *International Conference on Renewable Energies and Power Quality (ICREPQ 05), España*, pages 16–18, 2005.

[5] Ramon A Gallego, Alcir José Monticelli, and Rubén Romero. Optimal capacitor placement in radial distribution networks. *IEEE Transactions on Power Systems*, 16(4):630–637, 2001.

[6] Tariq Aziz and Nipon Ketjoy. Pv penetration limits in low voltage networks and voltage variations. *IEEE Access*, 5:16784–16792, 2017.

[7] Priyanka Chaudhary and M Rizwan. Voltage regulation mitigation techniques in distribution system with high pv penetration: A review. *Renewable and Sustainable Energy Reviews*, 82:3279–3287, 2018.

[8] FJ Ruiz-Rodriguez, M Gomez-Gonzalez, and F Jurado. Binary particle swarm optimization for optimization of photovoltaic generators in radial distribution systems using probabilistic load flow. *Electric Power Components and Systems*, 39(15):1667–1684, 2011.

[9] Mazen Abdel-Salam, Mohamed Th El-Mohandes, and Lubna Mahmoud. A pso-based multi-objective method for optimal weight factors, placement and sizing of multiple dg units in a distribution system. In *2019 21st International Middle East Power Systems Conference (MEPCON)*, pages 914–920. IEEE, 2019.

[10] Carlos D Rodríguez-Gallegos, Manuel S Alvarez-Alvarado, Oktoviano Gandhi, Dazhi Yang, Wenjie Zhang, Thomas Reindl, and SK Panda. Placement and sizing optimization for pv-battery-diesel hybrid systems. In *2016 IEEE International Conference on Sustainable Energy Technologies (ICSET)*, pages 83–89. IEEE, 2016.

[11] Yashwant Sawle, SC Gupta, and Aashish Kumar Bohre. Optimal sizing of standalone pv/wind/biomass hybrid energy system using ga and pso optimization technique. *Energy Procedia*, 117:690–698, 2017.

[12] J Senthil Kumar, P Prem, and M Jagabar Sathik. Evaluation of dg impacts on distribution networks. pages 195–209, 2021.

[13] Ajay Singh, Ashish Shrestha, Sudip Phuyal, B Adhikari, and Antonis Papadakis. Particle swarm optimization approach for distributed generation allocation planning for voltage profile improvement. In *11th International Conference on Deregulated Engineering Market Issues in South Eastern Europe, Nicosia, Cyprus*, 2018.

[14] AD Rana, JB Darji, and Mosam Pandya. Backward/forward sweep load flow algorithm for radial distribution system. *International journal for scientific research and development*, 2(1):398–400, 2014.

[15] B Seixas Gomes de Almeida and Victor Coppo Leite. Particle swarm optimization: A powerful technique for solving engineering problems. *Swarm intelligence-recent advances, new perspectives and applications*, pages 1–21, 2019.

[16] Ponnapureddy Niveditha and MS Sujatha. Optimal allocation and sizing of dg in radial distribution system-a review. *INTERNATIONAL JOURNAL OF GRID AND DISTRIBUTED COMPUTING*, 11(6):49–57, 2018.

[17] Vasiliki Vita. Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks. *Energies*, 10(9):1433, 2017.