

Optimal Sizing and Location of Multi-Unit Photovoltaic System on Distribution Network Using Particle Swarm Optimization

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Abstract

This paper investigates the optimal sizing and location of multi-unit photovoltaic (PV) systems in a distribution network using Particle Swarm Optimization (PSO). The goal is to reduce power losses and improve voltage stability by PV installing as distributed generator (DG). The IEEE 33-bus and 69-bus radial distribution systems were used as test system. Power flow analysis was conducted using the Newton-Raphson method in MATLAB software. Simulation results revealed that integrating three PV units provided the best performance, reducing power losses by 65.52% and 69.16% for the IEEE 33-bus and 69-bus systems respectively. A scenario with a 20% increase in total load was also analyzed to simulate the impact of electric vehicle charging station (EVCS) to PV sizing and location. It found that, proper sizing and placement of PV integration can improve the network losses when EVCS connected to the distribution system.

1. Introduction

The increasing global demand for electricity, coupled with the urgent need to reduce carbon emissions and reliance on fossil fuels, has driven the widespread adoption of renewable energy technologies, particularly solar photovoltaic (PV) systems. PV systems offer several advantages including reduced transmission losses, lower energy costs, and environmental sustainability, making them an ideal candidate for integration into power distribution networks as distributed generator (DG) [1]. However, their integration introduces technical challenges such as voltage instability, reverse power flow, and increased power losses, especially when multi-unit PV systems are deployed without proper optimization [2], [3]. These issues are exacerbated by the intermittent nature of solar energy and the non-linear characteristics of distribution systems. The DG generates electricity close to the point of load consumption, can address these issues if optimally placed and sized. Therefore, optimization techniques are essential to maximize the benefits of DG while minimizing its negative impacts. Among these optimization algorithms, Particle Swarm Optimization (PSO) algorithm inspired by the social behavior of birds and fish, has emerged as an efficient and robust algorithm for solving complex single and multi-objective problems such as PV placement and sizing [4], [5],[6]. This study investigates the optimal integration of multi-unit PV systems into radial distribution networks using PSO, focusing on minimizing power losses and improving voltage stability in IEEE 33-bus and 69-bus systems. Furthermore, the research evaluates the

performance of the optimized network under increased load scenarios representing the impact of electric vehicle charging stations (EVCS), thereby enhancing the practical relevance of the solution for future energy systems.

Previous studies have extensively examined the optimization of distributed generation PV placement and sizing in distribution networks using various metaheuristic algorithms [7]. Among them, Particle Swarm Optimization (PSO) consistently demonstrated strong performance in minimizing power losses and improving voltage profiles [8]. Compared to other methods such as Firefly Algorithm (FA), Gravitational Search Algorithm (GSA), and Hybrid PSO variants, PSO offered faster convergence and more accurate solutions in complex multi-objective scenarios [9], [10]. These findings, supported by case studies on standard IEEE bus systems, highlight PSO as an effective technique for enhancing distribution system performance, especially when addressing the technical challenges introduced by multi-unit PV integration. This paper investigates the application of PSO for PV sizing and location for radial distribution networks and considers the impact of EVCS integration.

2. Research Methodology

The main objective of this project is to determine optimal sizing and location PV system while considering the integration of EVCS in the distribution network. The main methodology includes mathematical problem formulation, development of PSO algorithm and impact analysis of EVCS integration.

2.1 Test System Modelling

The IEEE 33-bus and 69-bus radial distribution systems were modeled in MATLAB to run the power flow analysis by using the Newton-Raphson method [11].

2.2 Problem Formulation: PV Sizing and Location

The optimal size and location of PV in distribution network capable to reduce network losses. It is crucial to ensure the system operate at minimum losses. Therefore, optimization algorithm such as PSO is required to solve the problem. The PSO approach can efficiently address the optimization issue in this study. To solve the challenge of sizing and locating of multi-PV units, the objective function of the optimization problem and constraints should be defined for minimizing the total power losses in the network. The power losses, P_{losses} in a network with n^{th} branches can be expressed as following Equation (1) [11]:

$$P_{losses} = \sum_{i=1}^n I_i^2 R_i \quad (1)$$

where,

- i = Branch or line index in distribution network
- R_i = Resistance of branch i
- I_i = Current flowing through branch i

The optimal PV size and location aims to minimize actual power losses in the distribution network while meeting power system load requirements and constraints. The objective function of this problem is to minimize the total power losses, $P_{total losses}$ in a system represent as follows in Equation (2) [12]:

$$\text{Minimization } P_{total losses} = \sum_{i=1}^n P_{losses} \quad (2)$$

Managing constraints is crucial for addressing and resolving the the problem for this study. This constraint handling rule ensures the operation within the limits and fulfil all the operation constraints. The following constraints must be met which are constraint of power balance, constraint of voltage bus, constraint of DG operation and total power of DG.

a) Constraint of power balanced

In power balancing, the total power generated in a distribution network must equals to the sum of the total load, P_{Load} and total power losses, P_{Losses} . This limitation is crucial for achieving a power balanced between generated power and demand loads as follows in Equation (3)[13]:

$$\sum_{i=1}^k P_{PV} + P_{Substation} = P_{Load} + P_{Losses} \quad (3)$$

where,

- P_{PV} = Power generated by distributed generator i

$P_{Substation}$ = Power supplied by the substation
 P_{Load} = Total power demand (load) in the system
 P_{Losses} = Total power losses in the system
 k = Total number of PVs in the network

b) Constraint of bus voltage

To guarantee that the network operates in stable and reliable condition, the voltage at each bus must be within acceptable limits and can be expressed as in Equation (4) [13]:

$$V_{min} \leq V_i \leq V_{max} \quad (4)$$

where,

V_{min} = Minimum acceptable voltage level
 V_{max} = Maximum acceptable voltage level
 V_i = Voltage magnitude at bus i

All bus voltage in the distribution network system must be within the acceptable limit which is $\pm 5\%$ from 0.95 to 1.05 p.u.

c) Constraint of DG power limit

Each PV unit's size must be within a predetermined minimum and maximum limits, reflecting the technical and cost restrictions of DG deployment. This can be expressed as follows as Equation (5) [14]:

$$P_{PV,min} \leq P_{PV} \leq P_{PV,max} \quad (5)$$

where,

$P_{PV,min}$ = Minimum allowable PV power output
 $P_{PV,max}$ = Maximum allowable PV power output
 P_{PV} = Power output

In this study, the limits of each PV unit is set between 0.001MW to 2.5MW. The output cannot exceed the distribution network's load demand and considering the PV size limitations.

d) Total power of PV

PV power must be less than the network's total load and losses. Power injection from DG units to the main source can increase power losses, hence it's important to avoid this effect. Therefore, the PV output can be limited based on the following Equation (6) [15]:

$$\sum_{i=1}^k P_{PV} < P_{Load} + P_{Losses} \quad k = \text{no. of PV unit} \quad (6)$$

2.3 Test System and EV Charging Scenarios for Distribution Network Analysis

This study has been tested on the IEEE 33-bus and 69-bus radial distribution systems to evaluate the effects of PV and EVCS integration. Power flow analysis is performed using MATLAB and the Newton-Raphson method. Multiple scenarios are tested, including the systems without PV and multiple PV units (up to 4 units). An approximate 20% load increment is considered to simulate the impact of Electric Vehicle Charging Stations (EVCS). The main purpose is to analyze the effect of increased demand from EVCS to the power losses, voltage profiles, and optimal PV size and placement. The bus voltage limits are maintained within the standard operating range, with the maximum and minimum voltage of 1.05 p.u. and 0.95 p.u. respectively. In this study, it is assumed that the EVCS to be placed at bus numbers 9, 22, 25, and 28 for IEEE 33-bus system. Moreover, the EVCS assumed to be placed at bus numbers 25, 31, 45, and 61 for IEEE 69-bus system for determining PV size and location.

There are four case studies that are considered to evaluate the effect of EVCS on IEEE 33-bus and 69-bus distribution networks. For case 1, type 3 charging stations, each bus with a capacity of 720 kW (180 kW \times 4 charging points per station) are connected to bus 9 only. For case 2, type 3 each bus with a load of 360 kW (180 kW \times 2 charging points per station) are connected to buses 9 and 22. For case 3, type 2 charging stations each bus with a capacity of 242 kW (22 kW \times 11 charging points per station) are connected to buses 9,22 and 25. Lastly for case 4, type 2 charging stations each bus with a capacity of 176 kW (22 kW \times 8 charging points per station) are connected to buses 9,22,25 and 28. The locations of EVCSs are randomly selected for both test system as shown in Table 1.

Table 1 The different case study and EVCS location for IEEE 33-bus and 69-bus systems

Case Study for EVCS	Test System / EVCS bus location		Total EVCS load
	33-bus system	69-bus system	
Case 1 (1EVCS)	9	25	180 kW x 4 = 720 kW each bus
Case 2 (2 EVCS)	9,22	25,31	180 kW x 2 = 360 kW each bus
Case 3 (3 EVCS)	9,22,25	25,31,45	22 kW x 11 = 242 kW each bus
Case 4 (4 EVCS)	9,22,25,28	25,31,45,61	22kW x 8 = 176 kW each bus

2.4 Particle Swarm Optimization for PV Sizing and Location

Particle swarm optimization is a population-based search approach that uses stochastic 'flying' of particles to identify the optimal solution in a search space. Particles iteratively sample a region between their prior best location ($Pbest$) and that of their most successful neighbors ($Gbest$). In this approach, a superior position can be attained. To improve their position, they change their search dimensions and update their individual best position. This mechanism leads particles to converge at the maximum or minimum. The velocity of each particle can be modified using the following Equation (7) [16]:

$$V_i^{k+1} = wv_i^k + c_1rand_1(Pbest_i - s_i^k) + c_2rand_2(Gbest_i - s_i^k) \tag{7}$$

where, $i = 1, 2, \dots, n$:

- i = Particle number
- n = Total number of particles
- V_i^k = Velocity of i^{th} particle at k^{th} iteration
- w = Weighting function
- c_1 and c_2 = Weighting factor
- $rand_1$ and $rand_2$ = Random number in range 0 and 1
- s_i^k = Current position of i^{th} particle at k^{th} iteration
- $Pbest_i$ = Best position of i^{th} particle
- $Gbest_i$ = Best value among the whole group $Pbest_i$

The weighting factor for the current position (search point in the solution space) can be calculated by the Equation (8)[16]:

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{iter_{max}} \right) \times iter \tag{8}$$

where,

- w_{min} = Initial weight factor
- w_{max} = Final weight factor
- $iter$ = Current iteration number
- $iter_{max}$ = Maximum iteration number

The update position (search point in the solution space) based on the velocity can modified by the following Equation (9)[16]:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{9}$$

Particle Swarm Optimization (PSO) algorithm is used to determine the best size and location PV in a distribution power system. It begins by gathering bus and line data for IEEE test systems and computing baseline power losses without PV using the Newton-Raphson approach. The PSO algorithm creates a population of particles, each representing a possible PV size and placement (bus number). Particle locations and velocities are iteratively adjusted based on personal and global best solutions to reduce power losses. Once the stopping condition is met, the best PV size and location are determined (Objective 1), power losses with and without PV are compared (Objective 2), and the impact of EVCS integration to the PV size and location is assessed (Objective 3). The overview of the project methodology is presented in Figure 1.

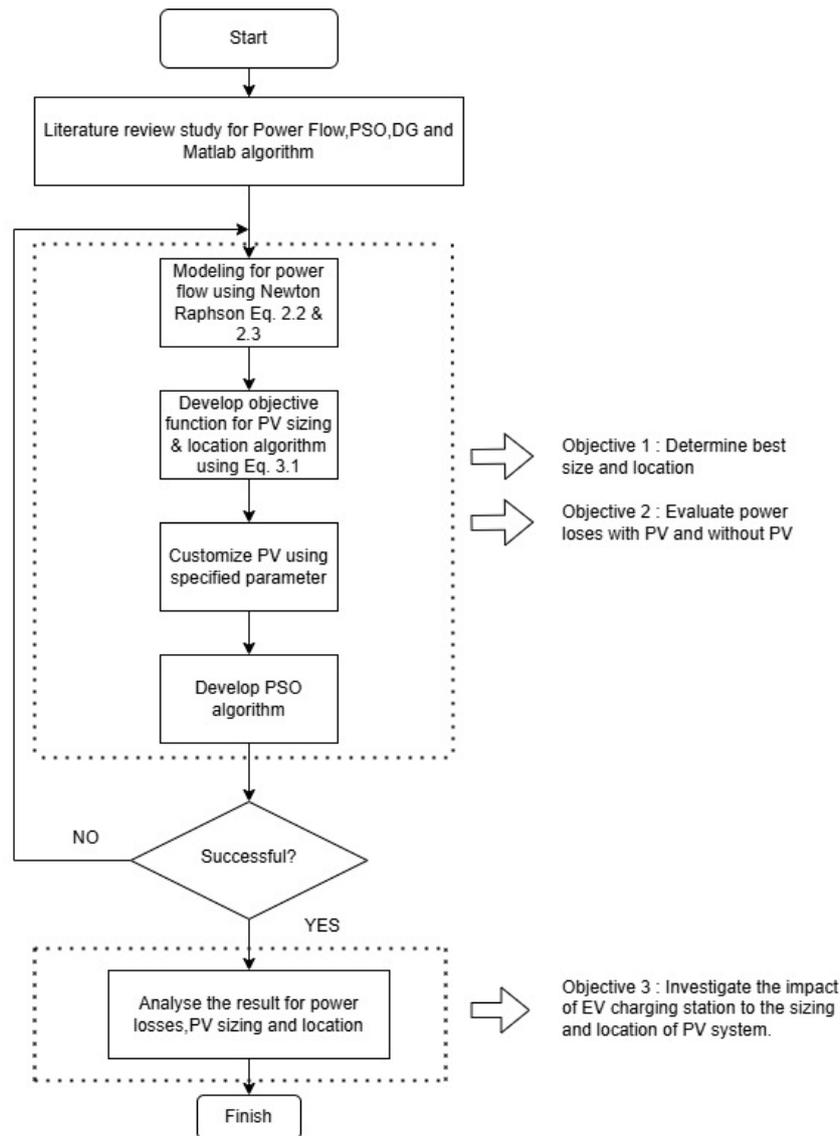


Fig. 1 Overview of the main methodology for PV sizing and location

The main methodology of this study can be summarized as follows:

Step 1: Initialize the system data

Collect the distribution system bus and line data for the IEEE-33 and IEEE-69 bus test systems. This data offers the necessary information for performing load flow analysis and optimizing PV allocation and sizing. These two-test system is considered for in this study.

Step 2: Calculate the power loss without PV integration in the network

The power losses in the system are computed using the Newton-Raphson method for the baseline case by using equations (1) and (2) without PV units. The main purpose is the determine the baseline of the total losses for assessing the impact of PV installation in the next steps.

Step 3: Define the objective function and system constraints in PSO algorithm

The Particle Swarm Optimization (PSO) algorithm is used to identify the optimal size and position for multiple PV units by using the objective function in equation (2) with respect to the constraints in the equations (3) to (6). It also includes the establishing the PSO parameters and initializing the particle population, which represents potential solutions during the iterative process.

Step 4: Calculate the power loss for each particle

The system's power losses are calculated for each particle (solution) by using equation (1) for minimizing the objective function in equation (2). The main objective is to determine the fitness/objective function of each particle.

Step 5: Generate and update particle positions and velocities

In PSO, the particles are assigned random positions and velocities according to the problem variable and constraints. During iterative process, the particle velocity and positions in PSO algorithm are updated based on their own best-known position, the best-known position of the swarm as defined in PSO rules.

Step 6: Stopping criteria: maximum iteration number

The PSO algorithm is keep searching the optimal solution based on the objective function and constraints until reached the maximum iteration number.

Step 7: Record the optimal PV size and location.

Once the optimization is complete, the best solution is stored to determine the optimal size and position of PV units to minimize power losses obtained by the PSO algorithm.

Step 8: Study the impact of EV charging station (EVCS)

The load at the selected bus is increased to approximately 20% of the total demand to represents additional load contributed by the EVCS in order to assess the impact of EVCS load into the power system. Then, the PSO algorithm is implemented to the best size and position of the PV with integration of EVCS in the power system.

Step 9: Analyse the results with and without PV and EVCS loads

The results are examined and compared with and without PV and additional 20% of EVCS load. This comparison demonstrates the advantages of PV allocation and sizing in terms of minimizing power losses and impact to the voltage stability.

2.5 PSO Parameter

The PSO algorithm requires parameters setting, including number of dimensions, particle number, maximum iteration, acceleration factors, velocities, and inertia weight as follows[6], [11], [17]:

- i. **Dimension (D)**
The dimension is determined by the number of the problem variable including the number of PV dan potential location (bus).
- ii. **Particle Numbers (N)**
The number of particles/population size set between 20 to 50 to evaluate the effect of population size to the optimal results.
- iii. **Maximum Iteration ($Iter_{max}$)**
The number of maximum iterations is set to 50 iterations for all cases.
- iv. **Acceleration Factor (c_1 & c_2)**
The value of the acceleration factor is set to 2.

2.6 Test System: IEEE 33-Bus and IEEE 69-Bus Test System

The simulations were carried out using MATLAB R2014b as the primary computational platform. The IEEE 33-bus and 69-bus radial distribution systems were selected as test networks due to their relevance and complexity for PV integration studies [18], [19]. The Particle Swarm Optimization (PSO) algorithm was implemented to determine the optimal sizing and placement of PV units within the distribution networks. In the optimization process, the number of PV units considered ranged from one to four, allowing analysis of performance trends as more units were introduced. Additionally, to evaluate the robustness of the proposed method under increased demand scenarios, an approximately 20% increase in total system load was introduced to simulate the effect of electric vehicle charging stations (EVCS) as discussed in Section 2.2. This allowed comprehensive analysis of the algorithm's performance in real-world, future-facing grid conditions [20], [21],[22].

3. Results and Discussion

This study aims to investigate the optimal size and location of multiple -DG (PV units) for minimizing the power losses in the power distribution systems. The study has been tested on the IEEE 33-bus and 69-bus networks considering up to four PV units based to evaluate the impact of PV size and location to the power loss and voltage magnitude. Simulations are conducted for the test systems with and without PV units and EVCS loads.

3.1 Effect of Population Size on Power Losses

The main purpose of this analysis is to evaluate the impact of PSO population size to power losses for 1 PV unit. Tables 2 and 3 compare power losses for different population sizes of $n=20$, $n=30$, $n=40$, and $n=50$ using a single PV placement for IEEE 33-bus and IEEE 69-bus system respectively. system. All n can produce the same optimal power losses for both test systems. However, it found that the $n=20$ has the fastest simulation time and higher standard deviation as compared to population sizes of $n=20$, $n=30$, $n=40$, and $n=50$.

Table 2 Comparison of different population sizes using 1 PV for IEEE 33-bus system

Number of Population Size, N	Power Losses (MW)	Location of PV (Bus)	PV Sizing (MW)	Elapsed Time, (s)	Standard deviation
20	0.17555	6	2.5	100.5567	1.6016×10^{-3}
30	0.17555	6	2.5	154.7135	1.4451×10^{-3}
40	0.17555	6	2.5	226.6016	1.2899×10^{-3}
50	0.17555	6	2.5	273.3817	1.3654×10^{-3}

Table 3 Comparison of different population sizes using 1 PV for IEEE 69-bus system

Number of Population Size, N	Power Losses (MW)	Location of PV (Bus)	PV Sizing (MW)	Elapsed Time, (s)	Standard deviation
20	0.083205	61	1.8727	173.5877	32.651×10^{-3}
30	0.083205	61	1.8727	234.7028	22.569×10^{-3}
40	0.083205	61	1.8727	316.5777	14.917×10^{-3}
50	0.083205	61	1.8727	395.5451	2.406×10^{-3}

3.2 Optimal Solution with Multiple PV Units for IEEE 33-Bus System

In this case, the population size and maximum iteration of 30 and 50 respectively are considered to evaluate the power losses reduction for PV sizing and location. Table 4 shows the optimal results of power loss, PV sizing, and location for the IEEE 33-bus test system with and without PV units. A single PV in the network contributes to a 50.25% of loss reduction with 0.1756 MW power loss and a minimum voltage of 0.968 p.u. Placing two PVs gives 58.56% of loss reduction with 0.1463 MW power losses. While 3 PV placements contribute to 65.52% of power loss reduction. Increasing the number of PV to 4 PV, the power losses can be reduced to 55.35% as compared to the system without PV installation. It shows that installation of PV units can reduce the system losses on the distribution network. The significant loss reduction can be obtained by installing 3 units of PV system in 3 different buses as presented in Table 4.

Table 4 Optimal PV sizing and location for IEEE 33-bus system with and without PV units

Case	PV Sizing (MW)	Location PV (Bus)	Power Losses (MW)	Loss Reduction (%)
Without PV	-	-	0.3530	-
1 PV	2.5000	6	0.1756	50.25
2 PV	1.0765	30	0.1463	58.56
	0.9903	12		
3 PV	1.0487	30	0.1217	65.52
	0.7629	14		
	1.1083	24		
4 PV	2.5000	19	0.1576	55.35
	0.9593	2		
	0.9593	30		
	0.9593	10		

3.3 Optimal Solution with Multiple PV Units for IEEE 69-Bus System

The performance of PSO algorithm has been tested on the IEEE 69-bus system by using population size and maximum iteration of 30 and 50 respectively. The optimal results and power loss reduction obtained by PSO is

tubulated in Table 5. The placement of a single PV in the network contributes to a 63.02% of loss reduction with 0.0832 MW power loss and a minimum voltage of 0.968 p.u. Placing two PV gives 67.11% of loss reduction with 0.0745MW power losses. With 3 PV placements, the loss reduction is 69.16%, and 4 PV yields 67.67% power loss reduction with 0.075MW power losses. It shows that optimal size of 3 PV units obtained by PSO algorithm can provide significant power loss reduction to this distribution network.

Table 5 *Optimal PV sizing and location for IEEE 69-bus system with and without PV units*

Case	PV Sizing (MW)	Location PV (Bus)	Power Losses (MW)	Loss Reduction (%)
Without PV	-	-	0.225	-
1 PV	1.8728	61	0.0832	63.02
2 PV	0.8383	66	0.074	67.11
	1.7349	61		
3 PV	0.5149	11	0.0694	69.16
	0.3836	18		
	1.7324	61		
4 PV	2.5	28	0.075	66.67
	0.8622	12		
	2.5	47		
	1.6446	62		

3.4 Impact of PV Installation to the Voltage Profile on IEEE 33-Bus and 69-bus System

Voltage magnitude is a very crucial element in solving the optimal sizing and location of PV in the network. Therefore, the voltage should be improved when the PV is injected into the radial distribution system. The voltage magnitude must meet the acceptable limits to improve the system. Tables 6 and 7 show the minimum and maximum bus voltage with different cases for both test systems. The result clearly shows that installation of PV units can be improved the voltage magnitude with acceptable limits for both test systems.

Table 6 *Minimum and maximum bus voltage for various PV installations (IEEE 33-bus system)*

Case	Minimum Voltage (p.u)	Bus with minimum voltage	Maximum Voltage (p.u)	Bus with maximum voltage
Without PV	0.85	17,18	1	1
1 PV	0.92	17,18	1	1,2,19
2 PV	0.95	32,33	1	1,2,19
3 PV	0.94	32,33	1	1,2,19
4 PV	0.95	31,32,33	1	1,2,19

Table 7 *Minimum and maximum bus voltage for various PV installations (IEEE 69-bus system)*

Case	Minimum Voltage (p.u)	Bus with minimum voltage	Maximum Voltage (p.u)	Bus with maximum voltage
Without DG	0.90	64,65	1	1,2
1 DG	0.96	19-26	1	1,2
2 DG	0.97	64,65	1	1,2,3
3 DG	0.98	64,65	1	1,2,3
4 DG	0.98	64,65	1	1,2,3

Figure 2 and Figure 3 show the improved voltage profile of both test systems on each bus with and without installation of PV. It can be clearly seen that after the installation of PV, the voltage profile is improved within the

desired limits. The PV sizing and location is very suitable to solve the voltage profile problem for distribution network.

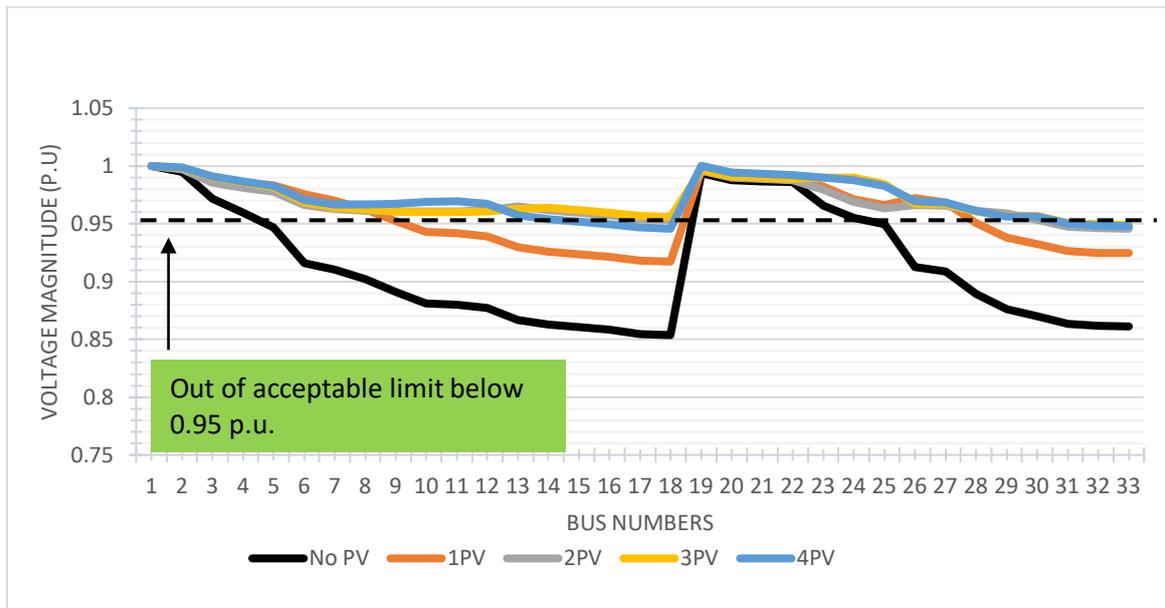


Fig. 2 Voltage magnitude versus bus number for IEEE 33-bus system

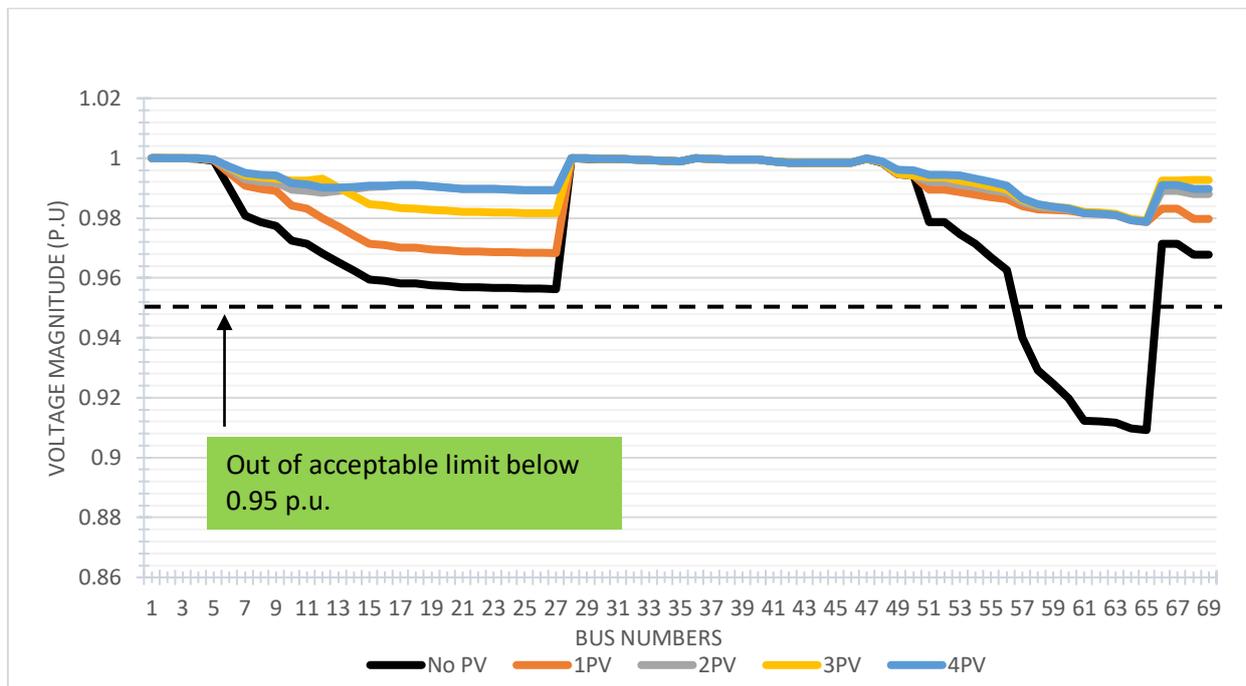


Fig. 3 Voltage magnitude versus bus number for IEEE 69-bus system

3.5 Convergence Characteristic of PSO Algorithm for IEEE 33-Bus and IEEE 69-Bus System

This section describes the convergence characteristic of the PSO for minimizing power losses after 50 iterations. Figures 4 and 5 show that the PSO algorithm can provide minimum power losses for all cases. It can highlight the effectiveness of the PSO for searching for the optimal solution in this problem.

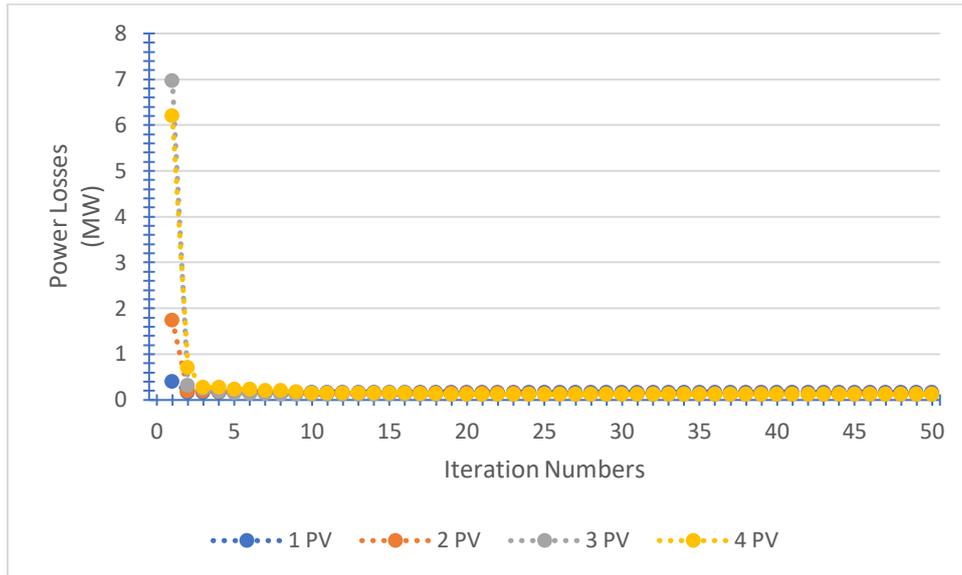


Fig. 4 Convergence characteristic of power losses against iteration number for IEEE 33-bus system

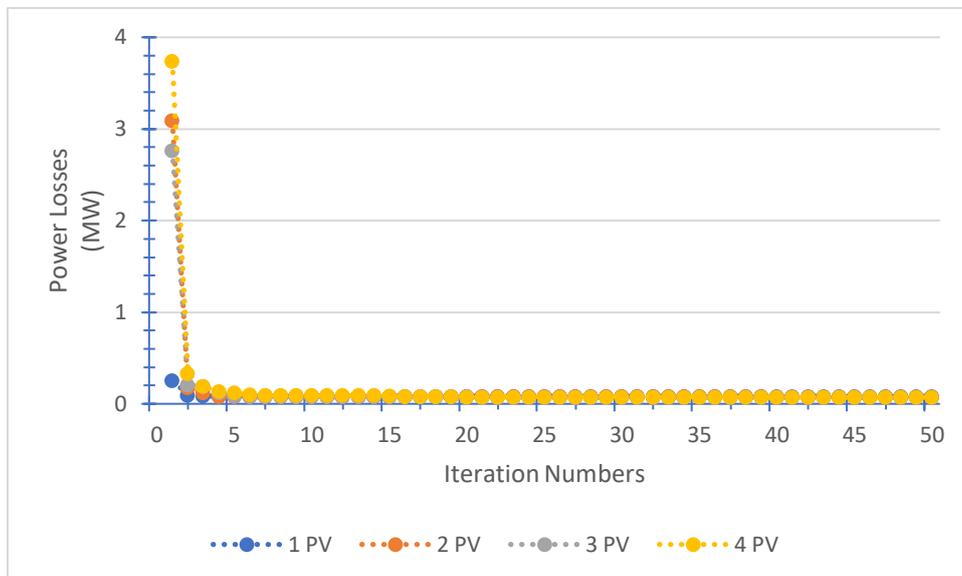


Fig. 5 Convergence characteristic of power losses against iteration number for IEEE 69-bus system

3.6 Optimal PV Sizing and Location Considering EV Charging Station (EVCS)

The main purpose of this study is to determine the location and sizing of PV when the total load increased approximately by 20% from total load to represent the EVCS in the system. The simulations are set from 1 EVCS to 4 EVCS with 3 and 4 PV units. Tables 8 and 9 present the effect of EVCS to power losses in the IEEE 33-bus and IEEE 69-bus distribution systems along with the optimal placement and sizing of PV units.

Table 8 shows the optimal sizing and location of PV considering the EVCS in the IEEE 33-bus system. In general, power losses will be increased when the EVCS or load demand is increased in the system. Therefore, the proposed sizing and placement of PV can significantly reduce the losses. From the Table, 4 PV units performed with lower losses compared to 3 PV units when considering additional EVCS loads. The optimal locations and sizes of PV vary depending on the EVCS load distribution.

Table 9 provides the simulation results and analysis for the IEEE 69-bus system. The higher losses due to increased EVCS loads at buses such as 25, 31, 45 and 61 can be effectively reduced through optimal placement and sizing of PV as presented in Table 9. The 4 PV units give lower power losses except in one case where EVCS at buses 25 & 31 where 3 PV is slightly better. When loads are increased at multiple buses, the PV locations and sizes adjust accordingly to achieve further power loss reduction.

Table 8 Optimal sizing and location PV when increasing 20% load for EVCS on IEEE 33-bus system

EVCS Bus Location and Sizing / 20% of Load increment	Losses without PV (MW)	Losses with PV (MW)	No. of PV	Location of PV (bus number)	PV Size (MW)
9 (0.744 MW each)	0.62942	0.18387	3	30,24,9	0.93533,1.0824,1.8624
		0.17276	4	15,30,24,9	0.58686,0.87443,1.0796,1.2737
9,22 (0.372 MW each)	0.48941	0.16689	3	30,24,9	0.94295,1.0533,1.4799
		0.1556	4	30,9,14,24	0.94452,0.89767,0.54569,1.0296
9,22,25 (0.248 MW each)	0.47299	0.16001	3	25,10,30	1.133,1.1795,1.0174
		0.14887	4	25,13,6,31	0.99942,0.82038,1.011,0.65834
9,22,25,28 (0.186 MW each)	0.50194	0.16773	3	25,29,12	1.0761,1.2522,1.0567
		0.15512	4	7,13,30,25	0.95339,0.70874,1.0015,0.88754

Table 9 Optimal location and sizing of PV when increasing 20% load for EVCS on IEEE 69-bus system

EVCS Bus Location and Sizing / 20% of Load increment	Losses without PV (MW)	Losses with PV (MW)	No. of PV	Location of PV (bus number)	PV Size (MW)
25 (0.76 MW each)	0.37418	0.11256	3	25,53,61	1.1429,0.66782,1.689
		0.11099	4	2,61,25,11	2.5,1.7276,1.0684,0.6894
25,31 (0.38 MW each)	0.28323	0.088133	3	25,61,69	0.68462,1.7502,0.41463
		0.088508	4	30,25,51,61	0.74852,0.74852,0.74852,1.6882
25,31,45 (0.253 MW each)	0.26342	0.084566	3	24,61,69	0.58198,1.7466,0.39303
		0.083802	4	61,11,62,25	1.2919,0.5715,0.3853,0.5715
25,31,45,61 (0.19 MW each)	0.3956	0.17069	3	41,15,61	1.0047,0.75895,2.0826
		0.16789	4	61,2,21,46	2.0623,2.5,0.68438,0.67696

Based on the simulation and analysis conducted on the test system, it can be clarified that the appropriate size and placement of PV in the distribution system will contribute to the minimization of power losses. The suitable number of PV in this IEEE 33-Bus test system is at 3 buses where power losses is 0.1217 MW and power losses reduction is 65.52% as compared to system without PV. However, installing 4 PV increases losses to 0.1576 MW which is higher than all other PV cases and achieves only 55.35 % reduction, confirming that 3 PV is optimal.

The suitable number of PV in this IEEE 69-Bus test system is 3 PV, minimizing power losses to 0.0694 MW with a loss reduction of 69.16%. In contrast, 4 PV raises losses to 0.075 MW which is higher than the 3 PV case with only 66.67% reduction, demonstrating that 4 PV degrades efficiency and is unsuitable for this system.

For the increasing 20% of total load for EVCS, the results show that using 4 PV generally reduces power losses better than using 3 PV. In my assumption and research [38], the IEEE 33-bus system, the PV units are usually placed at buses that are less sensitive to load changes. On the other hand, in the IEEE 69-bus system, the PV are placed at the more sensitive buses where load changes have a bigger impact [39]. Choosing the right buses for PV placement helps reduce power losses, which lowers the overall cost and keeps the voltage more stable across the network. In this analysis, reliability is also considered, with the goal of making the system more reliable while keeping losses and voltage problems as low as possible.

4. Conclusion

This research presents the application of PSO algorithm for finding optimal size and location of photovoltaic (PV) intallation in the distribution network. It was tested on the IEEE 33-bus and 69-bus systems. From the simulation and analysis, it can conclude that installation of PV to 3 buses can produce lower power losses. In IEEE 33-bus system, the power losses can be reduced to 65%. Moreover, power losses in IEEE 69-bus system can be decreased by 70% with 3 PV system installation in different buses. The study also found significant benefits in voltage profile and power loss reduction when comparing the system performance with and without PV installation. Proper PV integration of PV can ensure the voltage levels within the allowable range in both test systems. Additional load from the EVCS can contribute to the higher power losses in the distribution system. It found that the proper size and location of PV system is capable to reduce the power losses in the system. Therefore, proper coordination and placement of PV can play a significant role in addressing higher demand from the EVCS in the future.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Mohamad Nor Akhmal Mohd Najib, Mohd Noor Abdullah; **data collection:** Mohamad Nor Akhmal Mohd Najib; **analysis and interpretation of results:** Mohamad Nor Akhmal Mohd Najib, Mohd Noor Abdullah, Khairul Rijal Wagiman; **draft manuscript preparation:** Mohamad Nor Akhmal Mohd Najib, Mohd Noor Abdullah, Khairul Rijal Wagiman, Mochammad Junus. All authors reviewed the results and approved the final version of the manuscript.*

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