Optimal PV Sizing and Location Based on Volt – Var Control and UPFC Using Particle Swarm Optimization for Microgrid System

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Received June 10, 2024, Revised February 17, 2025, Accepted April 2, 2025, Published December 30, 2025

Abstract. *This research article details the creation and execution of a photovoltaic (PV) control system augmented with Volt-VAR (VAR) and Universal Power Flow Control (UPFC) to boost power system efficiency. The research examines the IEEE 13 bus test system, assessing four principal control strategies for effective power demand management: PV control, PV-VAR control, PV-UPFC control, and their amalgamation with Particle Swarm Optimization (PSO) for load forecasting. The PSO method is utilized to enhance load forecasting precision, facilitating accurate synchronization of PV generation with 24-hour power demand variations. The research examines the mechanisms of photovoltaic regulation, with the objective of optimizing photovoltaic resource usage and ensuring smooth integration with the electrical grid. The PV-VAR control system is examined to improve reactive power management, voltage stability, and grid resilience. The integration of photovoltaic systems with unified power flow controllers is examined to attain accurate control over power flow dynamics in the distribution network. The Open Distribution System Simulator (OpenDSS) is employed to assess electricity flow and examine grid performance under diverse load scenarios. Simulation findings illustrate the efficacy of the proposed technology, indicating a direct linkage between the photovoltaic system and the power grid optimized by particle swarm optimization. The ideal dimensions and location of the PV system were determined to be 100 kV at Bus 680, underscoring the system's capacity to conform to grid demands. This study offers essential insights into the obstacles and opportunities associated with the integration of photovoltaic systems into contemporary electricity grids. The research enhances the creation of sustainable, efficient, and resilient distribution networks in the renewable energy sector through comprehensive simulations and analysis.*

Keywords: photovoltaic; VAR and UPFC; sizing and location

1. Introduction

Solar photovoltaic (PV) technology, which is utilized globally to harvest energy from the sun for diverse applications, provides numerous advantages [1-2], such as abundant and cost-free energy sources that also possess an ecologically sustainable quality. Constantly discussed as a vulnerability and obstacle in PV system technologies that have been encountered during sizing and designing, the instability phenomenon known as potential-induced degradation (PID) and light-induced degradation (LID) in crystalline PV module technology has been a subject of concern. For its actual area act, this phenomenon may lead to ongoing technical risks regarding durability and dependability.

A technology called Volt-Var is used in power distribution systems to assist reduce power loss and improve system stability and performance by precisely adjusting the voltage and flow of electricity [3]. To sum up, Volt-Var played a significant role in controlling the power supply system to ensure stability and efficiency in applications with continuously fluctuating demands. The optimal approach for resolving Volt-Var issues is contingent upon several aspects, including the intricacy of the system, specific objectives, and limitations. Nevertheless, the following are a few efficacious methods that are frequently employed: Optimal Power Flow (OPF) is a mathematical optimization method employed to determine the most efficient operation of a power system. The process considers multiple variables, including generation, load demand, trans-mission constraints, and equipment limits, to identify the most efficient configurations for voltage and reactive power control devices. Integration of Distributed Energy Re-sources (DER): DERs, such as solar photovoltaic systems, wind turbines, and energy storage devices, can be integrated to effectively address Volt-Var concerns. They achieve this by offering localized reactive power supply and voltage management. Algorithms for optimizing the relationship between voltage and reactive power (Volt-Var Optimization) [4-6]. Optimization algorithms such as Particle Swarm Optimization (PSO) [7-8], Genetic Algorithms (GA) [9], and Gradient Descent [10] can be employed to iteratively modify Volt-Var settings to decrease losses, optimize voltage profiles, and improve system efficiency. By employing smart inverters and voltage regulation devices equipped with sophisticated control capabilities, voltage and reactive power can be efficiently managed at distribution system levels. These devices could promptly react to variations in system circumstances and ensure that the volt-age remains within acceptable parameters. Advanced Distribution Management Systems (ADMS) are sophisticated software systems that are used to efficiently manage and control the distribution of electricity. The ADMS system combines different features including SCADA, outage management, distribution management, and Volt-Var control to offer real-time monitoring, analysis, and control of distribution networks. It allows utilities to adjust Volt-Var settings using up-to-date data and predictive analytics. Reactive power compensation involves the installation of capacitor banks and other devices at certain points in the distribution network to enhance voltage regulation and minimize losses. By dividing the distribution network into voltage control zones and using distinct Volt-Var control algorithms tailored to the specific features of each zone, it is possible to enhance voltage regulation and effectively manage reactive power. In the end, the most effective strategy typically involves utilizing a blend of these methods that are customized to meet the specific needs and attributes of the distribution system in consideration. Furthermore, it is crucial to engage in ongoing monitoring, analysis, and optimization to sustain optimal Volt-Var management over an extended period.

PSO has been used extensively in research relevant to the development of microgrid systems. The researchers [11] proposed SSPSO, which has the accuracy and performance of tracking virtually the GMPP, is applied and compared to other algorithms. To match the suggested model with the system's output, the impedance is adjusted using a DC-DC buck boost converter. When the same PV shaded patterns are used with other conventional algorithms, the simulation results demonstrate that, in comparison to the currently used selected techniques, the novel hybrid SSPSO can track the GMPP quickly, efficiently, and with a high quality of tracked power. The average tracking efficiency presented by the suggested SSPSO is 99.99%. In [12] takes a different approach from most others, focusing on the Volt/VAR optimization (VVO) variant of the OPF problem formulated in rectangular voltage coordinates. Most studies utilize the polar coordinate formulation. A comparative analysis of the relative performance of the two algorithms for this problem is offered. The VVO problem is solved using the heuristic particle swarm optimization (PSO) and the traditional primal-dual interior-point method (PDIPM). Presents are four case studies based on the IEEE 14-bus, 30-bus, 118-bus, and 6-bus test systems. Based on the quality of the solution and computational efficiency, the comparative performance analysis shows that the two methods have complementary strengths. It might not make sense to solve the optimization problem for maximum line peak power loss reduction in [13]. In this case, it would be more suitable to minimize the total line power losses throughout the course of the day, or line energy loss. To rate the line energy loss reduction while considering a single time interval—the Feasible Optimization Interval (FOI)—a suitable derivation has been established. Therefore, by considering solely the FOI, the optimization process can be solved for maximum line energy-based benefits. These saves having to perform the computations for every time interval across the complete amount of time. The Abu Dhabi Distribution network's two 11kV feeders have successfully used the technique. A PSO-based optimization strategy for distributed generation (DG) sizing and placement was presented in [14]. The goal of the best possible DG unit installation and capacity estimation is to increase bus voltage and minimize active power loss in the system. On an 85-bus network, the technique that is highlighted is applied. In the MATLAB environment, programs are created for the radial distribution system's load flow. Utilizing the Forward and Backward Sweep (FBS) approach, the PSO-based optimization method is put into practice. Among all AI-based optimization techniques, PSO-based optimization is well-known for being highly popular since it requires very little processing effort while producing incredibly precise results. Consequently, the suggested study project encourages the use of this method for maximum capacity. Particle swarm optimization (PSO) is used in [15] to analyze a case study and find the best position and size of solar installations in electric distribution networks to maximize network voltage profile and minimize losses. Masirah Island, Oman's distribution network is regarded as a case study system. The MATLAB load flow toolbox is used to simulate and model the test system. The best place for solar photovoltaic (SPV) units within a microgrid has been proposed by [16] using particle swarm optimization (PSO).

Considering various distribution network restrictions, PSO has been used to reduce the power losses of radial networks. This research proposes a new average overall voltage stability index that may be used to measure the voltage stability levels of buses in a microgrid. To compute solar radiation, the beta probability distribution function was employed. Microgrid systems with 33 and 69 buses have been used to test the suggested method. The RDGs' average overall voltage stability index and voltage profile have both improved. The recommended PSO technique has been validated by comparing its findings with those of other widely used algorithms. A methodology for optimization is presented in [17] to determine the appropriate placement and dimensions of distributed generation units in a local distribution network. An approach called particle swarm optimization is used to carry out the optimization. The findings demonstrate the significance of choosing the DG units' placement and size to improve the local radial distribution system's voltage stability computer programs. Grey Wolf Optimizer (GWO) and Particle Swarm Optimizer (PSO), two meta-heuristic-based algorithms, are presented in [18] to tackle the network reconfiguration problem in the presence of deploying multiple renewable Distributed Generators (DGs). To reduce the actual power loss, these algorithms are implemented on the IEEE 33-bus. The findings unmistakably show that the voltage profile has improved, and that real power loss and reactive power loss have significantly decreased. The PV farm's location and sizing are optimized by Particle Swarm Optimization (PSO) in [19], which also increases the overall reliability of the system by lowering losses and voltage drop. The findings show that optimum placement and sizing of PV installations can lower losses and voltage drop while boosting system reliability.

We present volt-var and universal power flow control methods for photovoltaic (PV) systems in microgrid systems in this research. This will assist in ensuring smooth integration and optimal efficiency by considering variables like probability, system size, and geographic location. Reducing active power and reactive power losses is essential for increasing the system's overall stability and efficiency. This can be achieved by integrating controls into the system. These controls are essential for maximizing system performance, ensuring dependable operation, and reducing inefficiency since they govern power flow intelligently. In addition, the integration of control strategies safeguards the stability of the power system, averting disruptions and guaranteeing smooth, uninterrupted power transfer across the network.

This research examines the incorporation of photovoltaic systems into a microgrid, emphasizing the appropriate positioning and scale of photovoltaic modules. The research utilizes volt-var control methods to regulate voltage and reactive power, alongside Unified Power Flow Controllers (UPFC) to improve system stability and efficiency. We employ the Particle Swarm Optimization (PSO) technique to identify the ideal configuration, ensuring the microgrid functions with low losses, improved voltage profiles, and superior power quality. This method effectively tackles the intricate power flow issues in microgrids while enhancing sustainability via the incorporation of renewable energy.

2. Methodology

The main objective of the current research was the development of volt-var and universal power flow control techniques for photovoltaic (PV) systems in microgrid systems. In order to guarantee that the appropriate amount of electricity is injected into the grid, the procedure requires the fulfillment of particular processes under PV conditions. The mechanisms in question were developed using optimal sizing and location determined by particle swarm optimization. Solar energy systems have drawn substantial attention in academic and research communities due to their renewable energy characteristics and savings that generate electricity. The growing consumption of electrical energy in various industries has a significant impact, necessitating a comprehensive investigation, analysis, and resolution of issues related to the flow of power throughout the system. Efficient energy management is essential for supervising both the system’s and the energy source's operations. Renewable energy sources that produce direct current (DC) are crucial in their impact on connecting to the power grid. The integration of renewable energy sources into power systems has a significant impact on electricity consumption. We have examined the power system's components to determine how they affect stability and frequency, among other things. In keeping with the objective of investigating the control of renewable energy sources in grid connections, the control of the power system increases the stability of electricity demand management. It is important to provide background information on microgrid systems, photovoltaic technologies, and the significance of volt-var and UPFC controls. The exact focus of your study should be introduced, with an emphasis placed on its uniqueness and significance within the discipline. The installation of the microgrid system is depicted in Figure 1, which includes a photovoltaic two condition, first volt-var control, and UPFC control.

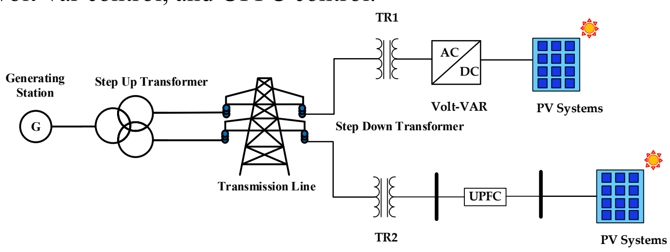

Figure 1. The concept of volt-var and UPFC controls in microgrids.

The microgrid opted to utilize research conducted on the IEEE 13 bus standard technology. The system consists of several components, including the main generator, main transformer, voltage regulator, transmission line, transformer, capacitor, and load. The microgrid made a strategic decision to use the knowledge gained from previous study on the IEEE 13 bus standard technology, which is a widely recognized framework in the area. This decision was based on the insights obtained from Figure 2. This technology offers a strong basis for the design and implementation of the microgrid, guaranteeing compatibility, reliability, and efficiency. Within this structure, the microgrid has many crucial components, each of which has a significant impact on its operation and effectiveness. The components consist of the main generator, which acts as the principal source of electrical power generation; the main transformer for voltage conversion and distribution; and the voltage regulator for ensuring system stability. In addition, the microgrid includes crucial components such as transmission lines to facilitate efficient power transfer, transformers to regulate voltage, capacitors to correct power factor, and loads that represent the different electrical customers in the system. These interrelated parts create a unified network that allows the microgrid to efficiently control its energy resources and fulfil the needs of those who use it.

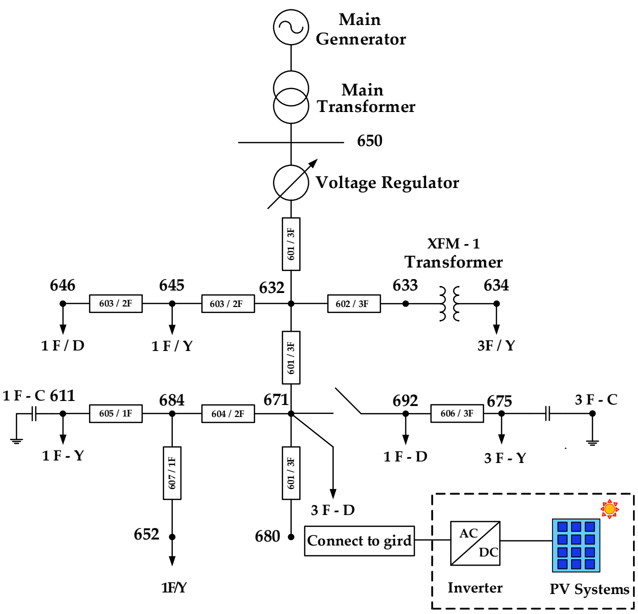

Figure 2 . The IEEE 13 bus installs PV systems.

3. Problem Formulation

The main objective of this study is to improve the efficiency of active power losses, reactive power losses, voltage profiles, and cost savings. Additionally, it aims to boost the overall performance and dependability of the power system. The research aims to optimize the system's operation, minimize waste, and maximize resource utilization by addressing these critical aspects. This will contribute to sustainable energy practices. Furthermore, to ensure that the intended results are achieved, the study implements rigorous limitations on both the lowest and highest magnitudes of voltage, as well as restraints on power balance. These limitations are crucial safeguards that prohibit any deviations from the desired solution and provide system stability even when operational conditions change. The study aims to create a thorough and strong framework for dealing with the difficulties involved in optimizing and managing power systems using these approaches.

3.1 Particle Swarm Optimization (PSO)

Begin by introducing Particle Swarm Optimization as a popular metaheuristic optimization algorithm inspired by the social behavior of birds or fish. Explain its effectiveness in solving optimization problems across various domains. Describe the basic concept of PSO, which involves simulating the behavior of a swarm of particles moving through a multidimensional search space to find the optimal solution. High-light the key components of PSO, including particles, positions, velocities, and fitness evaluation.

Algorithm Description:

Provide a step-by-step explanation of the PSO algorithm:

Initialization:

Define the population size (number of particles), dimensionality of the search space, and initialize particle positions and velocities randomly within specified bounds.

Initialize personal best positions (p_{best}) for each particle based on its current position and evaluate the fitness of each particle.

Iterative Optimization:

Iterate through a predefined number of generations or until convergence criteria are met.

Update the velocity and position of each particle according to its current velocity, personal best position, and global best position (g_{best}) found by the swarm.

Evaluate the fitness of each particle's new position and update personal best positions if necessary.

Update the global best position based on the best fitness value found by any particle in the swarm.

Termination:

Terminate the algorithm when a specified convergence criterion is satisfied, such as reaching a maximum number of iterations or achieving a satisfactory solution.

PSO Equation:

Present the mathematical formulation of the PSO algorithm. The update equations for the velocity and position of each particle are typically represented as follows:

Velocity update equation:

$$\begin{aligned} v_{i,d}\left(t+1\right) &= w \cdot v_{i,d}(t) + c_1 \cdot r_1 \cdot (pbest_{i,d} - x_{i,d}(t)) \\ &+ c_2 \cdot r_2 (gbest_d - x_{i,d}(t)) \end{aligned} \tag{1}$$

Position update equation:

$$x_{i,d}\left(t+1\right) = x_{i,d}(t) + v_{i,d}(t+1) \tag{2}$$

Where:

$v_{i,d}(t)$ is the velocity of particle i in dimension d at time t.

$x_{i,d}(t)$ is the velocity of particle i in dimension d at time t.

w is the inertia weight.

c_1 and c_2 are acceleration coefficients.

r_1 and r_2 are random numbers between 0 and 1.

$pbest_{i,d}$ is the personal best position of particle in dimension d.

$gbest_d$ is the global best position found by the swarm in dimension d.

3.2 Volt-Var Control

Operational calculations of power flow, transformers, transmission lines, and demand loads in systems use power flow control techniques to identify problems with daily load profiles. The factors in the power system have an impact on the stability of voltage magnitudes through changes in voltage-ampere conditions. We also used PV system compensation. Furthermore, we employed PV system compensation for power flow analysis (PFA) to determine the power transfer from the grid, thereby augmenting the source power. The electrical grid uses volt-var to regulate the reactive power supply. By increasing the photovoltaic (PV) source, which makes power in the system, above the calculated voltage level, the power flow analysis (PFA) checks the health of the power system using the volt-var. This helps reduce power consumption and mod-ern load can be in Equation (3) as follows [20]:

$$I_{inj}(v) = Y_{system} V \tag{3}$$

Where $I_{inj}(v)$ the current injection of the power conversion component, V is the system voltage, Y is apparent power.

The voltage bus can be presented in an Equation (4) as:

$$V_{n+1} = \left[Y_{system} \right]^{-1_{inj(v_n)}}{}_{n \in 0,1,2,....untilconverged} \tag{4}$$

The power system impact is determined by the voltage magnitude level of injecting reactive power into the grid. Typically, the voltage magnitude of the grid is modified throughout the synchronizing process, which is a limitation. Thus, the control of voltage and reactive power in the power converter is referred to as the control of volt/var. Figure 3 illustrates the volt/var approach as shown in references [21,23,24].

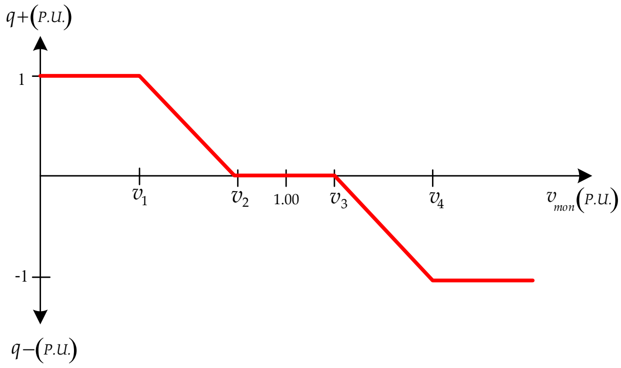

Figure 3. The voltage magnitude control is based on the Volt/var control scheme in p.u. [3]

Applying the monitored voltage to the volt/var curve determines the volt/var function for controlling the PV system's inverter $v_{mon}[t]_j$. where compute the per-unit value of the required reactive power (DRC) using Equation (5).

$$q_{Dfun}\left[t\right]_j = f_{vv}\left(v_{mon}\left[t\right]_j\right) q_{Dfun}\left[t\right]_j = \begin{cases} -\Delta v_{mon_{drc}}\left[t\right]_j \times ArGraLowV \; if \; v_{mon_{drc}}\left[t\right]_j < DbvMin \\ -\Delta v_{mon_{drc}}\left[t\right]_j \times ArGraLowV \; if \; v_{mon_{drc}}\left[t\right]_j > DbvMin \\ 0, \; otherwise \end{cases} \tag{5}$$

Where $q_{Dfun}\left[t\right]_j$ is the property to obtain the desired reactive power value in pu. The DRC function is applied for smart inverter setting power value, according to Equation (6).

$$q_{Dfun}\left[t\right]_j = \begin{cases} -\Delta v_{mon_{drc}}\left[t\right]_j \times ArGraLowV \; if \; v_{mon_{drc}}\left[t\right]_j < DbvMin \\ -\Delta v_{mon_{drc}}\left[t\right]_j \times ArGraLowV \; if \; v_{mon_{drc}}\left[t\right]_j > DbvMin \\ 0, \; otherwise \end{cases} \tag{6}$$

Equation (7) is the voltage difference calculated according to the show.

$$\Delta v_{mon_{drc}}\left[t\right]_j = v_{mon_{drc}}\left[t\right]_j - v_{window_{drc}}\left[t\right]_j \tag{7}$$

Where $v_{window_{drc}}$ is the DRC function corresponds to the average voltage that is calculated to capable of storing the voltage of previous time steps.

The $Dyn\,\mathrm{Re}\,acavgwindowlen$ property is set the length of time scale.

$$v_{window_{drc}}\left[t\right]_j = \frac{1}{m} \times \sum_{k=1}^{m} v_{mon_{drc}}\left[t-k\right]_j \tag{8}$$

The DRC function combined volt/var desired reactive power is the sum to result in Equation (9)

$$q_{Dfun}\left[t\right]_j = f_{vv}(v_{mon}[t]_j + \begin{cases} -\Delta v_{mon_{drc}}\left[t\right]_j \times ArGraLowV \; if \; v_{mon_{drc}}\left[t\right]_j < DbvMin \\ -\Delta v_{mon_{drc}}\left[t\right]_j \times ArGraLowV \; if \; v_{mon_{drc}}\left[t\right]_j > DbvMin \\ 0, \; otherwise \end{cases} \tag{9}$$

3.3 The Universal Power Flow (UPFC) Control

The universal power flow controller (UPFC) [24-28] is used to represent the equivalent circuit of the distribution system (DS) in the model created for the open electric distribution system (OpenDSS)[29]. UPFC systems utilize the DS to regulate voltage by directing reactive power towards achieving the target power factor (PF). However, we have relocated the current version of UPFC to the control queue in OpenDSS, the circuit model's model. This change has resulted in increased stability and accuracy. Figure 4 [21] displays the uncomplicated configuration of the UPFC model. The OpenDSS model has implemented the UPFC application on distribution systems. The objective of the UPFC is to regulate the voltage and compensate for reactive power in the system.

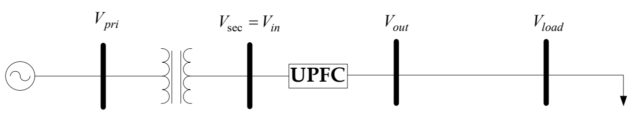

Figure 4. The simple circuit of UPFC model.

The equivalent circuit for UPFC can mathematically consider the power flow problem using the Thevenin series voltage source. The parameters are the series impedance X_s and shunt current source. I_s shows in Figure 5 [15], where X_s is the impedance of transformer in the UPFC. The current source calculation is given by Equations (10).

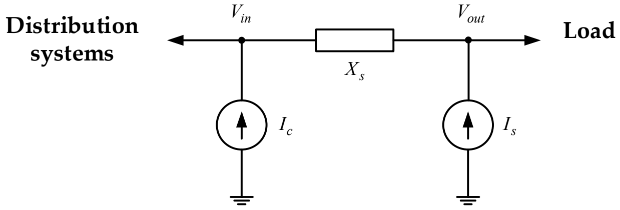

Figure 5 The internal circuit of the UPFC model.

$$I_s = \frac{V_{diff} - (V_{out} - V_{in})}{jX_s} + I_s\left[z-1\right] \tag{10}$$

Where V_{diff} is calculated according to the shown in Equation.

$$V_{diff} = (V_{ref} - \left|V_{in}\right| e^{j\theta_{vin}} \tag{11}$$

$$I_c = \frac{V_{out}}{I_s \times V_{in}} \tag{12}$$

$$I_c = -(real(I_c) \times Losses + imag(I_s)) \tag{13}$$

Where $I_s\left[z-1\right]$ is shift register containing the value of the current source I_s calculated in the previous power flow solution iteration. I_c is the value of the current source. V_{in} is the voltage input for the internal circuit of the UPFC model. V_{out} is the voltage output for the internal circuit of the UPFC model.

3.4 Proposed Methodology

The proposed methodology in Matlab is implemented utilizing the COM interface in a co-simulation environment with OpenDSS. List the microgrid's parts, which should include photovoltaic systems, Volt-Var control, unified power flow controllers, and other important parts like loads and power sources. Utilize the IEEE 13 bus standard to model the electrical network for simulating the microgrid system architecture, encompassing power lines, transformers, and loads. Develop target functions to reduce power losses in the microgrid, enhance voltage stability throughout the system, and optimize reactive power support via UPFC and Volt-Var management techniques.

The test results are displayed in this section. The initial analysis focused on four situations that employed a deterministic curve to represent the load demand and photovoltaic (PV) generation. The DG production profile is a continuous and standardized curve representing the output of a photovoltaic (PV) plant. This curve is derived from the available examples in EPRI (2020). This work assumes that all DG units have identical profiles, except for scenarios with firm generation, when the DG is expected to have a consistent level of power production. Moreover, in every instance, the identical load demand profile is considered for all system loads. The case system utilized to evaluate the proposed technique consists of unbalanced IEEE distribution test feeders comprising 13 bus. The fitness function to be minimized using Particle Swarm Optimization (PSO) is computed for each power flow solution acquired using OpenDSS as shown in Figure 7.

The PV optimal sizing and location in IEEE 13 bus steps run power flow on the OpenDSS programming COM interface Matlab using the 4 cases shown in Figure 6 follows:

Case 1: IEEE 13 bus test system design PV, not control condition PSO.
Case 2: IEEE 13 bus test system design PV, volt-var control condition PSO.
Case 3: IEEE 13 bus test system design PV, UPFC control condition PSO.
Case 4: IEEE 13 bus test system design PV, volt-var and UPFC control condition PSO.

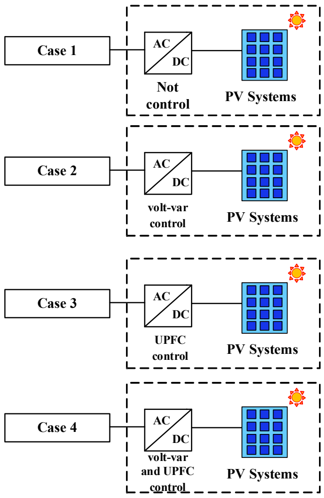

Figure 6 Algorithm PSO PV sizing and location case.

The initial condition location bus is 670, 671, 633, 680, 675, and 692 for the three-phase balance bus. The initial condition sizing of PV is a maximum of 100 kV, a maximum p.u. of 1.05, and a minimum p.u. of 0.95. The parameters for configuration of PSO optimization techniques shown in the Table 1.

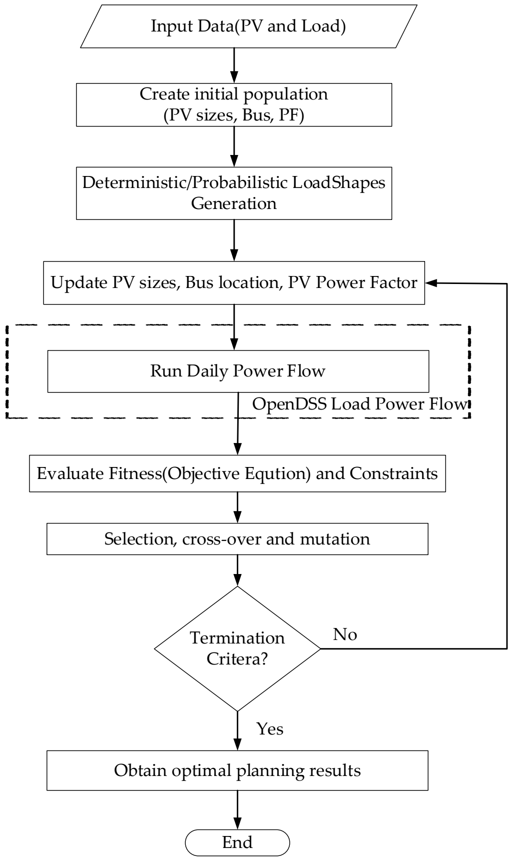

Figure 7 Algorithm PSO PV sizing and location chart.

Table 1 The parameters of PSO

Parameters	PSO
Population size	100
Generation/Iteration	200
Number of Variables	2
Inertia coefficient	1
Damping factor	0.80
c_1, c_2	0.775,1.40
Max. and Min. of PV location	6
Max. and Min. of PV sizing(kV)	1-100 kV

4. Simulation and Results

This article discusses the most efficient determination of the size and placement of the electrical grid using OpenDSS and the Particle Swarm Optimization (PSO) algorithm in the IEEE 13 bus test system. The comparison was categorized into four cases: the base case, PV, PV-VAR, PV-UPFC, and PV-VAR-UPFC. An analysis of the ideal condition of the PV system was conducted using the voltage magnitude level and the total energy loss as important variables. The study proved the best optimal sizes and location for the PV system. In the base scenario, the actual power output of the PV system was 2.4109 MW, while the power outputs for PV, PV-VAR, PV-UPFC, and PV-VAR-UPFC were 2.4087 MW, 2.4084 MW, 2.4087 MW, and 2.4084 MW, respectively. Table 2 presents the data comparisons for each scenario type for the power flow simulation using PSO process, including the available findings for maximum per unit voltage, minimum per unit voltage, total active power, total reactive power, total active losses, and Table 3 percentage compared to the base case.

When the result was a variation in the maximum per unit voltage, the PV system underwent modifications in both its dimensions and position. However, the installation of PV systems can lead to a daily load profile that decreases the need for energy between 8:00 a.m. and 4:00 p.m. During this time, the PV systems generate energy to meet the demand and compensate for any energy losses. When the PV system is connected to the electrical grid, it could decrease the amount of power that needs to be supplied by the main power source. Here, the PV placement shifted along with the PSO in the grid, and the most efficient PV was found at Bus 680, with a capacity of 100 kV. Figures 8 and 9 depict a comparison between active power and reactive power. The disparity in active power may have been caused by the introduction of transmission line joint reflection effects, which led to an increase in resonance peak power. This task was a simulation. We devised the method and conducted a comparative analysis with the standard system. The optimal location and dimensions of photovoltaic systems, together with the integration of VAR correction and UPFC, enhance the overall performance and reliability of the power system. The findings validate that the suggested approach enhances system resilience and reliability.

Table 2 Results for PV

Result data	Base case	PV	PV-VAR	PV-UPFC	PV-VAR-UPFC
1. Max p.u. voltage	1.0545	1.0588	1.0555	1.0588	1.0555
2. Min p.u. voltage	0.9973	0.9905	0.9936	0.9905	0.9936
3. Total Active Power (MW)	2.4109	2.4087	2.4084	2.4087	2.4084
4. Total Reactive Power (Mvar)	0.8556	0.8815	0.7670	0.8815	0.7670
5. Total Active Losses (MW)	0.0526	0.0530	0.0523	0.0530	0.0523
6. Total Reactive Losses (Mvar)	0.1215	0.1452	0.1432	0.1452	0.1432

Table 3 Results for percentage compared to the base case PV

Result data	Base case	PV%	PV-VAR%	PV-UPFC %	PV-VAR-UPFC%
1. Max p.u. voltage		0.41	0.09	0.09	0.09
2. Min p.u. voltage		-0.67	-0.36	-0.36	-0.36
3. Total Active Power (MW)		-0.09	-0.10	-0.10	-0.10
4. Total Reactive Power (Mvar)		3.04	-10.35	-10.35	-10.35
5. Total Active Losses (MW)		0.92	-0.54	-0.55	-0.55
6. Total Reactive Losses (Mvar)		19.57	17.91	17.90	17.90

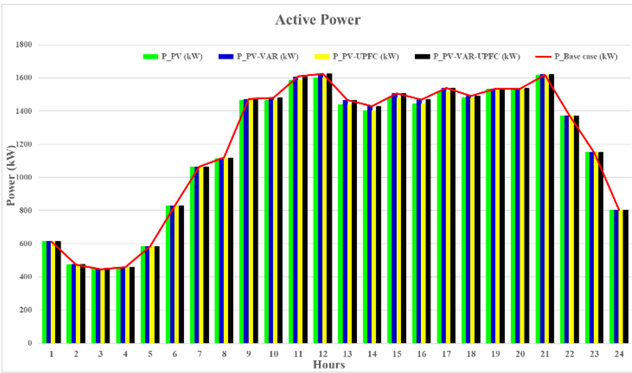

Figure 8. Comparisons of active power.

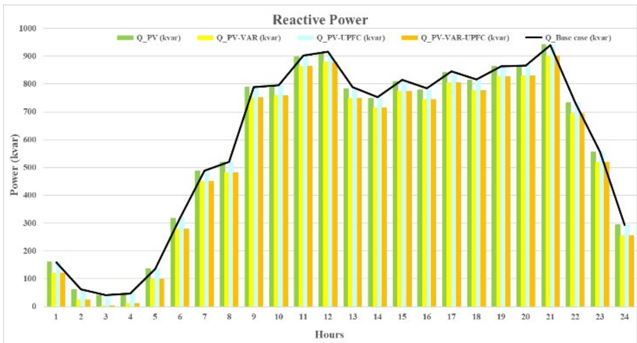

Figure 9 . Comparisons of reactive power.

5. Conclusions

This paper successfully tackled the challenge of meeting daily load demand through a meticulous optimization process focusing on both the dimensions and placement of the PV system. Photovoltaic technology, abbreviated as PV, harnesses sunlight to generate electricity, offering a sustainable and renewable energy solution. Leveraging this technology, we integrated the PV system into the electrical grid infrastructure to supplement power during periods of solar depletion. Our primary aim was to deploy the PV system for commercial loads, necessitating a thorough examination of optimal placement and sizing considerations. By employing Particle Swarm Optimization (PSO) and OpenDSS simulation tools, we were able to navigate the complexities of this task and achieve our objectives effectively. Furthermore, we established the optimal timing for PV penetration into the grid, considering factors such as probability, system size, and geographical location to ensure seamless integration and maximum efficiency. Integrating controls into the system is vital for reducing both active power and reactive power losses, which in turn improves the overall efficiency and stability of the system. Through smart power flow management, these controls play a crucial role in optimizing system performance, guaranteeing dependable operation, and minimizing inefficiency. Furthermore, the incorporation of control methods serves to protect power system stability, so preventing interruptions and ensuring seamless, continuous power transmission across the grid.

There have been substantial decreases in both active and reactive power losses. The voltage profiles and system stability have been markedly improved. The system has realized cost savings by minimizing energy losses and enhancing the integration of the photovoltaic system. The overall performance and reliability of the power system have been improved.

Future studies could prioritize researching the impacts of integrating PV systems with the inclusion of a battery energy storage system (BESS). Furthermore, it would be beneficial to investigate the progress of photovoltaic (PV) and battery energy storage systems (BESS). In conclusion, further endeavors should prioritize the resolution of the ambiguity surrounding load needs.

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