International Journal of Innovation in Computer Science and Information Technology
Vol.5, NO.1 , P: 72-79
Received: 21 August 2024
Accepted: 15 February 2025

Influence of Photovoltaic Wheeling Systems on Low Voltage Distribution Feeders in Electrical power system

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Abstract

Renewable energy generation (REG) is a crucial topic for researchers, policymakers, and governments to address global warming issues. Nowadays, distributed photovoltaic (DPV) systems are used to reduce losses in low-voltage distribution utilities and stabilize the voltage across all buses. An important aspect of this research is the allocation of these panels. In order to achieve optimal results, this paper simulates and analyzes algorithms to identify the best locations in low-voltage feeders and the impact of this penetration on harmonics, reactive power, and voltage profiles. In some cases, such as with long feeders or heavy loads like arc furnaces and large motors, simple allocation may not work ideally. Therefore, it is necessary to use static var compensators (SVC) or distributed or centralized capacitor banks. However, due to the cost of capacitor banks, it is advisable to use an automatic voltage regulator (AVR) to reduce losses and maintain voltage stability. In certain situations, conservation voltage reduction (CVR) can decrease power flows in distribution lines, freeing up capacity. Finally, the system is modeled and studied using CYME software with the Isfahan database.

Keywords: Pv systems, distribiution, CYME, dpv, drg

Introduction

In contemporary countries, one of the most pressing challenges is the escalating air pollution resulting from the burning of fossil fuels in electricity generation plants. Furthermore, enhancing the interconnection among thermal, hydro, and biogas power units is essential for ensuring a stable power supply and effective voltage regulation [1]. Distributed renewable generation is an effective option for reducing air pollution while also aiding in power and voltage control. Renewable energy represents the energy of the future and can be produced at a low cost. Conversely, when power generation is insufficient, it indicates governmental weakness, which can reflect a nation's overall vulnerability [1-3]. Distributed generation refers to a network of small generators connected to the distribution grid, situated near the demand. Daily load curves can exhibit peak clipping due to the use of distributed generators (DG) and distributed renewable generators (DRG) [1]. Several studies have identified various issues, including harmonic pollution, reactive power control, power quality problems, voltage deviations, reverse power flow, and protection challenges [4].

Distributed Renewable Generation (DRG)

To comprehend what distributed renewable generation (DRG) entails, it is essential to compare it with centralized systems. The table below illustrates that, in certain instances, DRG can meet demand at a lower cost.

Table 1- Comparison of DRG and Centralized Systems [1]

Item	Centralized PV	DPV
Visibility	√	×
siting	many acres	few acres
Sizing	MW	kW
Controllable	√	×
Performance aligned to power system	√	×
Funding	Government	Company
Location per operator	1	hundreds or more
Maintenance	frequently	rarely

DRG adheres to superior standards, regulations, and net metering policies, along with providing good inverter inertia. One of the simplest methods to manage excess photovoltaic (PV) power is through grid injection [1].
When power production exceeds consumption, the surplus energy is fed back into the grid. Certain loads, such as electric vehicles and water heating systems, offer advantages for PV systems. These loads are particularly beneficial for load management due to their favorable operational characteristics[4-6].

Performance Indices

In the context of electrical power systems, the utilization of indices is crucial for optimizing algorithms used in various case studies. These indices serve as key performance indicators that guide the adjustment of formulas to achieve improved results across different scenarios. For instance, maintaining the voltage within the range of 0.9 to 1.1 per unit (pu) is essential for the stable operation of electrical systems. When voltage levels deviate from this specified range, it may indicate an overload condition, a fault in the transmission line, or a reduction in demand on the utility feeder.One significant factor contributing to voltage instability is the operation of

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motors. Motors can lead to undervoltage conditions when they experience overshooting or draw excessive current, which in turn causes overheating. This overheating can damage the motors and negatively impact their performance. Therefore, monitoring and managing these indices is vital to identify the optimal locations for distributed photovoltaic (DPV) systems, ensuring that they provide maximum benefits to the overall power network. A critical threshold to consider is when voltage levels exceed the acceptable range for more than one minute. Such overvoltage conditions can arise from various factors, including the reactive power generated during the switching of capacitor banks or the integration of solar panels into the grid. Additionally, poor voltage regulation capabilities within the system or inadequate control measures can exacerbate these issues. When overvoltage conditions persist, they can lead to severe consequences, such as causing motors to enter saturation, which compromises their efficiency and functionality. Furthermore, these conditions may trigger circuit breakers to trip, disrupting the power supply and potentially causing widespread outages. In summary, the careful monitoring and management of voltage indices are essential for maintaining the stability and reliability of electrical systems. By ensuring that voltage levels remain within the optimal range, utilities can prevent overloads, minimize faults, and enhance the overall performance of distributed renewable energy sources. This proactive approach not only improves the efficiency of the power system but also contributes to the seamless integration of renewable energy technologies, ultimately supporting a more sustainable energy future [3].

Line Drop Compensator (LDC)

For voltage stability in feeder, the voltage must be ($v_{pu} \pm 5\%$) and ($f_{pu} \pm 0.1hz$) and distribution level ($v_{thd_{pu}} < 5\%$) to optimize the voltage profile and have flat voltage. In some cases, the conservation voltage reduction (cvr) can decrease the power in feeder to free up the feeder capacity for transmitting power.

A. Automatic voltage regulator

In utility, regulators can change the end users voltage. That means it could control the power factor of the utility and change the reactive power control. Utilities are required to maintain voltage levels within ±5% of nominal values at customer services using an integrated Volt Var Compensator (IVVC)[1].

B. Power factor correction

Capacitor banks uses for reactive power control or some harmonics pollutions. Capacitor banks has 1%-4% loss reduction in different scenarios. Utilities reduce losses by optimizing the power factor with integrated volt var control (IVVC). Since IVVC reduces the current to the load, thus reduces ($I2R$) losses. When the capacitors are on the side of the meters, customers can often avoid power factor penalties ranging from ($5\% - 12\%$) of the bill. Other forms of power factor correction include static var compensator (STATCOM) for huge dynamic loads like arc furnaces in a steel mill. All control equipment required to regulate the voltage to acceptable levels can be manually adjusted. However, most are automatically adjusted as part of an overall utility strategy through supervisory control and data acquisition system (SCADA).

System Under Study

In the system under investigation, the voltage level is set at 0.4 kV, and a transformer has been branched off from the main distribution line. The total length of the feeder is 1008 meters, which has been utilized for the integration of photovoltaic (PV) panels. This setup is significant as it highlights the role of distributed generation in enhancing the efficiency and sustainability of the electrical network.

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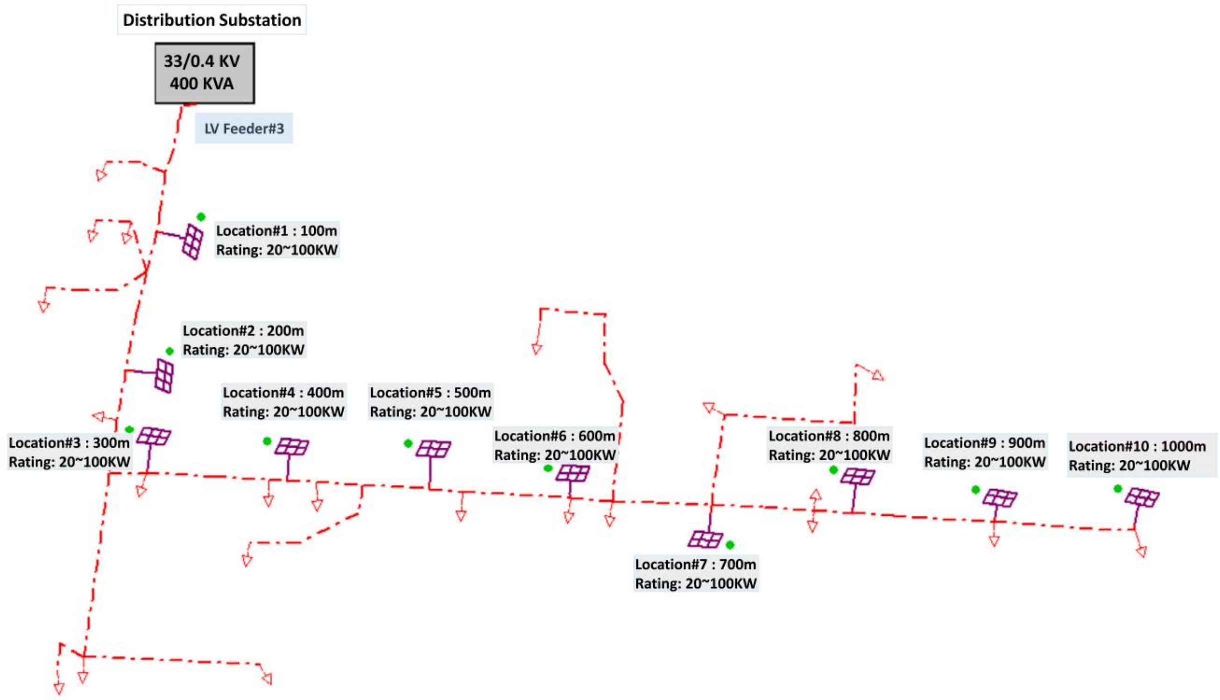

Figure (1) system under study[1]

In the current electrical distribution system, the majority of the loads are concentrated in the middle of the transformer branch-off, referred to as Zone 2. This positioning of the loads is significant when analyzing voltage stability and distribution efficiency within the network. It is observed that if there is an increase in load demand in Zone 1 while the load in Zone 2 decreases—yet the total demand remains consistent—the voltage at the transformer will experience an increase. This phenomenon is contrary to what many might expect; rather than a drop in voltage due to high demand, the voltage can actually rise when the load distribution shifts disproportionately. This increase in voltage can be attributed to the way electrical systems distribute power. When Zone 1 sees a rise in demand, the transformer compensates by redistributing power according to the changes in load characteristics. However, if the loads in Zone 2 are reduced simultaneously, not only does this shift create a less homogenous loading condition, but it also can lead to a voltage rise at the transformer as the system attempts to balance the demand across the zones. Understanding this dynamic is crucial, as excessive voltage can lead to equipment malfunction, heating issues, and long-term damage to electrical devices and infrastructure. To mitigate potential voltage issues in this scenario, the integration of Distributed Photovoltaic (DPV) systems presents a viable solution. There are ten locations available for the installation of DPVs, with capacity options ranging from 20 to 100 kW for these sites. The deployment of these solar panels can not only provide a supplementary power source but also help regulate voltage levels by offsetting demand during peak periods. By strategically positioning DPVs in Zones 1 and 2, utilities can create a more balanced power distribution, enhancing voltage stability across the entire network. The transformer in the system is specified as a Dy11 configuration with a capacity of 630 kVA. This type of transformer configuration plays a significant role in managing load balancing and voltage regulation. Dy11 indicates a delta-connected primary winding and a star-connected secondary winding, ideal for grounding and providing a stable voltage reference. Transformers of this specification are commonly used in distribution applications to handle varying loads effectively and mitigate issues related to voltage fluctuations. In conclusion, the load dynamics between Zones 1 and 2 in relation to the transformer's operation underscore the complexity of managing electrical distribution systems. The integration of distributed photovoltaic systems can help address voltage variability and load imbalances, fostering greater resilience and efficiency within the network. With careful planning and assessment of load patterns, utility providers can optimize the use of available resources, ensuring a reliable and stable power supply for all consumers.

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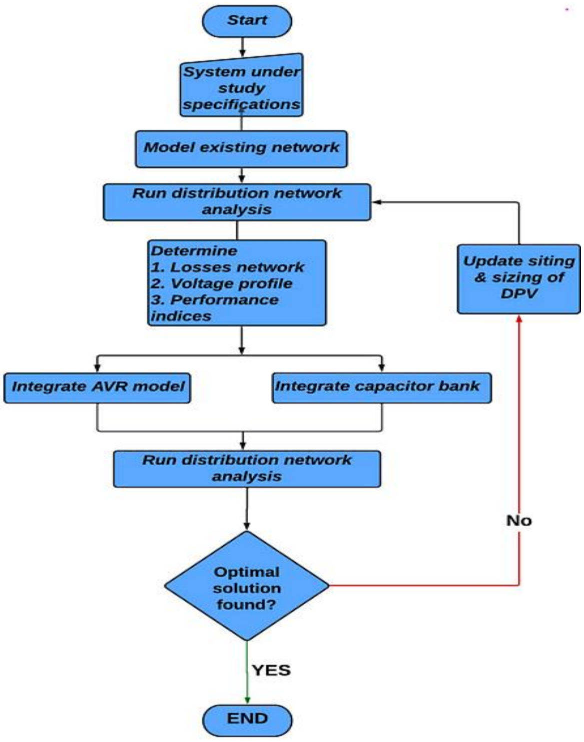

Figure (2) algorithm for optimazation paremeters[1]

Results & Analysis

For the simulation of the electrical distribution system, CYME software has been utilized to model and analyze various scenarios, particularly focusing on the integration of Distributed Photovoltaic (DPV) generation. In ideal conditions, DPV generation is simulated to increase and decrease with specific ramp rates, reflecting the natural variability of solar power production. These ramp rates are critical for understanding how quickly the generation can respond to changes in sunlight availability, which is essential for effective grid management. However, the performance of DPV systems can be significantly impacted by environmental factors such as cloud cover or direct sunlight. During cloudy weather, the output from solar panels can drop sharply, leading to a sudden decrease in power generation. Conversely, during sunny conditions, the generation can spike, resulting in excess power being fed into the grid. This variability presents challenges for the distribution system, as it must be capable of accommodating these fluctuations while maintaining voltage stability and reliability. One notable issue that arises from the integration of DPV generation is the phenomenon of reverse power flow in feeders. This situation occurs when the power generated by the DPV systems exceeds the local demand, causing electricity to flow back towards the transformer or the grid. While reverse power flow can be beneficial in terms of feeding excess renewable energy into the grid, it can also create operational challenges for distribution systems. For instance, transformers and other equipment may not be designed to handle reverse flow, potentially leading to overheating, equipment damage, or regulatory compliance issues. Moreover, the presence of reverse power can complicate the management of voltage levels within the network. If not properly controlled, it can result in voltage rises at certain points in the distribution system, which may exceed acceptable limits and endanger connected equipment. Therefore, utilities must implement effective monitoring and control strategies to manage these conditions, ensuring that both the generation and consumption of electricity are balanced. In conclusion, the use of CYME software for simulating DPV generation provides valuable insights into the performance and challenges associated with integrating renewable energy sources into the electrical distribution system. While ideal conditions allow for predictable ramp rates in generation, real-world factors such as cloud cover and sunlight variability can introduce complexities that must be carefully managed. Addressing issues related to reverse power flow and voltage stability is essential for maintaining the reliability and efficiency of the distribution network as it increasingly incorporates renewable energy technologies. By leveraging advanced simulation tools and implementing robust management strategies, utilities can better navigate the challenges posed by these dynamic systems and enhance the overall resilience of the electrical grid.

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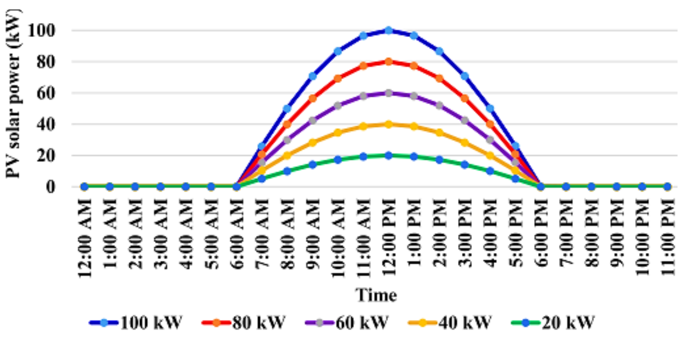

Figure (3) ramp rate of dpv [1]

Which it has changes in a day show as follow:

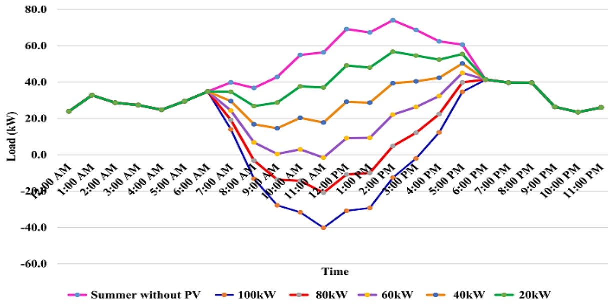

Fig (4) day load profile in summer [1]

In figure 3 , the maximum power is at noon(12 pm) in ideal situations. In figure 4, 60,80,100 kw dpv has the reverse power flow in distribution system.

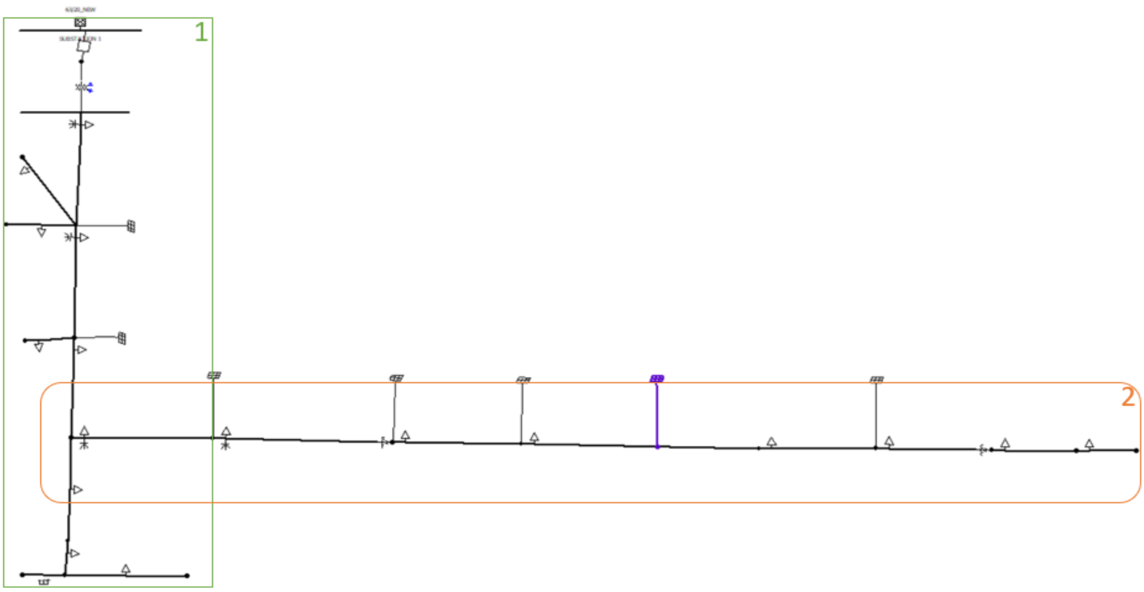

Fig (5) CYME simulation

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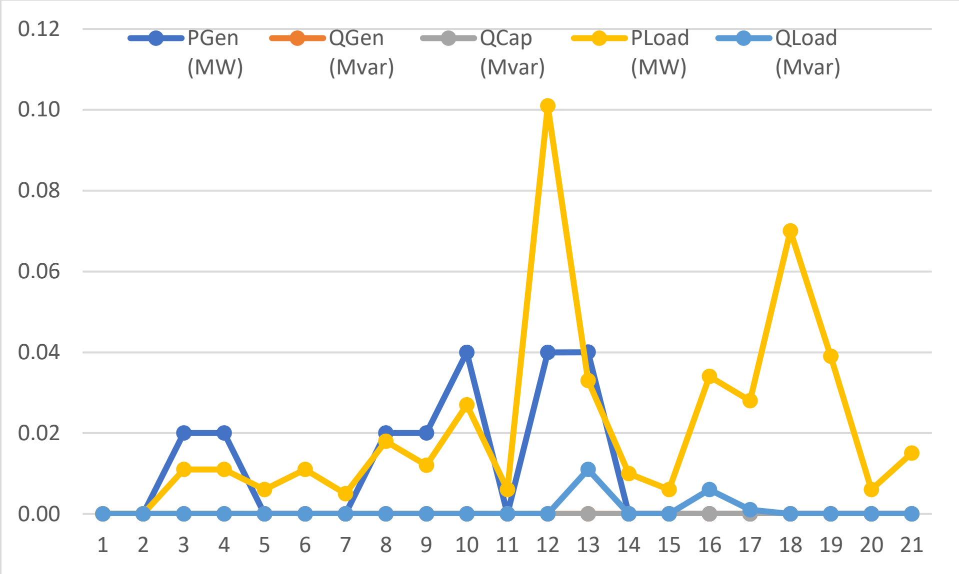

Fig (6) power generation and load mw, mvar for 238 kva demand without capacitor bank

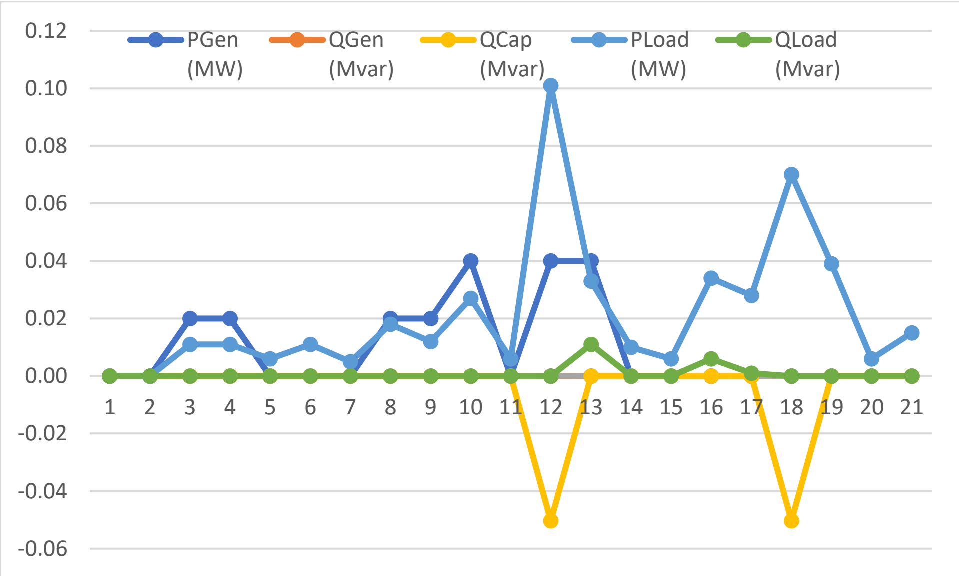

Fig (7)power generation and load mw, mvar for 238 kva demand with capacitor bank

Table 2- different scenarios [1]

System under study specifications.

Case	Case #1	Case #2	Case #3	Case #4
Season	Fall	Winter	Spring	Summer
Months	Sept., Oct., Nov.	Dec., Jan., Feb.	Mar., Apr., May.	June, July, Aug.
Transformer loading (%)	16.7	29.3	11.8	18.5
Feeder loading (kW)	14.2/67.1	41.4/117.2	14.5/47.4	23.5/74.1
Loss Load Factor (LLF)	0.32	0.44	0.35	0.38

In fig3, the maximum power is at noon(12 pm) in ideal situations. In fig4, 60,80,100 kw dpv has the reverse power flow in distribution utility and its result is voltage deviation. For that, the dpvs should not be located at four last places. At two simulations that results are in fig6 and fig 7, fig 8 and fig9, with

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50kvar capacitor bank, voltage profile has better situation in compare to without capacitor bank. [2, 3]. The data that uses in cyme simulation, come from Isfahan database from Daneshmand consultant and paper[1]. The feeder has 300 A rated current.

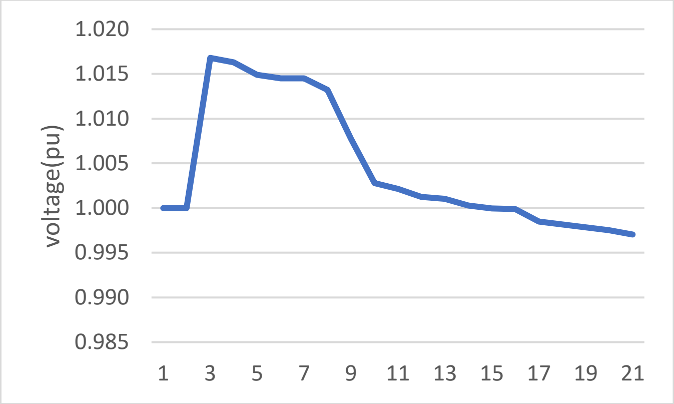

Fig (1) voltage profile without capacitor bank

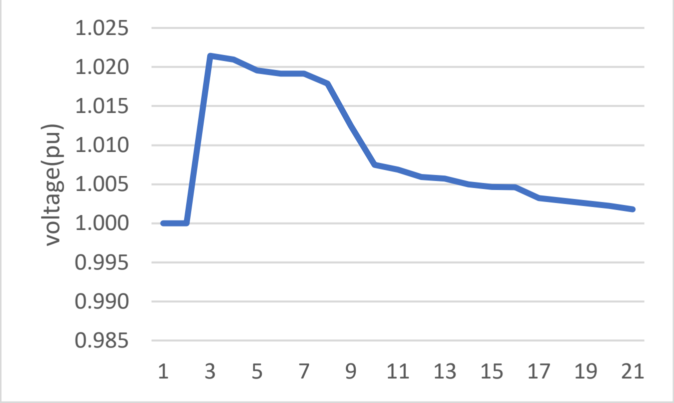

Fig (9) voltage profile with capacitor bank

Conclusion

Distributed Photovoltaics (DPVs) are increasingly being integrated into distribution utility systems, providing a significant source of renewable energy that can match or exceed local load demands. However, the effective siting and sizing of DPVs are critical factors that influence the overall performance of the electrical distribution network, particularly concerning voltage profiles and system stability. This research article explores the implications of DPV integration, focusing on their effects on active and reactive power flow, voltage control, and overall power quality. To assess the impact of DPVs, various scenarios were tested using CYME software, a powerful tool for simulating electrical distribution systems. The simulations aimed to identify the optimum penetration levels for DPVs, ensuring that the integration of these systems would not compromise the voltage stability or reliability of the network. The results indicated that the optimum location for DPV installation, in terms of loss reduction and compliance with system requirements, is at location #7. Here, a penetration level of 20 kW resulted in a significant reduction of losses, quantified at -871 kWh/year. One of the key advantages of DPVs is their ability to alter both active and reactive power flows within the distribution network. By generating electricity locally, DPVs can help control voltage levels, ensuring they remain within permissible limits while minimizing energy losses. This capability is particularly important in maintaining the quality of power supplied to consumers and enhancing the overall performance indices of the system. However, the integration of DPVs is not without challenges. In long feeders, the absence of additional voltage regulation measures, such as Automatic Voltage Regulators (AVRs) and capacitor banks, can lead to voltage drops, especially under increased load conditions. For instance, if the load increases in the first zone of the feeder, the voltage quality may improve due to the localized generation from DPVs. Conversely, an increase in load in the second zone can exacerbate voltage drop issues, potentially pushing voltage levels beyond acceptable limits. Moreover, in traditional feeders without DPV integration, voltage drops are already a concern, even with the use of capacitor banks. This highlights the necessity for careful planning and management when incorporating DPVs into existing systems. The use of additional

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AVRs and capacitor banks can provide further opportunities to enhance the capacity for installing more PV systems within the feeder, thereby maximizing the benefits of renewable energy integration. In conclusion, while DPVs present a promising solution for enhancing the sustainability and efficiency of electrical distribution networks, their successful implementation requires meticulous consideration of siting, sizing, and voltage management strategies. The findings from this research underscore the importance of optimizing DPV placement to achieve loss reduction and maintain voltage stability. Future studies should continue to explore innovative solutions for integrating DPVs, including advanced control strategies and the potential for hybrid systems that combine renewable energy sources with traditional voltage regulation methods. By addressing these challenges, utilities can better harness the potential of DPVs, contributing to a more resilient and sustainable energy future.

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