Power Factor Control of Solar Photovoltaic Inverter as a Solution to Overvoltage

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***Abstract*— Renewable energy system has become one of the main solutions to overcome the greenhouse effect. Due to its availability, reliability and safety, solar photovoltaic (PV) system gets the attention from people around the world. Apart from reducing electricity bills, this system is also maintenance-free. In this paper, a simulation was performed using DIgSILENT software in order to compare the voltage profile with and without the solar PV system. The voltage profile of the system can be improvised by installing a predetermined capacity of solar PV system. However, the distribution system will experience overvoltage when the solar PV capacity installed is more than the local loads. In this paper, the power factor control of solar PV inverter is shown to improve the voltage profile across the feeder in a distribution system.**

Keywords*— *Solar Photovoltaic System, Overvoltage, Voltage Profile, Power Factor

I. Introduction

Due to the fast growing global population and increasing energy demand, renewable energy system has become one of the main attraction around the world [1]. Renewable energy sources include hydro power, biomass, wind, solar, geothermal, wave and tidal energy. Global Status Report 2017 of Renewable Energy Policy Network for the 21st Century (REN21) has stated that nearly 62% of renewables has accounted for the net addition to global power generating capacity [2]. This is due to the target to reduce the usage of fossil fuels since fossil fuels being one of the main contributions to greenhouse effect [3].

Solar photovoltaic (PV) is one of the renewable energy sources which is currently on demand since it is a carbon-free technology. Apart from that, it is also easy to install, safe, reliable and maintenance-free [4]. The Sun is an amazing supporter which sends incredible amount of light energy towards the Earth. This has made solar PV system to become a part of the citizens' day-to-day experience as millions of solar PV modules are installed on rooftops and building fronts. This can be seen in the Global Status Report 2017, in which REN21 reported that in 2016 where 47 % of solar PV has been newly installed [2].

Solar PV is an intermittent source as the output from the solar PV panels can change unexpectedly and instantaneously depending on the climate [4-5]. The most significant constrain when installing solar PV are overvoltage, equipment overloading and numerous operations of voltage regulators. The power flow of normal system is uni-directional [6] and drops rapidly when the weather is cloudy. However, during the sunny day, penetration level of solar PV tends to increase intensely. This can lead to the rise of output power and the system begins to function bi-directionally which can eventually cause an overvoltage in the distribution feeder [7].

One of the challenging issues is overvoltage occurrence when the solar PV is connected to a distribution network system [8]. Due to solar PV system limitations, few considerations need to be taken into account in order to solve the issues related to overvoltage. Besides that, high capacity of solar PV is one of the reasons that lead to the overvoltage of the distribution network system [9]. There are many solutions to overcome these limitations including changing the size of the cable, changing the tap of On-Load Tap Changer (OLTC) transformer, electrical energy storage system (EESS), demand response and lastly power factor control [8, 10-11].

Among all the methods described above, power factor control acts as the most effective method because it is cost efficient method and consumes less time to react. Power factor can be controlled by using the capabilities of a solar PV inverter [10]. The solar PV's inverter will operates at capacitive power factor and this eventually provides solution to overcome the overvoltage. Apart from that, since the characteristic of capacitive power factor is to absorb reactive power, it reduces the voltage rise of a distribution network.

This paper describes three different cases of installing solar PV to the distribution network and the occurrence of overvoltage caused by solar PV with high capacity. Apart from that, this paper also explains the simulations that have been conducted and the methods to overcome overvoltage. The effect of controlling power factor is also discussed in this paper.

II. Solutions to Mitigate Overvoltage

A number of studies have been performed in finding the solutions to mitigate overvoltage of the distribution system. Tie and Gan [11] highlighted that the size of the cable influences the voltage rise using the Open Distribution Simulation Software (OpenDSS). The simulation result proves that increasing the size of the cable reduces the voltage rise of the distribution network.

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Changing the tap of OLTC transformer is one of the solutions to mitigate overvoltage. However, due to the rapid demand of solar PV, Chirapongsananurak and Hoonchareon [12] mentioned that the overvoltage issues of distribution network can no longer be mitigated by changing the tap of OLTC transformer. Due to the sudden change of climate, operation of OLTC transformer is not efficient enough to compensate the rapid change in voltage. Apart from that, the lifetime of the OLTC reduces with increasing number of OLTC operations.

EESS are one of the effective solutions to overcome challenges related to renewable energy technologies. This has been verified by the authors of [13]. EESS is designed to reduce overvoltage and smooth the solar PV output fluctuations. The EESS simultaneously regulates its output to overcome the effect to the power grid caused by any inconsistency in solar PV output. EESS is applied to store part of energy generated by solar PV is stored in EESS. Besides that, EESS also absorbs any excess of active power exported to the utility grid by solar PV.

According to Hashemi and Østergaard [8], the load can be directly applied with demand response and the control signal can be generated by central server. Through this application, reverse power flow and peak demand can be decreased. Even though demand response can control the load demand as well as lessening the grid loss of the network, this method is considered as an undependable method in controlling the grid voltage. This is because the demand response is dependent on the customers' consumption. Besides that, the usage of solar PV is inconsistent throughout the year. Thus, the authors proposed to combine the demand response technique with real power curtailment. The practice of energy storage can reduce the energy loss due to reverse power flow and can be utilized for overvoltage mitigation.

Adjusting the power factor of the inverter to absorb the reactive power is a common solution to prevent overvoltage issues due to solar PV. Solar PV inverter can generate and absorb reactive power to alter the voltage. Reno, Broderick and Grijalva [14] mentioned that many smart inverters applied in the latest grid codes such as Germany. These inverters are used to support the voltages of the distribution network system. The voltage of the end feeder decreases with a generator in leading power factor. On the other hand, the end feeder voltage increases with a generator in lagging power factor. The results from the case study in this paper proves the hypothesis statement above.

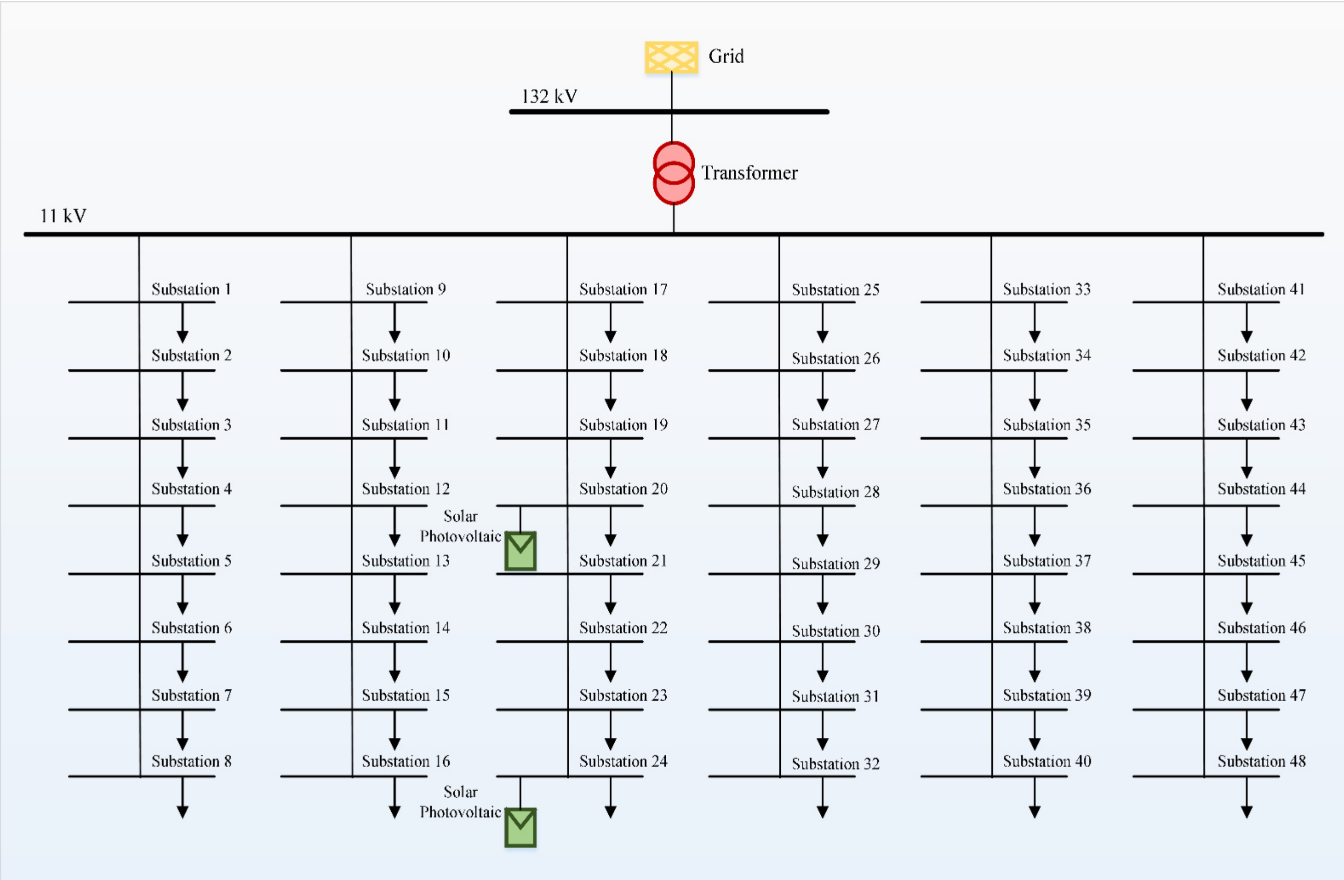

Fig. 1. A distribution network designed using DIgSILENT software

III. Network Modelling

A typical distribution network is designed using Digital Simulation and Electrical Network Calculation Program (DIgSILENT) software. This distribution network consists of a 30 MVA 132/11 kV OLTC transformer, six feeders with eight substations each and solar PV systems. Loads are between the ranges of 0.3 MW + 0.1 MVAR to 0.5 MW + 0.2 MVAR are placed randomly at various busbar. The type of cables used are 11 kV XLPE Insulated Power Cables with the constant length of 1.5 km. All the parameters and the network diagram are based on Malaysian standards. Figure 1 shows the electrical network that is used for the case study. The solar PV system is analysed for four different cases. The results are plotted and discussed in the next section.

IV. Results

Solar PV system is one of the solutions to improve the voltage profile of a vulnerable network. The network will see an overvoltage if the capacity of the solar PV system installed is more than the loads. Fig. 2 until Fig. 5 shows the comparison of voltage profile for four different cases as mentioned below.

From the graphs, the voltage at the end substation before installing solar PV systems for all the cases is 11.017 kV. The voltage drops due to the high amount of power losses resulting from the resistance in cable. Therefore, changes in voltage profile is simulated by installing solar PV systems with different capacity. The acceptable limits must within ±5 % of 11 kV (nominal voltage) [15-16].

A. Case 1

Case 1 as in Fig. 2 compares the voltage profile at three different conditions, namely; voltage before installing solar PV systems, voltage after installing a 1 MW solar PV system and voltage after installing a 5 MW solar PV system. This solar PV systems are installed at Substation 20.

According to Fig. 2, the installation of 5 MW solar PV increases the voltage profile of the network more significantly when compared to 1 MW solar PV installation.

B. Case 2

Case 2 in Fig. 3 shows the comparison of the voltage profile across the feeders for three different conditions which are before installing a solar PV system, after installing two of 1 MW and 5 MW of solar PV systems. The solar PV systems are installed at Substation 20 and Substation 24.

From the graph, although installing two units of 1 MW solar PV systems improves the voltage of the network, yet, the difference is less significant. On the other hand, after installing two units of 5 MW solar PV systems, the voltage profile of the network improves. However, due to the high capacity of the solar PV generator, the network experiences an overvoltage.

C. Case 3

Case 3 in Fig. 4 shows the voltage profile in three different conditions, namely; voltage before installing solar PV systems, voltage after installing 5 MW solar PV systems at unity power factor and voltage after changing the power factor of 5 MW solar PV systems from unity to 0.9 capacitive. The solar PV systems are installed at Substation 20 and Substation 24.

The voltage at the end substation is 11.648 kV and is beyond the acceptable limits due to the high capacity of solar PV system. However, the voltage at the end substation drops to 11.293 kV after changing the power factor from unity to 0.9 capacitive.

D. Case 4

Case 4 as in Fig. 5 shows the voltage profile for three different conditions, namely; voltage after installing 2 units of 5 MW solar PV systems at unity power factor, voltage after changing the power factor of solar PV systems from unity to 0.9 inductive and voltage after changing the power factor of solar PV systems from unity to 0.9 capacitive. The solar PV systems are installed at Substation 20 and Substation 24.

By changing the unity power factor to inductive power factor, the voltage rises more than the overvoltage conditions. As shown in Fig. 4, voltage across the feeder is 11.974 kV after operating in inductive power factor.

E. Case 5

Case 5 discusses the impact of solar PV on the bus voltages in a weak and strong electrical grid. Figure 6 shows the voltage profile of a weak (5 kA) network with and without installing 2 units of 5 MW solar PV systems at unity power factor and Figure 7 shows the voltage profile for a strong (15 kA) network with and without installing 2 units of 5 MW solar PV systems at unity power factor.

V. Discussion

As shown in Case 1, at unity power factor, the solar PV system acts as an active power source which improves the voltage profile of the feeder [17]. Therefore, 5 MW solar PV at the unity power factor can improve the voltage. This has been proven in Fig. 2 and from (1).

$$P = VI \tag{1}$$

The higher the power, the higher the voltage will be.

However, when the capacity of the solar PV system is too high, the amount of active power produced will also be high which may lead to overvoltage scenario. Yet, this overvoltage can be resolved by controlling the power factor of the solar PV system, which is discussed in Case 3.

Case 4 compares the voltage across the feeders after changing the solar PVs' power factor 1 to 0.9 inductive and 0.9 capacitive. The nature of inductive power factor is compensating reactive power [14]. Therefore, high capacity and high reactive power leads to overvoltage. On the other hand, the characteristic of a capacitive power factor in a photovoltaic system is absorbing reactive power [18-19]. Thus, the application of solar PV system with 0.9 capacitive power factor act as one of the solution to mitigate the overvoltage. Generally, power factor is also one of the power strengthener parts in a solar PV system [3]. Hence, controlling the power factor of solar PV is most suitable and cost efficient method to ensure that the voltage profile is always in the optimum range.

Case 5 shows that there is no much significant differences on voltage profile for both weak and strong network distribution. This might due to small size of PV solar installation contribute fewer changes on the fault analysis in any network distribution.

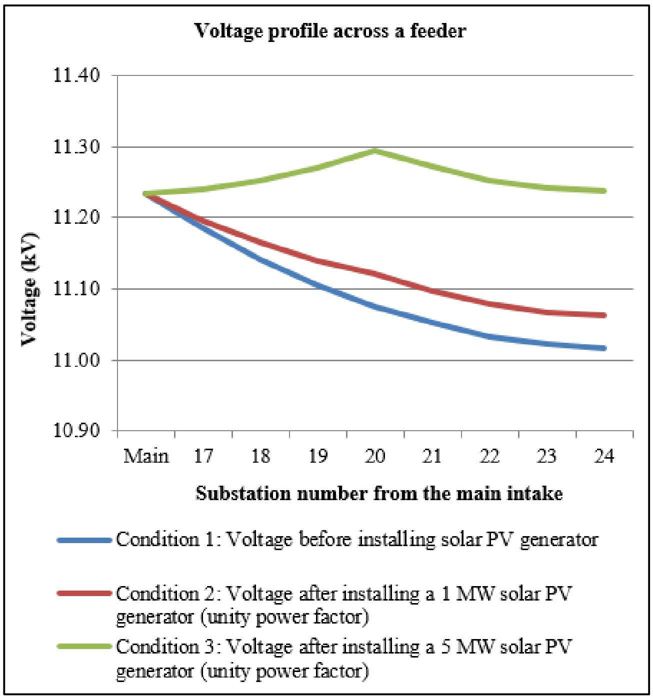

Fig. 2. Voltage Profile across the Feeders in Case 1

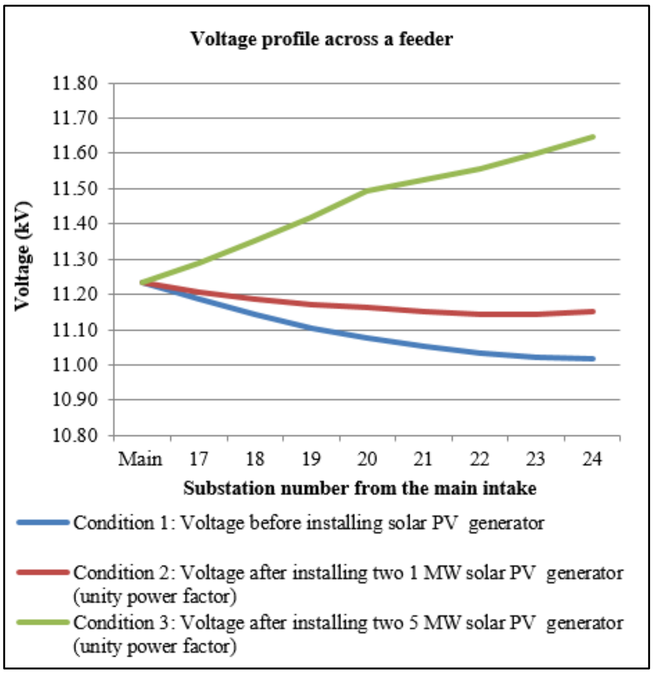

Fig. 3. Voltage Profile across the Feeders in Case 2

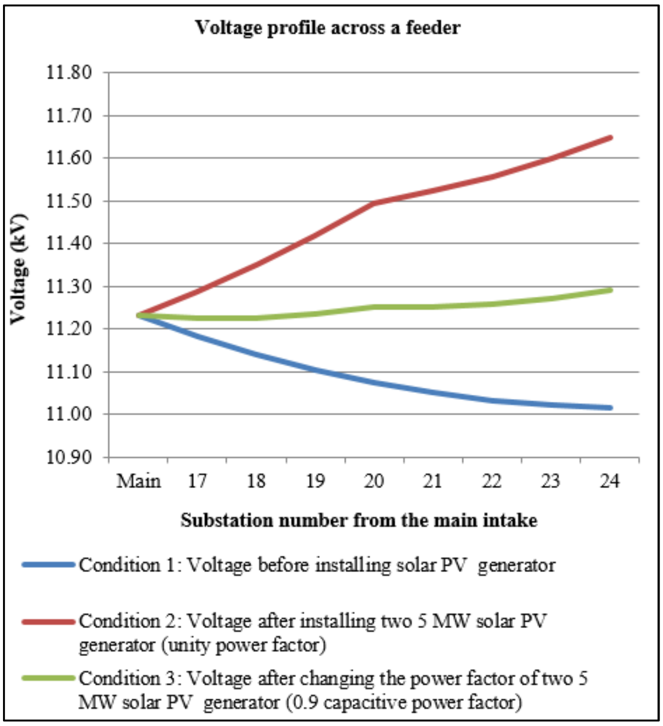

Fig. 4. Voltage Profile across the Feeders in Case 3

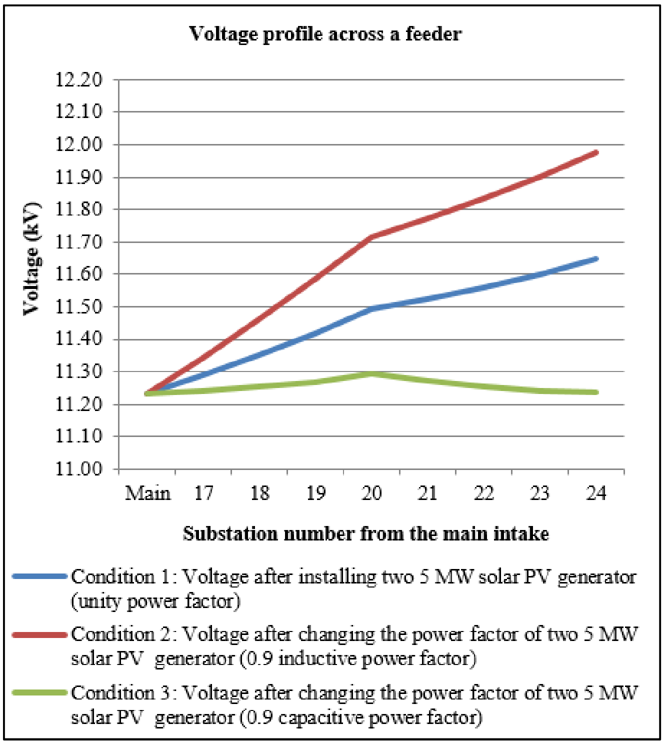

Fig. 5. Voltage Profile across the Feeders in Case 4

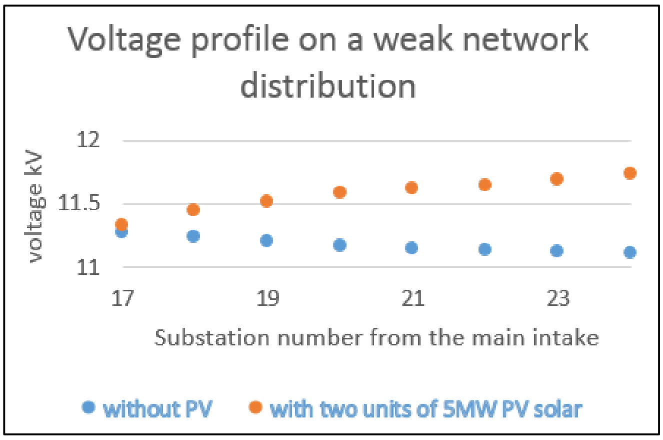

Fig. 6. Voltage Profile for Weak Network Distribution

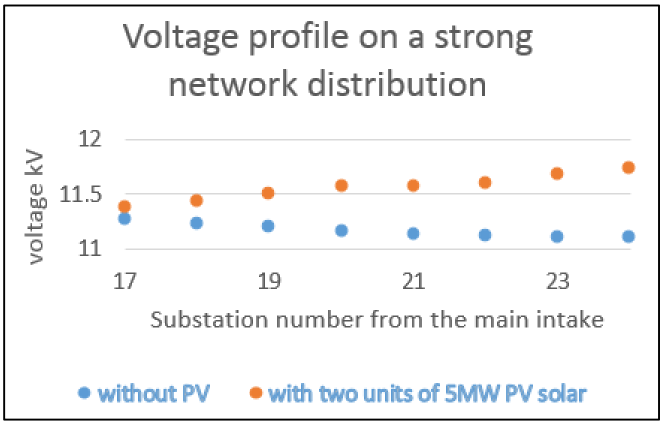

Fig. 7. Voltage Profile for Strong Network Distribution

TABLE I. CASES SUMMARIZATION

Case	Discussion
1	1 unit of solar PV generator installed at unity power factor: • 1 unit of 1 MW solar PV generator: improve the voltage from 11.017 kV to 11.063 kV • 1 unit of 5 MW solar PV generator: improve the voltage from 11.017 kV to 11.237 kV
2	2 units of solar PV generators installed at unity power factor with different capacity • 2 units of 1 MW solar PV generators: increase the voltage from 11.017 kV to 11.151 kV (within the limits of ± 5 %) • 2 units of 5 MW solar PV generators: increase the voltage from 11.017 kV to 11.648 kV (overvoltage: exceeded the ± 5 %)
3	Changing the power factor from unity to 0.9 capacitive of 2 units of 5 MW solar PV generators • At unity power factor: 11.648 kV (overvoltage) • At 0.9 capacitive power factor: decrease from 11.648 kV to 11.293 kV (within the limits of ± 5 %)
4	Comparing inductive power factor with capacitive power factor • Capacitive power factor absorbs reactive power: improves the overvoltage feeders • Inductive power factor produces reactive power
5	Minimal changes is observed in voltage profile for a weak (5kA) and strong (15kA) network with solar PV.

VI. CONCLUSION

Many countries are struggling to resolve the issue of global warming. The usage of renewable energy, especially solar PV, has become one of the alternative solution to overcome this problem. Installation of solar PV system can improve the voltage profile of the distribution network. However, the distribution network experiences overvoltage when solar PVs' capacity is beyond the loads. One of the solutions to overcome the overvoltage is by controlling power factor of solar PV system. A simulation was performed using DIgSILENT software and graphs of voltage profile across the feeder with three different conditions in three different cases were plotted. Voltage of the end feeder after installing two 5 MW of solar PV generators at unity power factor is 11.648 kV which has exceeded the limits. After changing the power factor from unity to 0.9 capacitive, the voltage of the end substation drops to 11.293 kV, which is 3 % lower. On the other hand, the voltage of the end substation increases by 2.4 % after installing 5 MW of solar PV systems at 0.9 capacitive power factor when compared to the voltage before installing the photovoltaic systems. Overall, the results from these studies conclude that controlling the power factor of solar PVs' inverter improve the voltage profile, thus mitigating the overvoltage issue.

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