Voltage Regulation Using Reactive Capability of Solar Inverter

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submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY IN
ELECTRICAL ENGINEERING

DEPARTMENT OF ELECTRICAL ENGINEERING
FACULTY OF TECHNOLOGY
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CERTIFICATE

This is to certify that the project entitled 'Voltage Regulation Using Reactive Capability of Solar Inverter' is done for Skill Enhancement Course (SEC) by 3rd Year Electrical Engineering Students is an authentic work carried out by them at Faculty of Technology, University of Delhi under my guidance.

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The Content embodied in this project work has not been submitted earlier for the award of any degree/diploma to the best of my knowledge and belief.

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Project Team:

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ABSTRACT

To make our energy supply more secure and to reduce the effects of climate change, renewable energy—especially solar power is being added to the electricity grid at a rapid pace. Solar power systems use devices called PV inverters to convert the DC electricity produced by solar panels into AC electricity that can be used in homes and on the grid.

Traditionally, these inverters have been used mainly to provide **active power**, which is the actual usable energy. However, they are also capable of supplying **reactive power**, which helps support voltage levels and improve the overall stability of the power system. This capability is often ignored.

In this study, we make use of the inverter's ability to provide reactive power. By doing so, we can **reduce power losses in the network, maintain node voltage to a certain value**(let's say 1 p.u.) and **increase the amount of load the system can safely handle**. Essentially, using the inverter's full capabilities makes the distribution system more efficient and more robust.

*code: https://github.com/Hardeep007/Voltage-Regulation-Using-Reactive-Capability-of-Solar-Inverter.git

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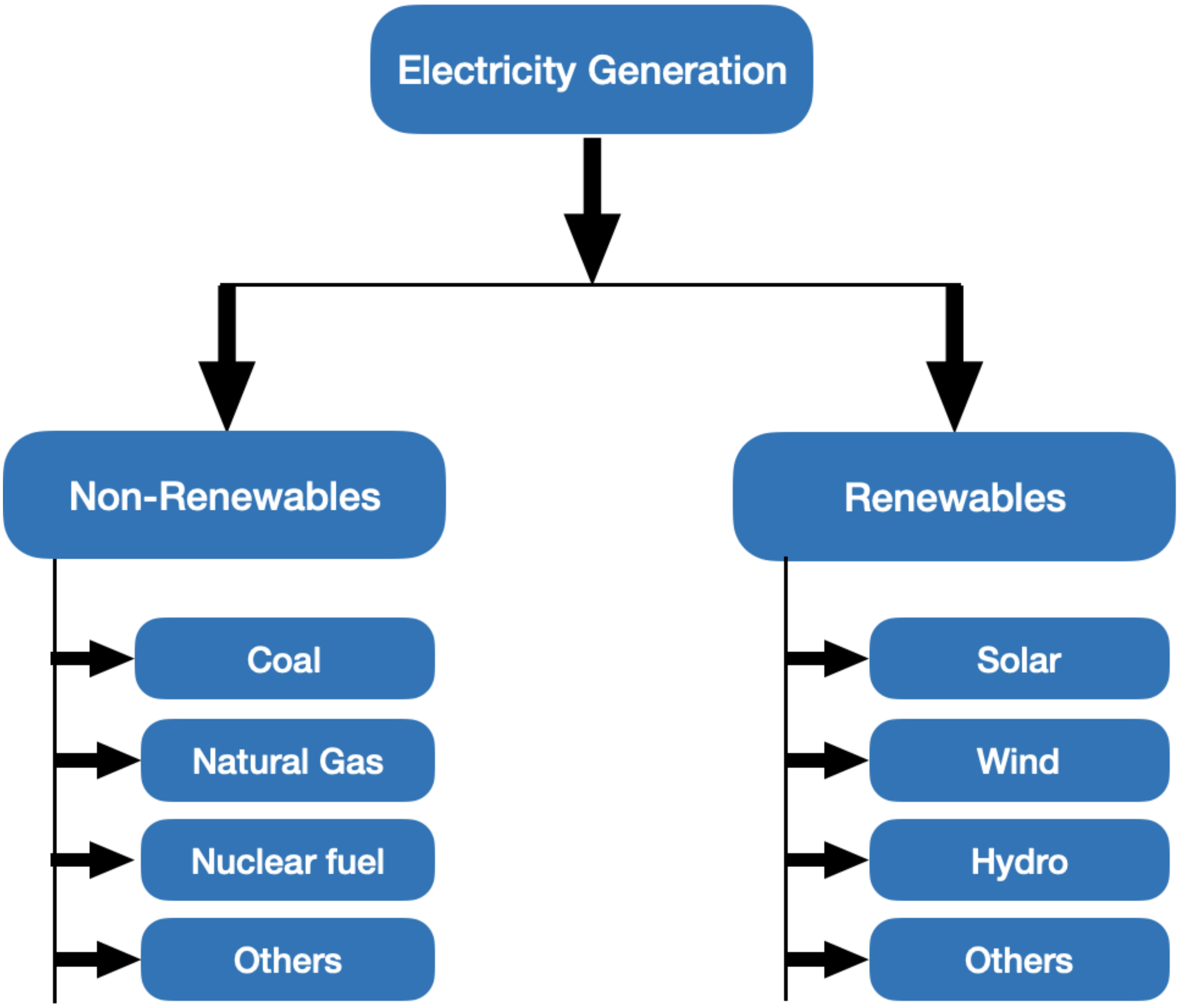
1. INTRODUCTION

As technology continues to evolve, our daily life becomes increasingly dependent on electronic devices, digital services, and automation. This advancement has caused global energy consumption to rise sharply. The rapid growth of data centres and online services—each requiring massive amounts of electricity—has further accelerated this demand[1], making energy use grow almost exponentially. To meet this rising demand, most countries still rely heavily on non-renewable fossil fuels.



In fact, nearly 60% of all electricity produced today is directly or indirectly linked to non-renewable source of energy[2]. This level of dependence is concerning because fossil fuels are limited in supply, and their extraction and use contribute significantly to environmental problems such as air pollution and climate change. To ensure long-term energy security, it is necessary to shift from these depleting resources to renewable energy sources that are naturally abundant and environmentally friendly. Among all renewable options, solar energy has emerged as one of the most promising.

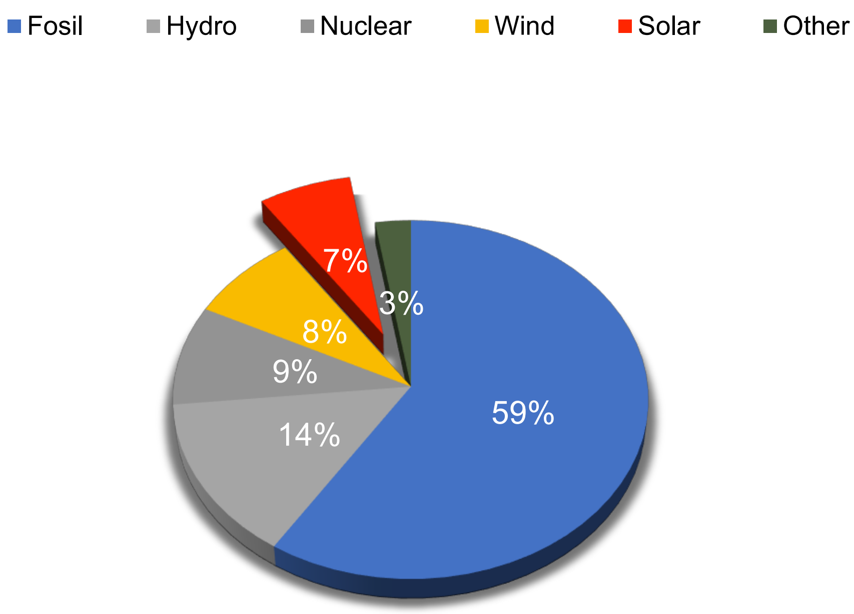


Figure 1 Electricity generation from different sources

Although it currently contributes about 6.9% of the world's total electricity generation, its popularity continues to grow due to its high reliability, decreasing installation cost, and very low maintenance requirements. The rapid global adoption of solar photovoltaic (PV) technology reflects this shift clearly. Installed solar capacity worldwide increased dramatically—from 136,172 MW in 2013 to 1,046,614 MW in 2022—representing a remarkable growth of over 600%. This surge shows how vital solar energy has become in meeting the world's increasing energy needs sustainably[3].

Solar PV panels generate electricity by converting sunlight into electrical energy, but this energy is produced in the form of direct current (DC). Since homes, industries, and the electrical grid operate on alternating current (AC), additional equipment—such as converters, inverters, and controllers—is required to transform the DC output of the panels into usable AC electricity. Traditionally, most solar inverters operate at a unity power factor, meaning they only deliver

active power, which is the real, usable energy produced by the solar panels. However, recent research has revealed that these inverters are also capable of handling **reactive power**, which plays a crucial role in maintaining the stability of voltage levels in a power system. This means that modern PV inverters can either supply or absorb reactive power to or from the grid[4] depending on real-time requirements and their internal capability. Mathematically, this relationship between active power (P), reactive power (Q), and apparent power (S) is expressed as:

$$\mathbf{S = \sqrt{(P^2 + Q^2)},}$$

or equivalently,

$$\mathbf{Q = \sqrt{(S^2 - P^2)}}.$$

Understanding why reactive power is needed is essential. From power flow studies, it is clear that voltage stability in an electrical network depends heavily on the availability and proper management of reactive power. At each bus or node in the grid, reactive power directly influences the voltage magnitude. If reactive power is supplied to a node, the voltage tends to increase; if reactive power is absorbed, the voltage decreases. Ideally, power systems aim to maintain the voltage close to **1 per unit (1 p.u.)**[5] to ensure stable and efficient operation. In some cases, utilities may intentionally raise the voltage at a node to allow the system to carry more load safely. Traditionally, devices such as capacitor banks, reactors, and other hardware controllers have been used to regulate voltage. However, these solutions can be expensive and require additional installation and maintenance. In contrast, using the already existing solar inverter for reactive power support is far more economical and efficient.

Another important point is that solar PV panels do not produce constant power throughout the day. Their output fluctuates due to changing sunlight conditions, weather variations, and time of day. These fluctuations can lead to voltage instability in the system. This makes voltage regulation even more important and using PV inverters for both active and reactive power support provides a flexible and cost-effective way to maintain voltage stability while improving the overall reliability of the distribution network.

2. PROBLEM STATEMENT

When a large number of PV solar systems are connected to a distribution network, they introduce certain challenges because the amount of power they generate changes throughout the day. This fluctuation happens due to variations in sunlight intensity caused by clouds, shading, time of day, and weather conditions. As a result, the voltage levels in the distribution grid also fluctuate. Voltage stability is one of the most important requirements of a healthy power system, because if the voltage becomes too low or too high (beyond the allowable limit of ±10%), it can damage electrical equipment, reduce efficiency, and make the system unsafe. Low voltage also increases reactive power demand, and as the load grows, the system can even reach the point of voltage collapse.

In addition to voltage variations caused by solar generation, the grid also faces disturbances from sudden changes in load or from electrical faults. A reliable power system must be able to recover quickly from these disturbances in order to maintain stable and secure operation. This is where the **V/Q method**—which relates voltage (V) to reactive power (Q)—can play a very important role.

By supplying or absorbing reactive power at the right moment, voltage levels can be controlled and kept within safe limits. Using this reactive support not only improves voltage stability but also helps maintain a desirable power factor, making the system more efficient. Furthermore, by stabilizing the voltage, the overall energy losses in the distribution network can be reduced. Therefore, utilizing reactive power control through PV inverters offers an effective and economical solution to the voltage instability problems caused by increasing solar penetration in modern power systems.

3. METHODOLOGY

As discussed earlier, a solar inverter is capable of supplying or absorbing reactive power, but this capability is limited by its total MVA rating. The inverter cannot exceed this rating, so its ability to support the grid with reactive power depends directly on how large its apparent power (S) capacity is. Therefore, to make effective use of reactive support, it is important to size the inverter properly according to the needs of the system.

In this work, we assume that the PV panels have a total capacity equal to one-third of the total load on the distribution grid. Based on this assumption, the MVA rating of the solar inverter is selected to be **1.05 times the maximum active power** that the PV panel can deliver. For example, if the PV panel can provide a maximum of **40 MW**, we set the maximum apparent power rating (**Smax**) of the inverter to:

$$\mathbf{Smax = 40 \times 1.05 = 42\ MW}$$

Using the well-known relationship among apparent power (S), active power (P), and reactive power (Q):

$$Q = \sqrt{S^2 - P^2}$$

we can determine the limits of reactive power support available from the inverter. Substituting the values:

$$Q_{\text{limit}} = \pm\sqrt{{S_{max}}^2 - {P_{max}}^2}$$

$$= \pm\sqrt{42^2 - 40^2}$$

$$= \pm\sqrt{164}$$

So, the maximum reactive support capability of the inverter is:

$$\mathbf{Q_{limit} = \pm\ 12.806\ MVAR}$$

This represents the absolute upper and lower bounds of reactive power that the inverter can supply or absorb. However, the inverter will not operate at these extreme values all the time. The goal of the control strategy is simply to maintain the voltage at the selected bus as close as possible to **1 per unit**, which is the ideal voltage level in power systems.

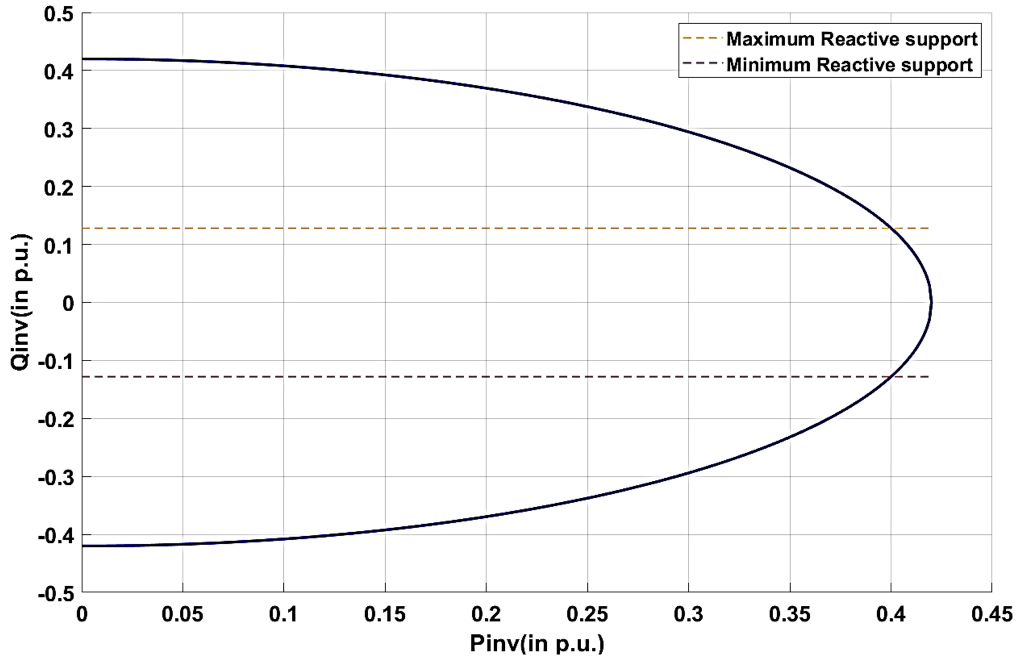


Figure 2 Available reactive support when active support is 0.4p.u. (or 40MW)

To decide where the PV system should be placed for the best impact, we identify the **three weakest buses** in the distribution network—those most prone to voltage instability. The PV system is then applied at these locations to provide reactive support and improve voltage stability across the grid.

To carry out this study, the first step was to perform a power flow analysis[6], which helps us understand how voltage, current, active power, and reactive power are distributed throughout the electrical network. Several analytical methods are available for this task, such as the Gauss–Seidel method and the Newton–Raphson **(NR)** method. Among these techniques, the Newton–Raphson method is known for its faster convergence, meaning it reaches accurate results more quickly and efficiently, especially in larger or more complex power systems. Because of this advantage, we selected the Newton–Raphson method[7] for our load flow calculations.

The next step was to choose a suitable power system on which the analysis could be carried out. For this purpose, we used the **standard IEEE 30-bus test system**, which is widely accepted in research because it provides a realistic and well-structured model of an electrical network.

After running the power flow analysis on this grid, we identified the **weakest buses**—those buses where the voltage tends to deviate from acceptable levels and where stability issues are more likely to arise. These buses were selected as the locations where reactive support would have the most impact.

Once the weakest buses were identified, we provided active support from the PV system to those buses. After that, to maintain voltage stability, we calculated the exact amount of reactive power needed at each bus to keep the voltage close to the ideal value of 1 per unit (1 p.u.). This step ensured that the voltage remained stable even when the load changed or when the solar output fluctuated.

Through this methodology, we ensured that both active and reactive power from the solar inverter were used effectively to improve the overall stability and performance of the distribution network.

When calculating the amount of reactive power needed to bring a bus voltage close to 1 per unit[5], there are situations where the inverter cannot provide the exact amount required. This limitation arises because every solar inverter has a fixed reactive power capability, defined by its maximum (Q_{max}) and minimum (Q_{min}) reactive power limits. These limits depend on the inverter's total MVA rating and the active power it is delivering at that moment. The inverter cannot operate beyond these boundaries without risking overheating, instability, or violating its design specifications.

Because of this, the system must check whether the required reactive power ($Q_{required}$) lies within the inverter's allowable limits. The following conditions ensure safe and practical operation:

- If the system requires more reactive power than the inverter can supply, that is,

$$\mathbf{Q_{required} > Q_{max},}$$

then the inverter supplies only its maximum possible reactive power:

$$\mathbf{Q_{supplied} = Q_{max}}$$

- Likewise, if the system requires the inverter to absorb more reactive power than its lower limit allows, that is,

$$Q_{required} < Q_{min},$$

then the inverter absorbs only up to its maximum absorbing capability:

$$Q_{absorbed} = Q_{min}$$

These boundary conditions prevent the inverter from being overloaded or pushed into unsafe operating regions.

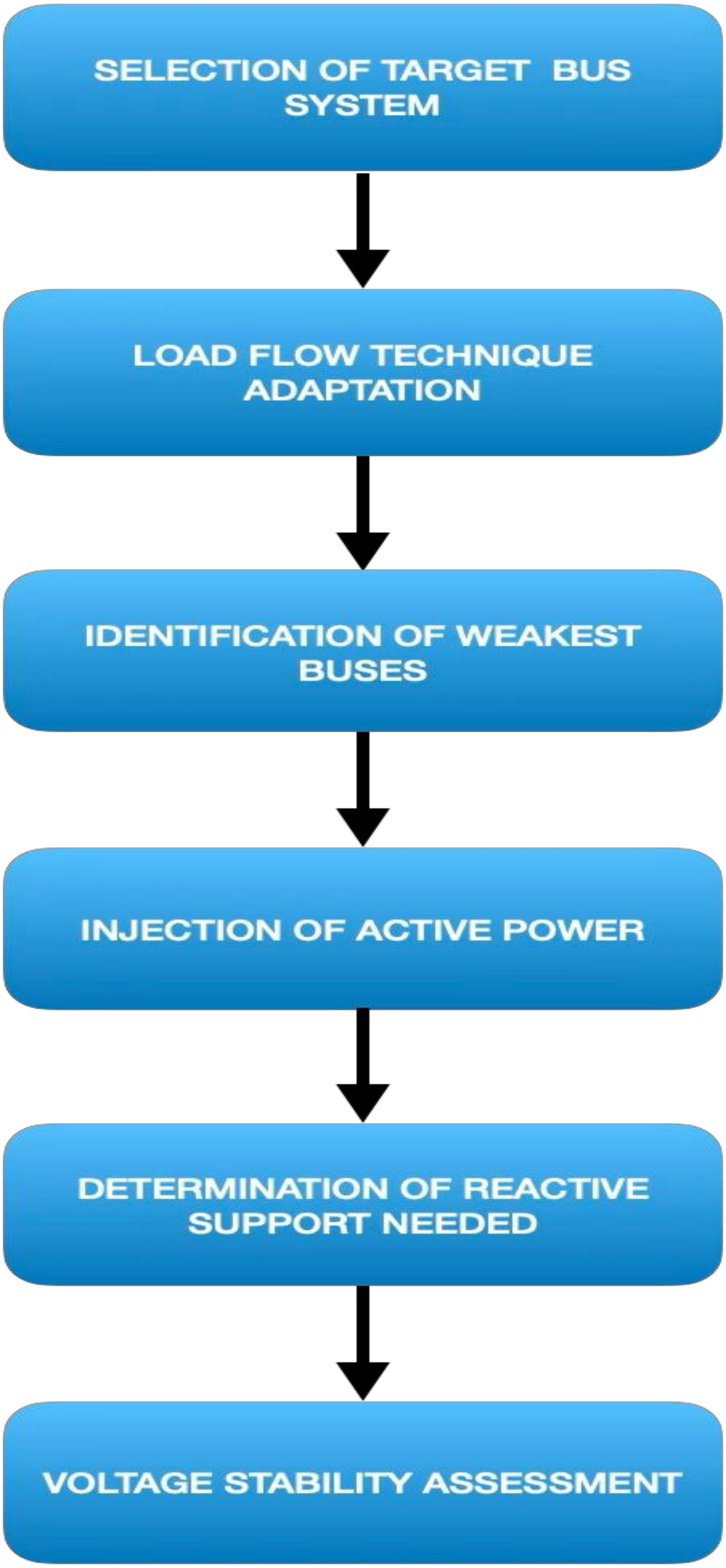
Once the inverter provides reactive power—either the exact required value or the nearest permissible value (Qmax or Qmin)—the voltage at the target bus becomes either exactly 1 per unit or very close to it. Maintaining voltage at or near this ideal level significantly enhances system performance. It reduces energy losses in transmission lines, minimizes unnecessary reactive power circulation, improves power quality, and prevents harmful voltage drops that could damage sensitive equipment. These improvements are presented and analysed in detail in the results section of the report.

To further verify the robustness and practicality of this method, we tested the algorithm (linked through the GitHub repository at the beginning of this report) under **different load factors**. A load factor indicates how heavily the system is loaded compared to its maximum capacity. Power systems rarely operate at a single fixed load; instead, they fluctuate throughout the day because of changes in industrial demand, household usage, and renewable generation variability. By testing across multiple load factors, we ensured that our voltage-regulation approach works effectively not just under ideal or light-load conditions but also under moderate and heavy load scenarios.

This extensive testing gives confidence that the proposed method is not only theoretically sound but also highly adaptable, practically feasible, and capable of maintaining stable voltage profiles across a wide range of realistic operating conditions.

Table 1 Values of Different Load Factors

CASE NO.	**LAMDA(λ)**	**LOAD FACTOR(1+ λ)**
CASE 1	0	1
CASE 2	0.5	1.5
CASE 3	1.05	2.05


SELECTION OF TARGET BUS SYSTEM
LOAD FLOW TECHNIQUE ADAPTATION
IDENTIFICATION OF WEAKEST BUSES
INJECTION OF ACTIVE POWER
DETERMINATION OF REACTIVE SUPPORT NEEDED
VOLTAGE STABILITY ASSESSMENT

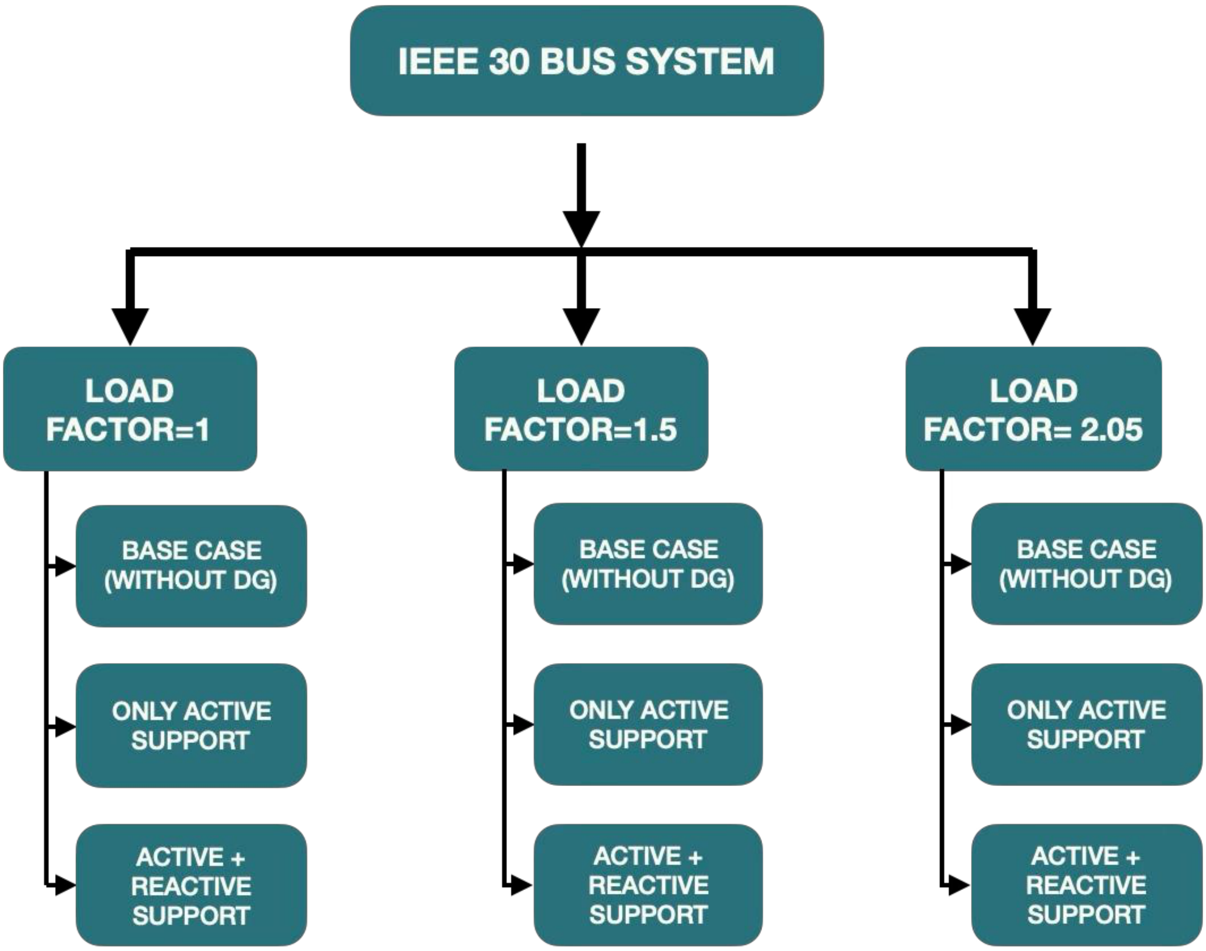
4. RESULTS AND DISCUSSION

To effectively demonstrate the efficiency and practical feasibility of the proposed methodology, two major performance indicators have been considered in this study:

1. **Node Voltage Behaviour** – Analysis of voltage magnitude at each bus to ensure the system maintains healthy and stable voltage levels.
2. **System Power Losses** – Evaluation of both active power loss (kW) and reactive power loss (kVAR) to determine the improvement achieved after DG placement.

These parameters directly influence the operational performance, reliability, and overall economic benefit of a power distribution system. Any improvement in these two indicators signifies a more efficient and stable network.

TEST CASE DISCUSSION



i) Base Case (Without DG)

In the base case, the distribution network is analysed under its normal loading conditions, without any Distributed Generation (DG) connected. A load flow study is carried out using the Newton–Raphson (NR) load flow technique, which is a widely used and efficient method for power flow calculations. Through this analysis, the voltage magnitude at each bus is obtained. The buses that exhibit the lowest voltage values are considered as the weakest buses because they are more prone to voltage instability and performance deterioration. These weakest buses play a crucial role in system improvement and are therefore selected as the optimal locations for DG placement in the next stages of the study.

ii) Active Power Injection Only

In this case, Distributed Solar Photovoltaic (PV) units are integrated into the network to support the system with active power. It is assumed that one-third of the total active power demand of the distribution system is supplied by these solar DG units. The identified three weakest buses are chosen for the installation of DG, and each bus is injected with the required amount of active power. After the DG installation, another NR load flow analysis is performed to observe the improvement in system performance.

The results show that injecting active power significantly improves the voltage profile of the system, especially at the weak buses. This happens because the local generation reduces the dependency on power supply from the grid, lowering the burden on transmission lines. As a result, there is a notable reduction in active power losses within the network. Although the reactive power losses also decrease to some extent, the improvement is limited because the DG units in this case supply only active power.

iii) Active + Reactive Power Support (V/VAR Control Method)

After analysing the first case, it is observed that while active power injection improves voltage levels, in some buses the voltage may rise above the acceptable range. For efficient power delivery, the bus voltage should ideally remain close to 1.0 per unit (p.u.). A voltage that is excessively high or too low can lead to malfunctioning, overheating, or damage of sensitive devices, affecting both the grid infrastructure and consumer-side equipment.

Voltage magnitude in a power system is strongly influenced by the reactive power available at each bus. Therefore, in the final case, both active and reactive power are supplied from the same DG units. The solar PV inverters are equipped with V/VAR control, enabling them to either inject or absorb reactive power depending on the voltage condition of the bus. When the voltage rises, the inverter absorbs reactive power, and when voltage drops, it injects reactive power. This creates a balance that ensures smooth voltage regulation.

With reactive power support included, the voltage profile becomes more stable and uniform across all buses. Additionally, the system losses reduce further due to minimized reactive power flow over long distances. This method demonstrates a highly effective way of maintaining voltage security, enhancing overall power quality, and ensuring maximum efficiency of the distribution network.

CASE I

In the first case scenario, the load factor is considered as 1, which signifies that the system is operating under full-load conditions. A load factor of 1 indicates that the actual power demand of the system is equal to the maximum designed demand, meaning the network is fully stressed and experiencing its maximum real power requirement. Under this condition, the total active power load in the network is approximately **283 MW**.

To reduce the burden on the grid and improve voltage stability, we assume that a portion of the total active power demand is supplied through Distributed Generation (DG) using solar photovoltaic (PV) systems. Based on earlier assumptions, **one-third (1/3rd)** of the total active load is planned to be supported by distributed solar power. Therefore, the required active power contribution from DG sources is calculated as:

Active Power from DG=283/3 MW ≈ 94.33 MW

To distribute this injected power efficiently and achieve maximum voltage support, the DG capacity of **94.33 MW** is divided across **three different buses** in the network. The selection of these buses is not random; instead, they are identified based on their voltage performance under the existing load condition.

First, a **base-case load flow analysis** is carried out using the Newton-Raphson (NR) method. This provides the initial voltage profile of the system without any DG support. By examining the results, we identify the **weakest buses**, i.e., buses with the lowest voltage magnitudes and highest vulnerability to voltage instability. These weak buses are the most suitable locations for DG placement, as injecting active power at these nodes can significantly improve their voltage levels and enhance the overall stability of the power network.

Thus, the three weakest buses identified from the base-case voltage profile are selected as optimal points for DG installation. The active power injection from solar PV sources is then introduced at these buses, and further load flow studies are performed to analyze the improvements in voltage profile, system losses, and overall grid performance.

Table 2 Voltage Magnitudes of top three weakest buses(Case1)

S.No.	**BUS NO.**	**VOLTAGE VALUE**
01	**30**	**0.994**
02	**7**	**1.000**
03	**26**	**1.007**

For this case the total losses came out to be 17.646MW and 8.446MVAR. These buses are then injected with active power of 40MW each which resulted in increase in the node voltage of the target buses as follows:-

Bus 30:- 0.994pu —> 1.079 p.u.

Bus 07:- 1.000pu —> 1.011 p.u.

Bus 26:- 1.007pu —> 1.116 p.u.

Also, the voltage of adjacent buses is subjected to some change for this case we have seen decrease in overall losses which now comes out to be 12.913MW and 7.708 MVAR.

To maintain the voltage value around 1pu we now calculated the amount of reactive power which needs to be supplied /absorbed which is represented in below. Pictorial and tabular form

Table 3 Determination of required Reactive Support (Case1)

S.No.	BUS NO.	Qsupplied/absorbed(MVAR)
01	30	-5.81
02	7	-7.37
03	26	-12.78

Here the negative sign signifies that the reactive power needs to be absorbed.

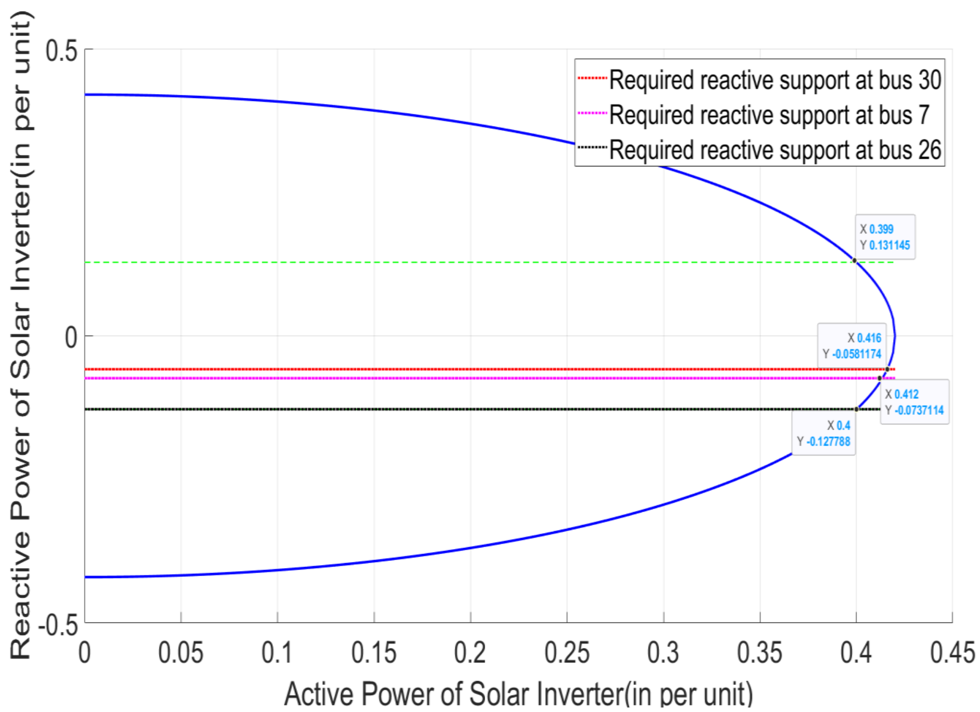


Figure 3 Reactive support needed at specified buses(Case 1)

For this case the total loss came out to be 15.662MW and 0.017MVAR.

This increase in loss can be justified from the voltage-profile represented in tabular form in tableno. 4 which depicts that between some of the nodes the voltage difference is increasing which leads to the increases in losses.

Table 4 Comparison of Voltage Values in all three sub scenarios(Case1)

S.No.	Bus No.	Voltages(in p.u.)		
		Without DG	Only P	P + Q
1	1	1.060	1.060	1.060
2	2	1.043	1.043	1.043
3	3	1.021	1.027	1.024
4	4	1.012	1.019	1.016
5	5	1.010	1.010	1.010
6	6	1.011	1.017	1.013
7	7	0.999	1.010	1.004
8	8	1.010	1.010	1.010
9	9	1.050	1.051	1.044
10	10	1.043	1.041	1.029
11	11	1.082	1.082	1.082
12	12	1.057	1.055	1.049
13	13	1.071	1.071	1.071
14	14	1.042	1.040	1.031
15	15	1.037	1.037	1.026
16	16	1.044	1.042	1.034
17	17	1.038	1.036	1.025
18	18	1.027	1.026	1.015
19	19	1.024	1.023	1.011
20	20	1.028	1.027	1.015
21	21	1.031	1.029	1.013
22	22	1.032	1.030	1.013
23	23	1.026	1.028	1.009
24	24	1.021	1.026	0.995
25	25	1.018	1.048	0.981
26	26	1.000	1.116	1.000
27	27	1.025	1.042	0.983
28	28	1.010	1.021	1.012
29	29	1.005	1.054	0.985
30	30	0.993	1.078	1.000

Pictorial comparison of the same is given figure 4.

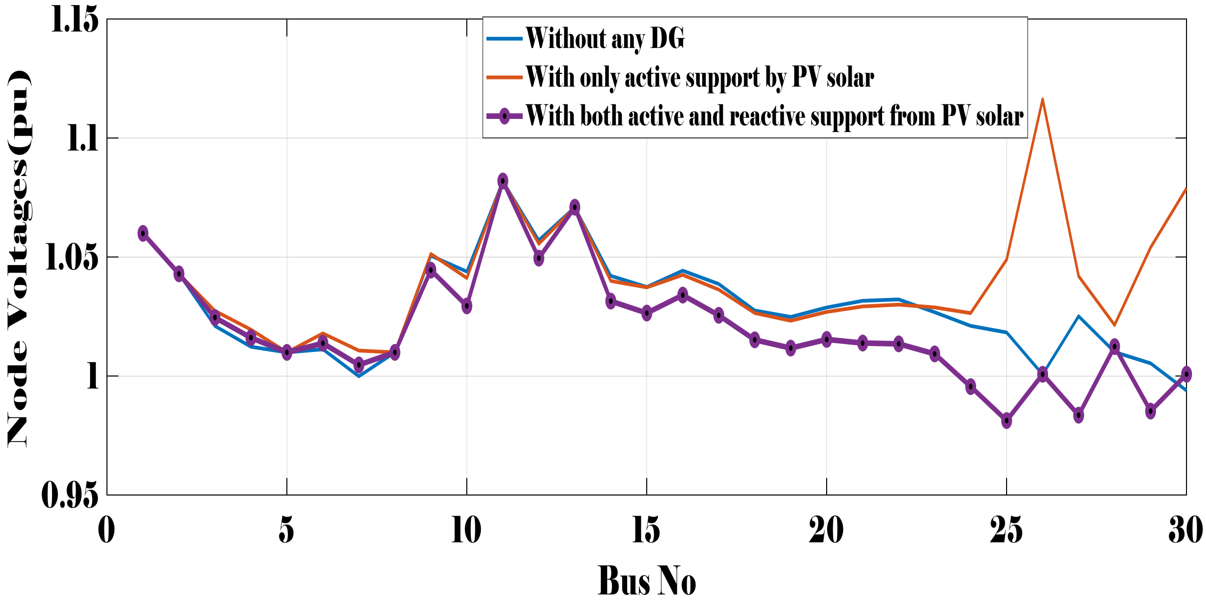


Figure 4 Voltage profile for different sub-cases(Case 1)

After reviewing all three sub cases we have calculated in table no. 5.

Table 5 Comparison of Active and Reactive Losses(Case1)

SUB-CASE	LOSSES	
	ACTIVE POWER LOSS(MW)	REACTIVE POWER LOSS(MVAR)
WITHOUT DG	17.646	22.446
ONLY P	12.913	7.708
P+Q SUPPORT	15.662	0.017

CASE -II

The default IEEE 30 bus system seems to be too ideal as all the node voltages are already near to 1 p.u. but practically there is a wide range of uncertainty in these node voltages.

Thus, we news to increase the load factor which will lead to variations in nodes voltages near to the real-world scenario hence for this case we have considered the load factor =1.5 i.e. lambda =0.5.

Now the total load is 425.1 MW and the active power injected will be (425.1)/3

=141.7MW

(Which will be given to three weakest buses.)

Base case analysis suggests us the following buses to be suitable for power injection:-

Table 6 Voltage Magnitudes of top three weakest buses(Case2)

S.No.	BUS NO.	VOLTAGE VALUE(p.u.)
01	**30**	**0.9061**
02	**26**	**0.9190**
03	**29**	**0.9252**

Considering the base case the total losses are absorbed as 44.309MW and 132.19 MVAR.

On injection of the above suggested/calculated active power the change in node voltages is as follows:-

Bus 30:- 0.9061pu —> 1.015 p.u.

Bus 26:- 0.9190pu —> 1.026 p.u.

Bus 29:- 0.9252pu —> 1.019 p.u.

And the line losses are 38.399MW and 87.439MVAR.

For further stability, we need reactive power support on each of these buses. The required reactive support is as follows:-

Table 7 Determination of required Reactive Support(Case2)

S.No.	BUS NO.	Qsupplied/absorbed(MVAR)
01	30	0.84
02	26	-2.57
03	29	-2.16

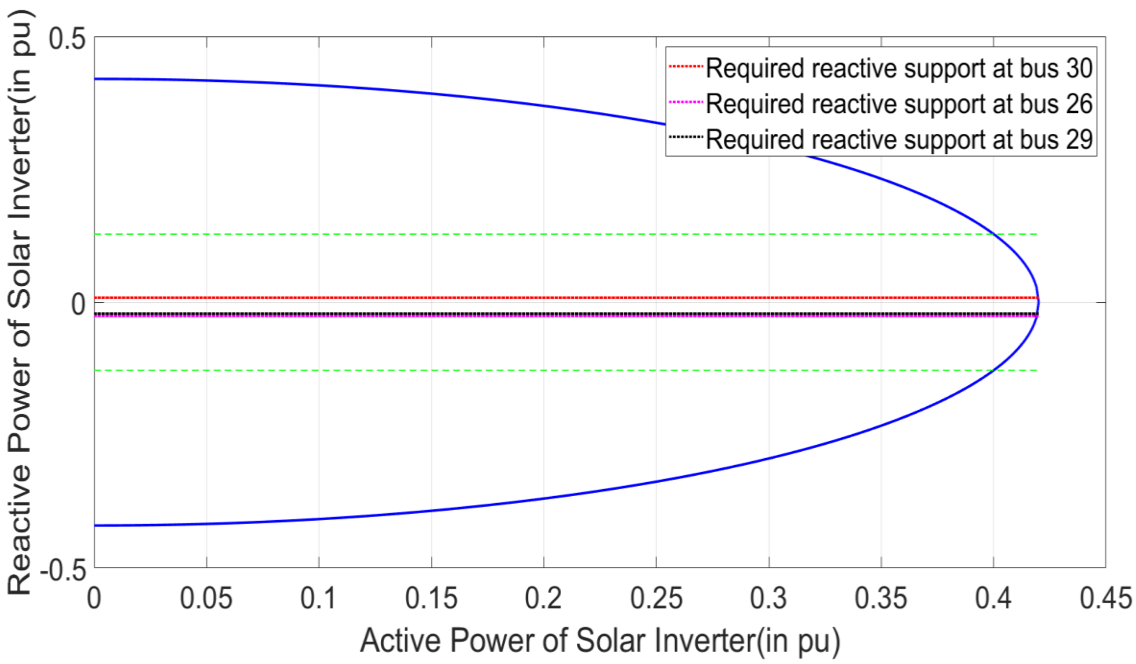


Figure 5 Reactive support needed at specified buses (Case 2)

A tabular comparison of voltage values among these three sub-cases are given in table:-

Table 8 Comparison of Voltage Values in all three sub scenarios(Case2)

S.No.	Bus No.	Voltages(in p.u.)		
		Without DG	Only P	P + Q
1	1	1.060	1.060	1.060
2	2	1.013	1.013	1.013
3	3	0.982	0.990	0.990
4	4	0.967	0.976	0.975
5	5	0.960	0.950	0.950
6	6	0.964	0.970	0.969
7	7	0.944	0.943	0.943
8	8	0.970	0.970	0.970
9	9	1.012	1.008	1.007
10	10	0.992	0.980	0.977
11	11	1.082	1.082	1.082
12	12	1.022	1.013	1.011
13	13	1.071	1.051	1.051
14	14	0.997	0.985	0.983
15	15	0.988	0.978	0.976
16	16	0.998	0.988	0.986
17	17	0.985	0.974	0.971
18	18	0.970	0.959	0.956
19	19	0.964	0.953	0.950
20	20	0.970	0.958	0.956
21	21	0.972	0.958	0.954
22	22	0.973	0.959	0.955
23	23	0.967	0.956	0.952
24	24	0.953	0.942	0.935
25	25	0.947	0.961	0.946
26	26	0.919	1.025	0.999
27	27	0.958	0.961	0.947
28	28	0.961	0.973	0.970
29	29	0.925	1.019	0.999
30	30	0.906	1.014	0.999

These voltage values have been represented as :-

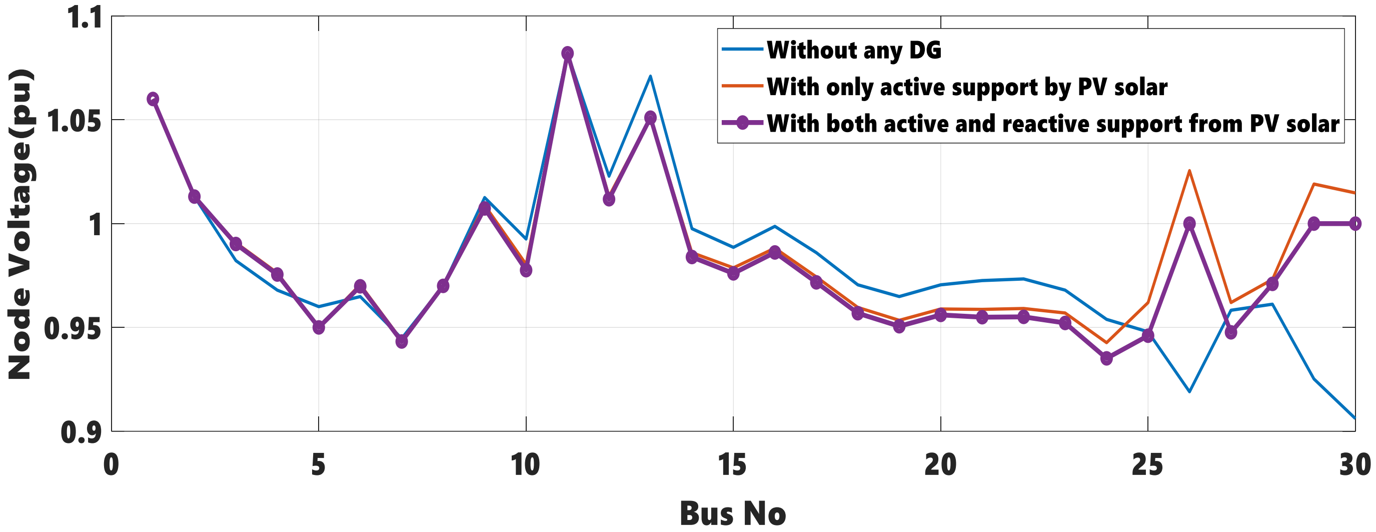


Figure 6 Comparision of different voltage profiles (Case 2)

Proceeding further, line losses of all three sub-cases are :-

Table 9 Comparison of Active and Reactive Losses(Case2)

SUB-CASE	**LOSSES**	
	ACTIVE POWER LOSS(MW)	REACTIVE POWER LOSS(MVAR)
WITHOUT DG	44.309	132.19
ONLY P	38.399	87.439
P+Q SUPPORT	39.221	90.225

CASE -III

For having a better idea of practical/real world scenarios we have considered one more case where we have increased the initial load 2.05 times that means load factor= 2.05 i.e. lambda=1.05

Subsequently the total load becomes 580.97 MW and the extra active power given will be- 580.97/3

= 193.65MW

For base case the top three weakest buses will be :-

Table 10 Voltage Magnitudes of top three weakest buses(Case3)

S.No.	BUS NO.	VOLTAGE VALUE
01	30	0.8078
02	26	0.8271
03	29	0.877

In this the above case the total active losses calculated are 95.139MW and similarly total reactive losses comes out to be 335.53 MVAR.

After providing the active power to weakest buses changes in voltage will be:-

Bus 30:- 0.8078pu —> 0.923 p.u.

Bus 26:- 0.8271pu —> 0.929 p.u.

Bus 29:- 0.8377pu —> 0.936 p.u.

Further calculation of losses given value of active power losses=76.024MW and reactive power loss= 241.005 MVAR.

As voltages values are still not close to 1 per unit hence a reactive support will be provided which is as given in table no. 11.

Table 11 Determination of required Reactive Support(Case3)

S.No.	BUS NO.	Qsupplied/absorbed(MVAR)
01	30	5.98
02	26	9.96
03	29	0.82

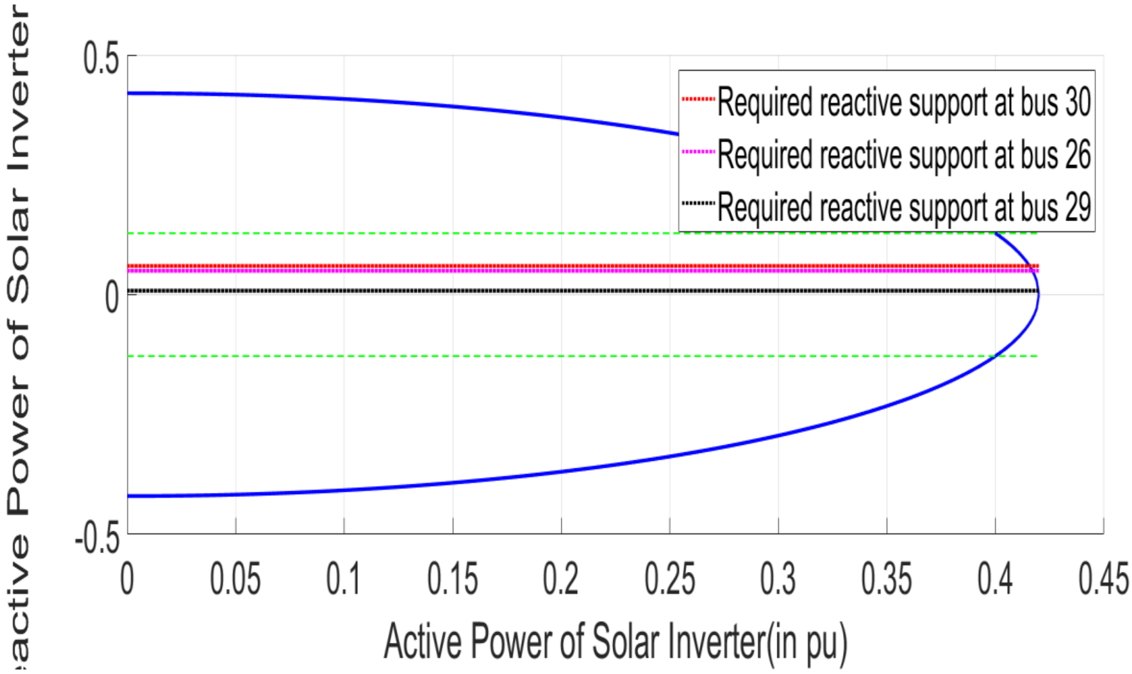


Figure 7 Reactive support needed at specified buses (Case 3)

For better understanding we have computed the voltage values of all three sub-scenarios in table no. 12:

Table 12 Comparison of Voltage Values in all three sub scenarios(Case3)

S.No.	Bus No.	Voltages(in p.u.)		
		Without DG	Only P	P + Q
1	1	1.060	1.060	1.06
2	2	0.993	0.993	0.993
3	3	0.944	0.944	0.950
4	4	0.928	0.923	0.930
5	5	0.960	0.910	0.910
6	6	0.933	0.916	0.925

7	7	0.917	0.885	0.890
8	8	0.960	0.920	0.930
9	9	0.975	0.957	0.967
10	10	0.936	0.906	0.922
11	11	1.082	1.082	1.082
12	12	0.975	0.947	0.961
13	13	1.051	1.021	1.031
14	14	0.938	0.908	0.923
15	15	0.925	0.897	0.914
16	16	0.942	0.913	0.928
17	17	0.925	0.896	0.911
18	18	0.900	0.870	0.887
19	19	0.892	0.862	0.879
20	20	0.901	0.871	0.888
21	21	0.906	0.873	0.892
22	22	0.906	0.874	0.894
23	23	0.895	0.865	0.889
24	24	0.876	0.844	0.876
25	25	0.871	0.870	0.926
26	26	0.827	0.928	1.002
27	27	0.889	0.882	0.938
28	28	0.927	0.916	0.930
29	29	0.837	0.933	1.001
30	30	0.807	0.922	1.001

A pictorial representation of these values is given in figure________

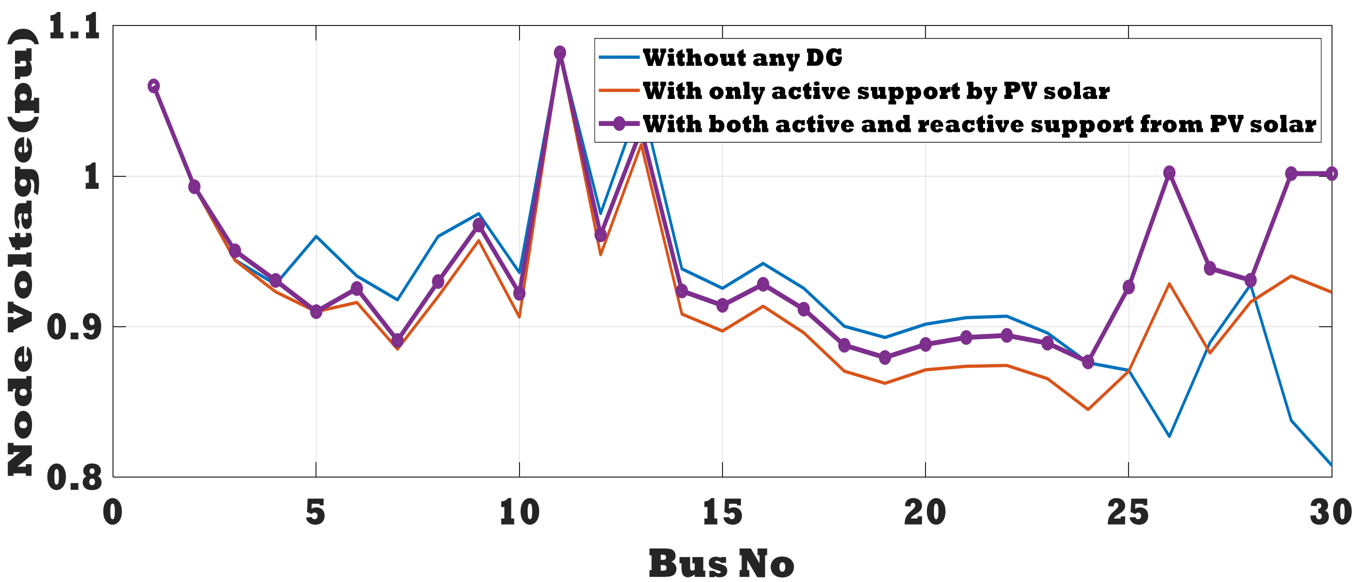


Figure 8 Comparision of different voltage profiles (Case 3)

Also, the line losses of all three sub-scenarios are :-

Table 13 Comparison of Active and Reactive Losses(Case3)

SUB-CASE	**LOSSES**	
	ACTIVE POWER LOSS(MW)	REACTIVE POWER LOSS(MVAR)
WITHOUT DG	95.139	335.53
ONLY P	76.024	241.005
P+Q SUPPORT	72.624	226.28

5. Conclusion

Voltage stability is one of the most critical pillars of a reliable power system, as even minor fluctuations can trigger significant equipment damage or, in extreme cases, widespread grid blackouts. Maintaining stable voltage levels is therefore essential, and finding solutions that achieve this without adding extra financial burden is highly valuable. In this context, utilizing existing infrastructure—such as solar inverters—to enhance voltage regulation becomes an efficient and practical approach.

In our study, we thoroughly examined the feasibility of implementing a Volt/VAR (V/VAR) control method using photovoltaic (PV) inverters. This was done through detailed loss calculations and an evaluation of node voltage profiles under various power factor conditions. The results demonstrated that solar inverters can effectively function as both sources and sinks of reactive power, providing much-needed voltage support. Remarkably, we were able to increase the system load by a factor of 2.05 while keeping the node voltage close to 1 per unit. Additionally, this approach helped reduce total system losses by 24.21% in Case 3, highlighting its technical and operational benefits.

Overall, the findings strongly reinforce the potential of PV inverters in improving grid stability through reactive power compensation. By leveraging equipment that is already part of the system, utilities can enhance voltage stability without incurring significant additional costs. This method not only strengthens grid resilience but also supports the broader integration of renewable energy sources, making it a practical and forward-looking solution for modern power networks.

6. FUTURE SCOPE

7. BIBLIOGRAPHY

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