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Impact of High Penetration of Solar PV Output to Line Loading, Voltage and Power Losses

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ABSTRACT

This paper presents the impact of high penetration of solar photovoltaic (PV) power plant to the grid on the line loading, voltage and power losses. In this study, the simulation works is done for IEEE 30 bus test system using Power System Simulation for Engineers (PSSE) software with and without solar PV integration. Simulation results show that high PV penetration of solar PV output causes higher line loading, introduce voltage variation and power losses in the network which might disturb the performance of the network.

Key words: high penetration. solar PV, transmission, voltage stability.

1. INTRODUCTION

The direct interconnection of utility-scale PV plant to the transmission level would be a good option for Malaysia since the high potential for Malaysia to receive abundant sunshine and thus solar radiation. Utility scale PV plant was first connected to the transmission level (230kV) in 2009 at Florida, USA. It then caught interest many countries to develop utility-scale PV plant in order to grab the opportunities of free sources of energy to produce electricity [1-5].

However, the implementation of large-scale PV needs specialized control to maintain reliability, stability and integrity of the grid. Solar has different characteristics compared to conventional thermal generators where the output power produced really affected by the weather condition and cannot be controlled by the load. During high penetration of solar PV output, the scenario of too much supply happen and affect the performance of the grid [6-10].

Duck curve has been used by researchers to represent power production over the course of a day. It shows timing imbalance between peak demand and electrical supply from the renewable energy. It was introduced by the California Independent System Operator (ISO) in 2012 [11-13]. California ISO in [14] performed daily detailed analysis form year 2012 to 2020 to study the behavior of grid conditions with the possibilities of oversupply risk. Over generation can occur in a short duration which affect adjacent area and can also affect wider area if oversupply happen in longer duration.

Grid system with renewable energy is easily controlled if demand and supply are matched. However, when both of it in opposite directions, it may affect the voltage stability in the system. The stability of the voltage for each bus within the allowable voltage range in the grid system is very important to maintain the continuation of power to be supplied in the grid. Otherwise the instability of the voltage reading will lead to blackout [15-17].

The system with high penetration renewable energy may also cause the system to carry high line loading and introduce more losses [18]. The cost to accommodate will also be higher. For example, when the demand is low while the renewable supply is high, the power produced can only be used if the power from the conventional generations are curtailed but this option is inefficient, expensive and may cause significant reliability issue [19-20].

Danling et. al in [21] study the impact of high penetration of solar PV output to the voltage fluctuation, power losses, voltage imbalance and exceedance of transformers and cable ratings. The paper also mentioned to use inverter's inherent reactive power to offset the real power effect which mitigate the voltage effect.

Based on case studies in Central Taiwan Science Park (CTSP) and Penghu Island, Taiwan, Yuan et. al in [22] investigate three types of technical challenges due to high penetration solar PV output to the grid which are voltage fluctuation, frequency regulation and transmission loss.

Temitayo in [23] discussed the future technical challenges on the grid connected to solar PV output and has categorized into six segments such as feeder issues, communication, cybersecurity, control, regulation issues as well as technology and techniques. During high penetration solar PV output, the author discussed the issue related to voltage fluctuations, power quality issue, dynamic stability and many more.

Adil Khan et. al in [24] in their simulation to study the voltage profile and stability analysis of grid connected to solar PV revealed that during high penetration of solar PV output will cause increase in voltage level and disturb the stability of voltage profile which lead the system to unstable. High PV penetration also affect the line loading, power quality faults current and load-supply mismatch.

This paper presents the impact of high penetration solar PV output to the line loading, voltage and power losses using simulations work for the IEEE 30 bus test system connected to the PV plant with high penetration solar PV output and analysis was done on the voltage variation, percentage of line loading and power losses for the affected busses and lines. The results give benefit to the researchers to study the impact of high penetration solar PV to the grid and study the mitigation way to solve power congestion issue.

2. METHODOLOGY

To observe the impact of high penetration solar PV output on the line loading, voltage and power in the system, 30 bus test system was developed based on IEEE data test system using Power System Simulator for Engineering (PSSE) Software. The diagram of the 30 bus test system is shown on Figure 1.

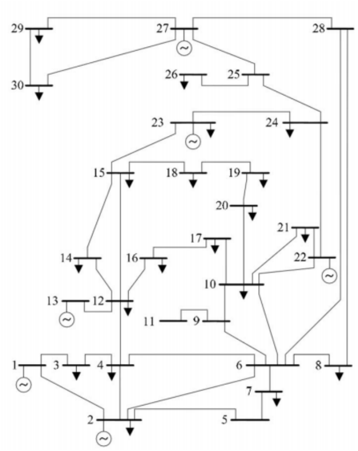

Figure 1: 30 bus standard IEEE test system without solar PV generator.

To study the impact of high penetration solar PV output to the grid, the system was first stabilized without solar PV generator to ensure it is stable. A utility size solar PV plant is then connected to one of the bus which was selected randomly. In this simulation works, the solar PV output was connected at bus number 6. Bus 6 is connected to bus number 2, 4, 7, 8, 9, 10 and 28. The observation has been made to all the buses and lines connected to bus number 6 to study the impact of high penetration solar PV to the local area.

The output of the solar PV is increased every 50 MW from 0 MW until the line loading show the system is stressed where the reading of the line loading is approaching 100 percent which indicate power congestion occur. Voltage reading for the related buses are recorded every time the output from solar PV output increased. Power losses are also calculated to observe the impact of high penetration solar PV to the power losses of the grid. The flowchart of the simulation works is presented in Figure 2.

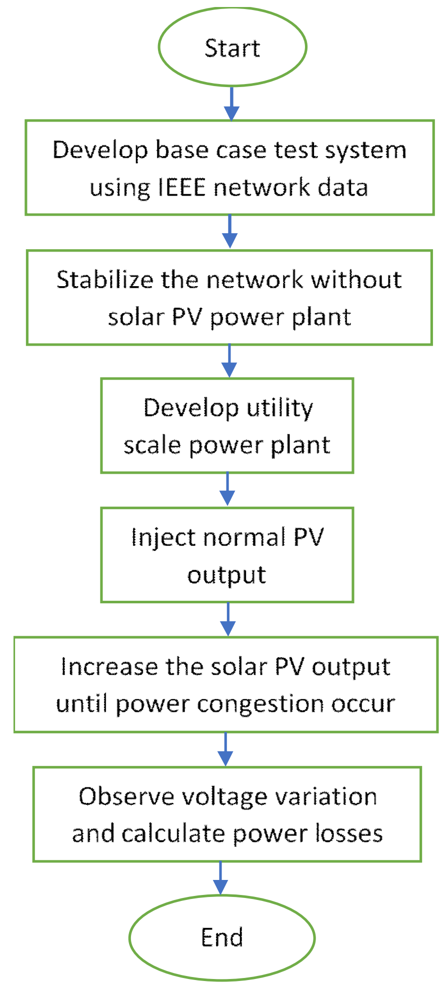

Figure 2: Flowchart

3. RESULT AND DISCUSSION

Figure 3 shows the stabilized local grid for the branches connected to bus number 6 when there is no PV generator connected to the system.

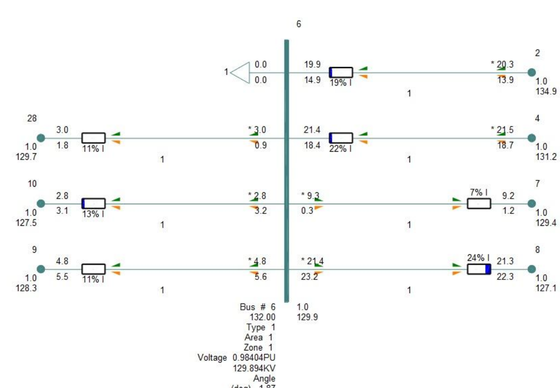

Figure 3: Local area of bus number 6

The reading for the voltage for all the busses are within the safety limit 0.95 p.u. to 1.05 p.u. and listed in Table 1 while the line loading for all the branches are less than 100 percent.

Table 1: Voltage reading for the busses connected to bus 6

Bus	Voltage
2	1.022
4	0.9937
6	0.984
7	0.9806
8	0.9631

After PV generator has been connected to bus number 6, the results of line loading, voltage and power as shown in Figure 4 to Figure 9 are captured to observe the impact of high penetration of solar output to the grid. The output of solar PV is increased every 50 MW until it reaches 300 MW.

From the captured figure, the percentage of the line loading for all busses are increased from Figure 4 to Figure 9. From the observation made, the most affected line on the loading percentage is the line connecting bus number 6 to 4. The line loading for this line is 15 percent in Figure 4 where the output of the solar PV is set 50 MW, it increases to 49 percent in Figure 5 when the solar PV output is 100 MW, increases again to 69 percent in Figure 7 when the solar PV output is 150 MW, keep increasing until finally achieve 99 percent line loading in Figure 9 when the solar PV output injected is 300 MW.

The results show that high penetration solar PV increase the percentage of the loading and can cause power congestion in the grid.

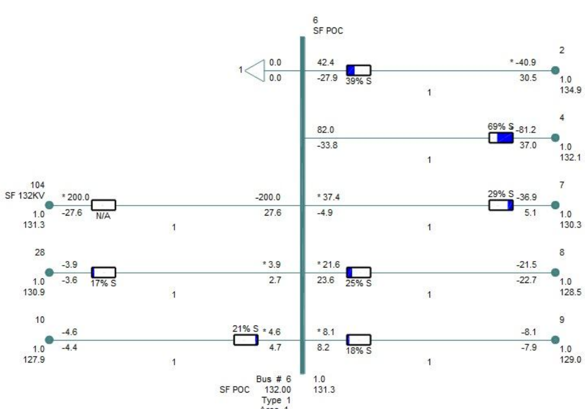

Figure 4: Simulations result for 50MW solar output

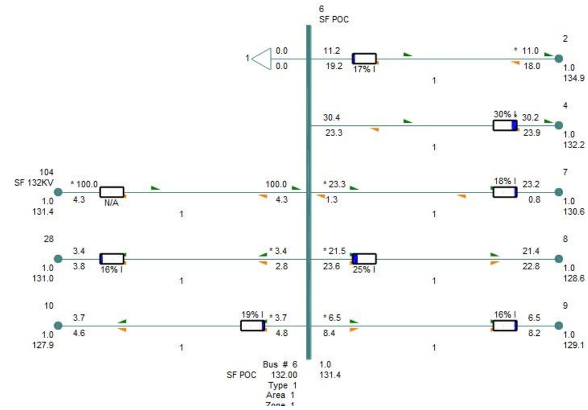

Figure 5: Simulations result for 100MW solar output

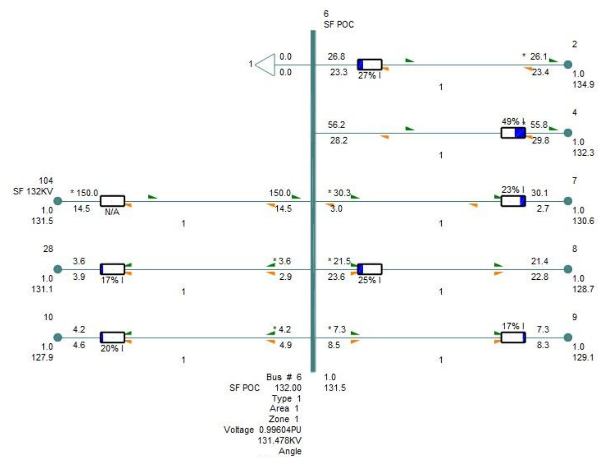

Figure 6: Simulations result for 150MW solar output

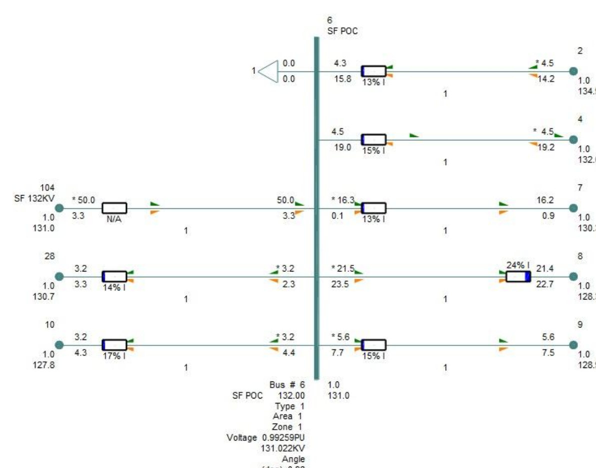

Figure 7: Simulations result for 200MW solar output

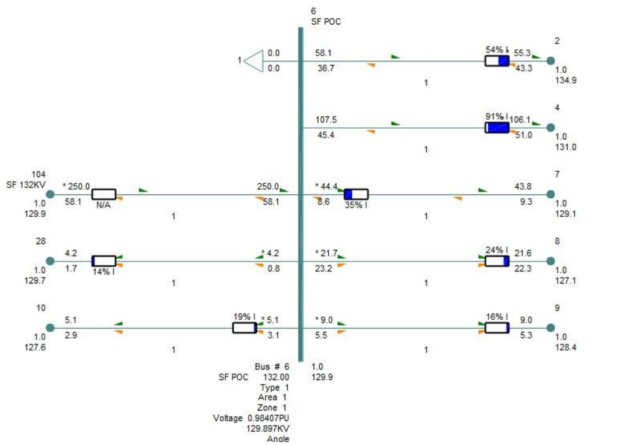

Figure 8: Simulations result for 250MW solar output

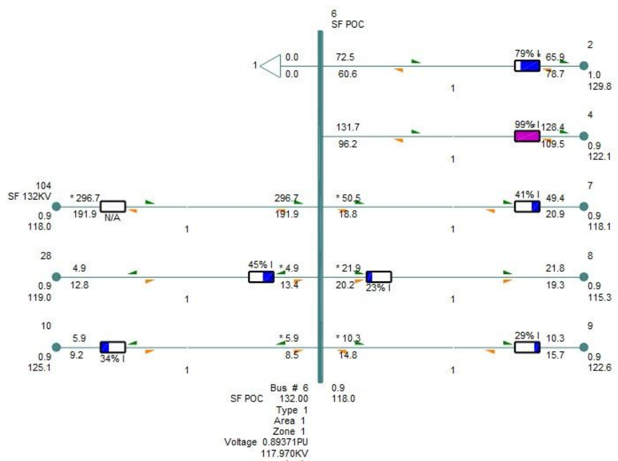

Figure 9: Simulations result for 300MW solar output

The line loading percentage shows increment when the solar output increases until it achieves 99% and this value is expected to increase more if the solar output is keep increasing. If the condition repeated frequently, it might reduce the lifetime of the cable and other equipment since it need to carry more power compared to the allowable maximum power that can be carried.

To study the impact of high PV penetration on voltage variation, the voltage reading for each bus from Figure 5 to Figure 9 are recorded in Table 2.

Voltage reading are varies due to high penetration solar PV output until it goes beyond the safety limit of transmission voltage allowance which is from 0.95 p.u. to 1.05 p.u.. Based on the data, graph in Figure 10 is tabulated to observe the trend in the voltage reading for each busses. The voltage for most of the busses are within the range of of 0.95 p.u. to 1.05 p.u. when the solar PV output injected to the grid up to 150 MW and the voltage reading started to reduce after 150 MW injected to the grid.

Finally, the voltage reading go beyond the safety range of less than 0.95 p.u. when the solar PV output supplied to the grid increased around 275 MW. In the real application, this condition may cause voltage instability and will lead the electrical supply to be discontinued.

Table 2: Voltage variation for different value of PV output

Bus	Voltage					
	50 MW	100 MW	150 MW	200 MW	250 MW	300 MW
2	1.022	1.022	1.022	1.022	1.022	1.0063
4	0.9998	1.0018	1.0021	1.0006	0.9928	0.965
6	0.9926	0.9953	0.996	0.9946	0.9841	0.9481
7	0.9873	0.9891	0.9892	0.9874	0.9779	0.9442
8	0.9716	0.9743	0.975	0.9736	0.9631	0.9275
9	0.9763	0.9777	0.9782	0.9776	0.9725	0.9552
10	0.9678	0.9686	0.9689	0.9687	0.9666	0.9591
28	0.9902	0.9927	0.9933	0.9919	0.9824	0.9502

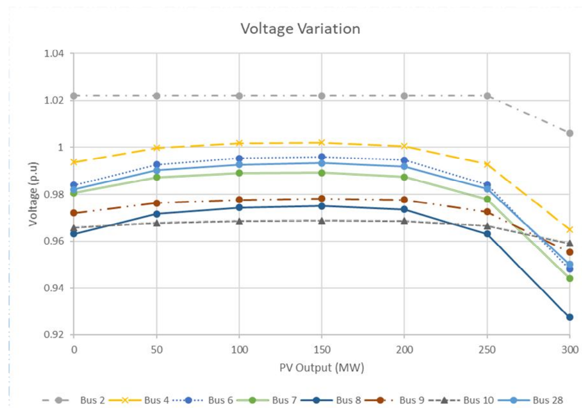

Figure 10: Trend in voltage reading for busses connected to bus 6

In the real application, the voltage stability need to be preserved in order to maintain the voltage in the safety range to operate. Normally safety precaution of load shedding will be applied if the voltage reading goes beyond the safety range within a few seconds to maintain safety stability.

To study the impact of high PV penetration to the grid on power loss for each busses, Table 3 (a) and 3(b) list out the calculated losses from each busses due to high penetration solar PV output to the grid.

Figure 11 shows the losses for the real power. The most affected branch is line connecting bus number 2 to 6. The power decreases when the output of solar power increases from 0 MW to 100 MW. At 150 MW, the real power loss at this branch is increases and reach 5.1 MW which is very high.

Figure 12 shows the reactive power losses. Again, the branch connecting bus number 6 to 2 is the most affected branch when the solar PV output increases up to 300 MW. As all known, solar PV output only supply real power.

Power losses is another factor to be considered during high penetration solar PV output to ensure that the excess power from the solar PV are manageable and efficiently distributed to the needed area and not trapped in the local area.

Table 3(a) Power Losses for Each Busses from 0 MW to 150 MW Output Power

Branch	0 MW			50 MW			100 MW			150 MW		
	Ploss	Qloss	Sloss	Ploss	Qloss	Sloss	Ploss	Qloss	Sloss	Ploss	Qloss	Sloss
6 2	0.4	-1	1.077	0.2	-1.6	1.612	0.2	1.2	1.217	0.7	-0.1	0.707
6 4	0.1	0.3	0.316	0	-0.2	0.200	0.2	-0.6	0.632	0.4	-1.6	1.649
6 7	0.1	-0.9	0.906	0.1	-0.8	0.806	0.1	0.5	0.510	0.2	0.3	0.361
6 8	0.1	0.9	0.906	0.1	0.8	0.806	0.1	0.8	0.806	0.1	0.8	0.806
6 9	0	0.1	0.1	0	0.2	0.2	0	0.2	0.2	0	0.2	0.2
6 10	0	0.1	0.1	0	0.1	0.1	0	0.2	0.2	0	0.3	0.3
6 28	0	-0.9	0.9	0	-1	1	0	-1	1	0	-1	1

Table 3(b) Power Losses for Each Busses from 200 MW to 300 MW Output Power

Branch	200 MW			250 MW			300 MW		
	Ploss	Qloss	Sloss	Ploss	Qloss	Sloss	Ploss	Qloss	Sloss
6 2	1.3	-2.6	2.907	2.8	-6.6	7.169	5.1	-13.4	14.338
6 4	0.8	-3.2	3.298	1.4	-5.6	5.772	2.5	-9.9	10.211
6 7	0.5	-0.2	0.539	0.6	-0.7	0.922	0.9	-1.5	1.749
6 8	0.1	0.9	0.906	0.1	0.9	0.906	0.1	0.8	0.806
6 9	0	0.3	0.3	0	0.2	0.2	0	-0.3	0.3
6 10	0	0.3	0.3	0	0.2	0.2	0	-0.2	0.2
6 28	0	-0.9	0.9	0	-0.9	0.9	0	0.9	0.9

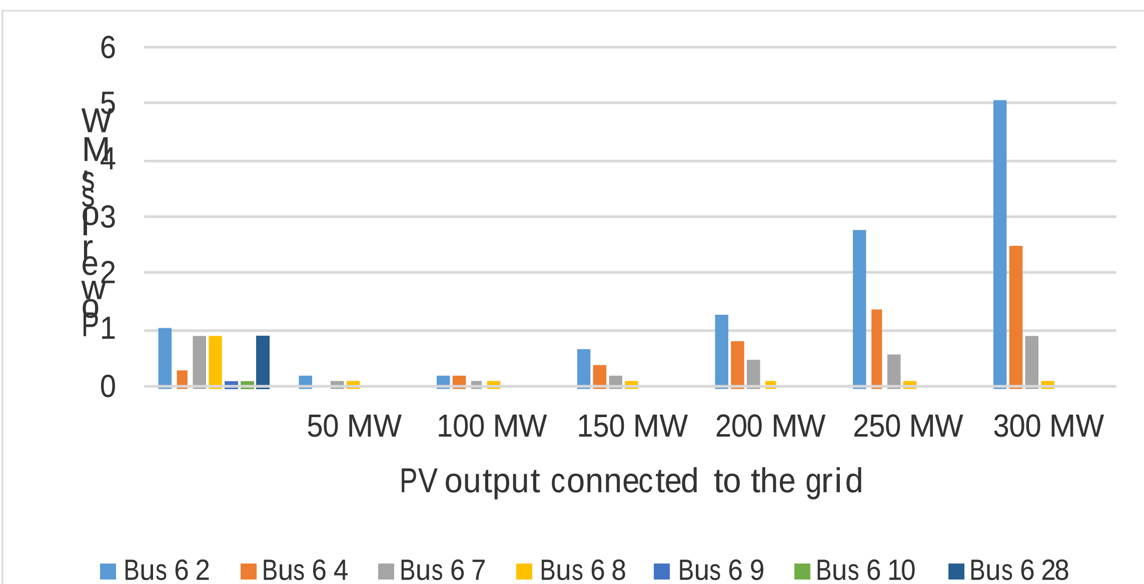

Figure 11: Real power losses

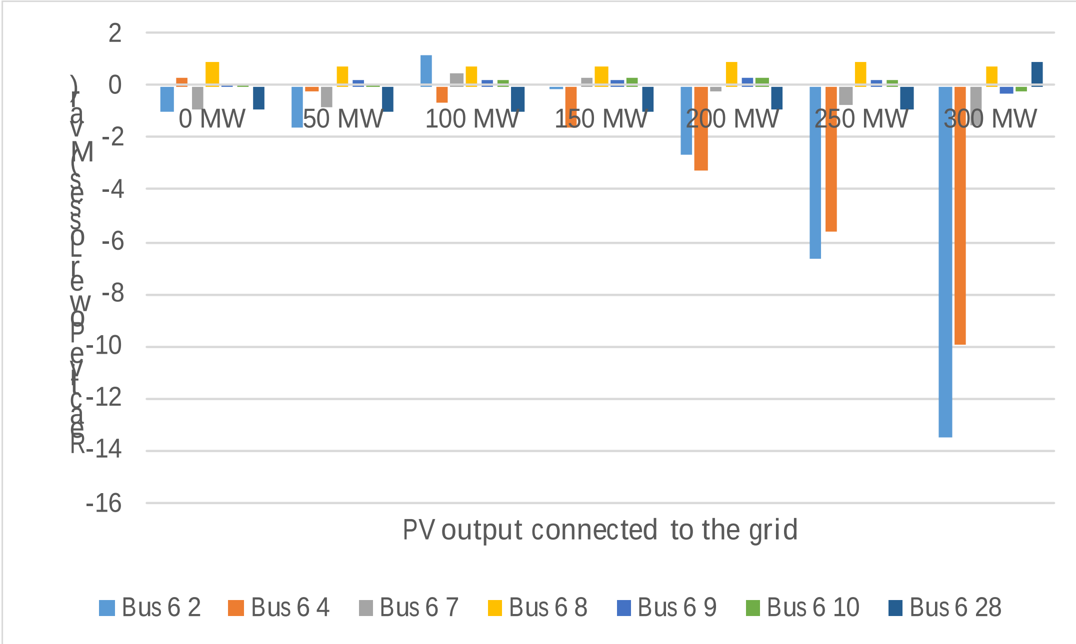

Figure 12: Reactive power losses

5. CONCLUSION

This paper has presented the impact of power congestion during high penetration of solar PV output to the network system by simulation works of standard 30 bus IEEE test system using PSSE software. The impact of the high penetration of solar PV output on the line loading, power losses and voltage variation in the network is observed and analyzed to understand the effect of high penetration solar PV output to the grid.

From the simulation results, it proves that the impact of high penetration solar PV output will cause voltage variation and might cause power losses in the grid and the results show that the scenario of instability occur in the grid system with large scale solar PV plant.

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