Voltage Stability Analysis of Grid Connected Photovoltaic Power System

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Abstract* — Performance of the power system can be improved by integrating renewable energy sources into the grid. In this paper various impacts of PV penetration on the performance of an IEEE 14 bus system is studied. Continuation power flow (CPFLOW) is performed on the system without PV system and with gradually increasing the solar power penetration. The solar plant is installed at bus 9 and 14 as these are the weakest buses. The simulation analysis was performed by PSSE (Power System Simulator for Engineers). Results of this research show the benefits of introducing solar power to existing power grid. It increases the power handling capacity of the system and voltage instability was occurring at higher loading factor. Finally, the steady state bus voltages became higher than without PV penetration and at a certain point it exceeds the permissible upper voltage limit, and that's the maximum point up to which, the penetration can be done.

Keywords: Voltage stability, photovoltaic system, PSSE, continuation power flow.

I. INTRODUCTION

Increased production of goods per head, increased prosperity and urbanization, rise in per head consumption, and easiness in energy access are the factors that are responsible for the increase in the total demand of electricity by a significant extent. Having a look at the difference of electricity demand and supply, huge quantities of coal and furnace oil are being used. These usages need to be reduced, as these are leading to tremendous costs in the form of subsidies and increment in the country's dependency on imports. Renewable energy sources have the ability to make a noteworthy contribution in these areas. Due to all of these, renewable energy needs to be studied and utilised to a great extent [1]. Therefore, commissioning of solar power units in the existing grid give rise to problems like, violation of bus voltages beyond the stipulated grid limits, power congestion, abnormal system losses and voltage instability. Solar power has an exceptionally good potential for providing electrical energy that is free & non-polluting. Its effectiveness as an electricity supply source has encouraged ambitious targets for solar PV system in many countries around the world.

II. SOLAR PHOTOVOLTAIC SYSTEM

The most important component of the photovoltaic (PV) system is the solar panels that generate electric power by the direct conversion of the sun's energy into electricity. The solar panels are mostly made with semiconductor material, with Silicon (Si) being widely used. Materials like Gallium (Ga) and Aluminium (Al) have better conversion properties and recently they are increasingly finding their application. The components of the PV system include the electronic devices to interface the PV output and the AC or DC loads.

A major challenge in maximum utilization of solar cells for power generation is improving cell efficiency and optimizing energy extraction. The solar cell can generate maximum power at a specific operating point, but that operating point varies depending on the atmospheric conditions. This varying output limits the ability of utilities to predict output power at a given time for that location and thus creating problem in scheduling their generation. The optimum operating point for the cell to generate the maximum power can be determined from the I-V (current-to-voltage) characteristic.

The voltage-current characteristic of a solar cell has two different regions:

The current source region
The voltage source region

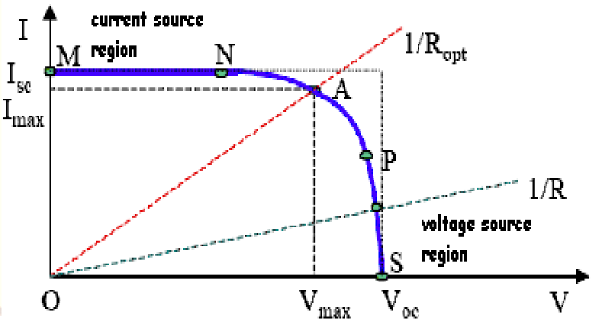

Fig. 1 Typical I-V characteristic of a solar cell

In the first region of the I-V characteristics, the solar cell has high internal impedance and the output current flows with a constant value while voltage keep on increasing, on the other hand the terminal voltage remains constant over a wide range of output current and internal impedance is low in the later region.

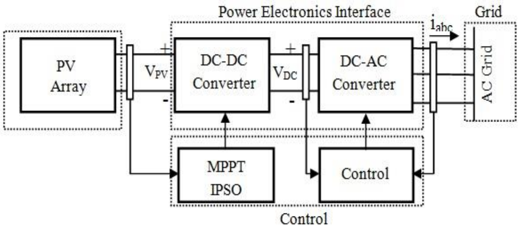

Fig. 2 Solar PV System Connected to Grid

Theory of maximum power transfer states that, “maximum power is delivered to the load when the source internal impedance and the load impedance become exactly same” [11]. Therefore, the impedance of the solar cell at the output side is matched impedance of the load. This will ensure operation of the solar cell at the optimum level. Thus the maximum power operating point can be maintained by controlling either the voltage or output current or both. Since environmental conditions like temperature and irradiance vary the maximum operating point, maintaining the operating point at the optimum point (MPP) becomes unpredictable, resulting in variation in the output power. An MPPT is thus employed to accomplish the task. Most MPPT controllers are based on the buck converter (step-down), boost converter (step-up) or buck-boost converter setup.

III. CONTINUATION POWER FLOW

Singularity of the Jacobian matrix of power flow equation occurs at voltage stability limit. Continuation power flow takes control of this problem. CPFLOW executes successful load flow solutions in accordance to a load scenario.

It comprises of prediction and correction steps. From a known base solution, a tangent (known as predictor) is employed so as to estimate next solution for an outlined pattern of load increase. The corrector step then determines the precise solution using Newton- Raphson technique employed by a traditional power flow. afterward a brand new prediction is formed for an outlined increase in load based upon the new predictor. Then corrector step is applied. This process goes until sensitivity is reached. The sensitive point is that the point where the tangent vector is zero. The flow chart of predictor-corrector scheme is illustrated in Figure 4.

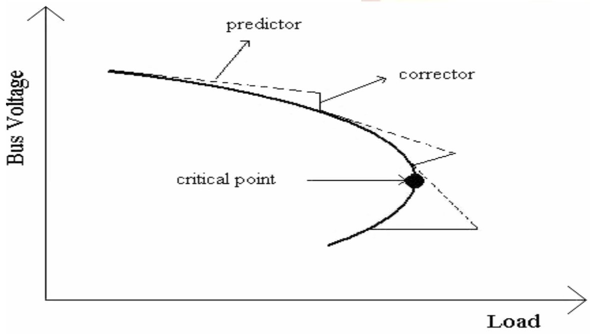

Fig. 3 Illustration of prediction-correction steps

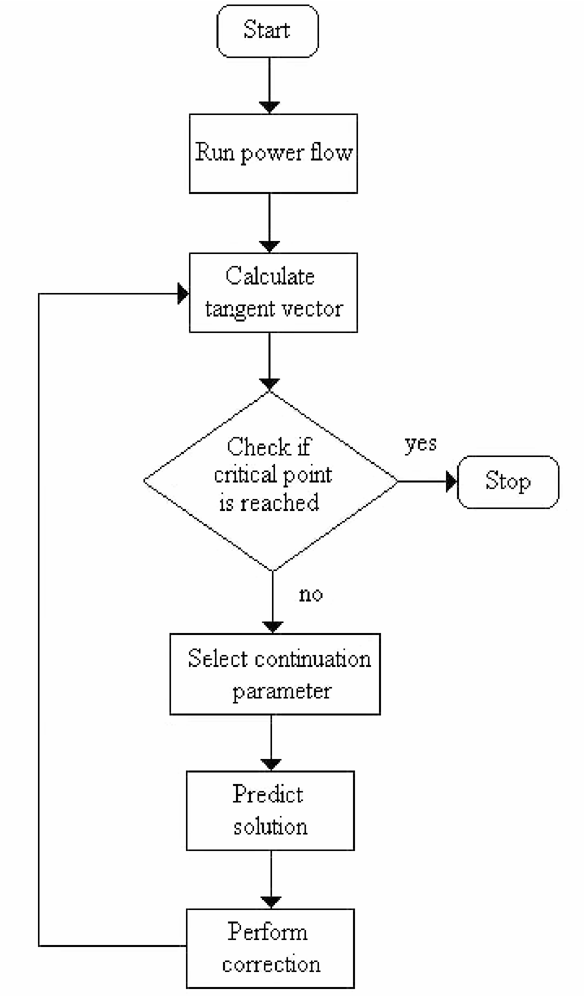

Fig. 4 Flow chart of CPFLOW

IV. MODELLING OF THE COMPONENTS IN PSS/E

PSS/E is capable of performing both steady state analysis and transient analysis. The dynamic simulation feature is to be used here because of its capability to simulate the transient behavior of each and every component used in the system, during a fault and post fault conditions. PSS/E consist of large no of load models built in itself, tap changers, generator models and reactive compensation models. Therefore, it is very important to select proper built in models to simulate the scenario of the system in order to have an accurate detail that matches real life scenarios and thus achieving excellence.

V. OVERVIEW ON IEEE 14 BUS TEST SYSTEM

A mathematical model of standard 14 bus system is created in PSS/E with 100 MVA and 69 KV as base. It consists of 14 buses, 4 transformers, 12 static loads and three voltage levels. The system can withstand the N-1 contingency due to which if tripping of any one of the transmission line or one of the generating unit occures, the system will operate normally. The dynamic file of PSS/E has contained only the dynamic data of the generators.

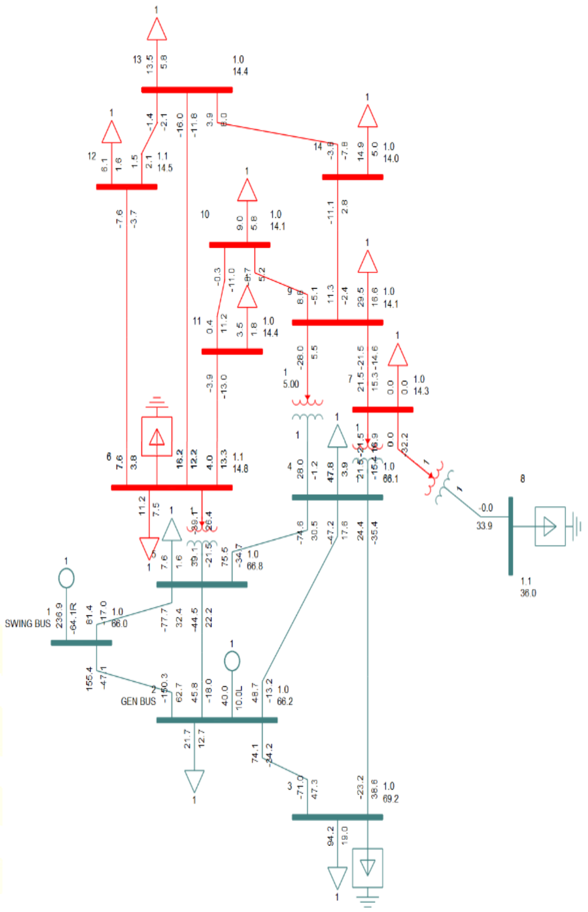

Fig. 5 IEEE 14 bus model in PSS/E

Table. I Line Data for IEEE 14 Bus System

Between Buses	Line Impedence	
	Resistance (Ω)	Reactance (Ω)
1-2	0.92268	2.81708
2-3	2.23719	9.42535
2-4	2.76662	8.3946
1-5	2.57237	10.6189
2-5	2.71139	8.27843
3-4	3.28557	8.14274
4-5	0.63559	2.00486
5-6	0	0
4-7	0	0
7-8	0	0
4-9	0	0
7-9	0	5.23758
9-10	1.51447	4.02305
6-11	4.522	9.46963
6-12	5.85175	12.1791
6-13	3.1494	6.20215
9-14	6.05171	12.8728
10-11	3.9064	9.14445
12-13	10.518	9.51629

Table. II Tap Setting Values for Transformers

Transformers	Tap Ratio	Between Buses
1	0.932	5-6
2	0.969	4-9
3	0.978	4-7

Table. III Bus Data for IEEE 14 Bus Test System

Bus No.	Generation		Load	
	Real Power MW	Reactive Power MVAr	Real Power MW	Reactive Power MVAr
1	232.4	-16.9	0	0
2	40	42.4	21.7	12.7
3	0	23.4	94.2	19
4	0	0	47.8	3.9
5	0	0	7.6	1.6
6	0	0	11.2	7.5
7	0	0	0	0
8	0	0	0	0
9	0	0	29.5	16.6
10	0	0	9	5.8
11	0	0	3.5	1.8
12	0	0	6.1	1.6
13	0	0	13.5	5.8
14	0	0	14.9	5

VI. SIMULATION RESULTS

Continuation power flow has been performed to observe the effects of large scale solar PV integration on the voltage stability. Figures below show the P-V curve for different solar PV penetration levels. The results are also tabulated in table 4. It can be seen from the figure 6 and 7 that for small penetration, the critical point is nearly identical to the base case. However, as we go on increasing the solar PV penetration levels, the voltage stability critical point increases more and more. This indicates that by integrating more distributed photovoltaic power plants, we can improve voltage stability of the system. But, on the other hand, as we increase the penetration level, the voltage level of the buses goes on increasing and it breaches the upper voltage limit at a certain point. Voltage profile of buses with different penetration is also shown in figure 8 and 9.

Table. IV Changes in the Load Margin at Different Penetration Level

PV Penetration Level	Load Margin	% Change
Base Case	853 MW	-
5%	930 MW	9 %
10%	1018 MW	19 %
20%	1088 MW	27.5 %

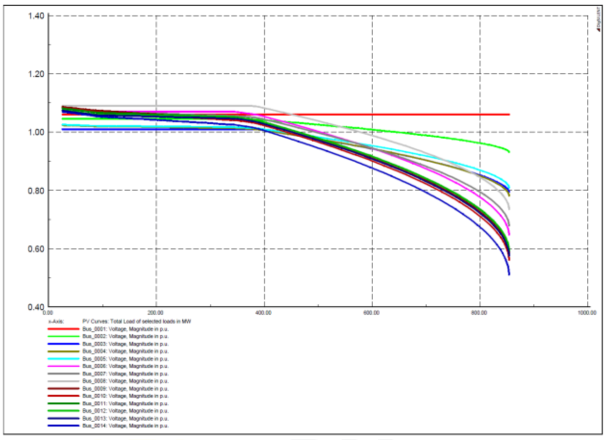

Fig. 6 Power-voltage (P-V) curves for IEEE 14 bus systems without solar

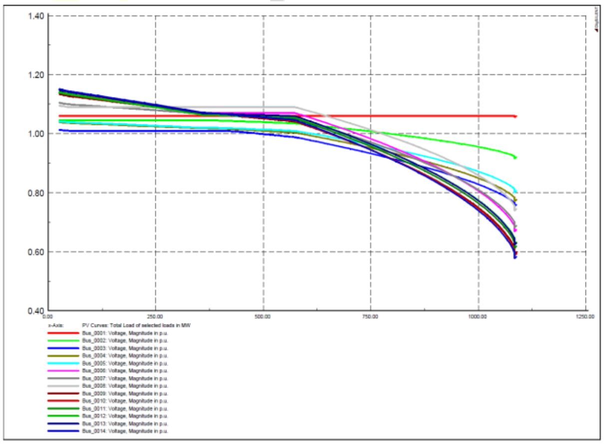

Fig. 7 Power-voltage (P-V) curves for IEEE 14 bus systems with 20% PV penetration

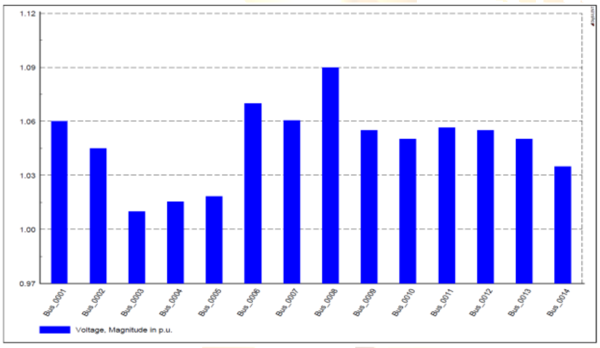

Fig. 8 Voltage profile of buses without solar plants

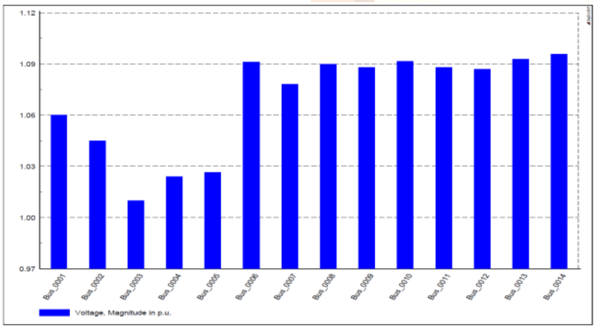

Fig. 9 Voltage profile of buses with 20% penetration

VII. CONCLUSIONS

On the basis of research done here in this report regarding effect of large scale integration of solar PV plant on the power system voltage stability, following conclusions can be made:

The maximum allowable percentage of PV that can be integrated to the existing grid is found to be around 30%. This conclusion is based on frequency deviation in the system under a disturbance. Also, it was found that as the PV penetration into the grid increases, frequency deviation also increases. An equivalent size of conventional generation was deactivated before penetration. This frequency deviation is occurring due to the absence of mechanical inertia which in case of conventional generating units, always present. The maximum allowable percentage of PV that can be integrated to the existing grid is found to be around 30, after further penetration the bus voltages were seen to reach 1.1 per unit. The voltage recovery time is also increased when PV plants are present in the grid. The main cause of this phenomenon is the loss of reactive power.

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