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Voltage Stability Analysis of IEEE118 Bus System with Wind Penetration

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Abstract

The increased penetration of renewable energy sources affects the voltage stability of the system. This article provides steady state voltage stability analysis with wind penetration. The standard IEEE 118 bus system is used for the analysis. The system is modelled in PSSE software and NR-Power flow method is used to perform the power flow studies with various levels of wind penetration. From the load flow studies voltage profile at load buses is analysed through PV curves. System is further studied with reactive power compensation provided at wind generator terminals. All cases are analysed for voltage stability with respect to increase in loading of the system.

Keywords: IEEE 118 System, Shunt Compensation, Voltage Stability, Wind Penetration

1. Introduction

There is an increased emphasis on the development of sustainable energy technology employing renewable energy sources in view of rapidly depleting nature of conventional sources and their environmental effects. India is one of the countries with large production of energy from renewable sources. Among the various renewable energy sources, wind energy electric conversion systems have been found to be viable in contributing sizable value of electric power, when installed in locations where adequate wind potential is available over most of the year. As of November 2020, 38% of India's installed electricity generation capacity is from renewable sources (136 GW out of 373 GW), in that wind energy (39 GW out of 136 GW) is contributing significantly and most rapidly growing one. The role of our country in the global wind energy scenario is remarkable and holds 4th rank in the world.

The National Institute of Wind Energy, India, estimated that the country has a wind potential of more than 300 GW at a hub height of 100 m and solar potential of about 750 GW, assuming 3% waste land is made available[1]. Now, the Government of India has set a target of installing 175 GW of renewable energy capacity by the year 2022, which includes 60 GW from wind energy. With wind energy being increasingly integrating into the power system, the stability of power system is becoming a major concern for the power system planners and operators. Many efforts have been made to study the challenges caused by the integration of wind generators to the grid[2], which includes the generation uncertainty, power quality issues, angular and voltage stability, reactive power support, fault ride-through capability, protection, cyber security, electricity market, planning, socio-economic, and environmental challenges. However, in the grid impact studies of wind power integration, voltage stability is an important issue that can affect the operation and security of power system.

The voltage stability of the system is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. Power system is voltage stable if voltages after a disturbance are close to voltages at normal operating condition. The factors contributing to voltage stability are the generator reactive power limits, load, reactive power compensation devices present in the system and the action of voltage control devices.

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Many researchers have done appreciable work on the impact of wind turbine generators on voltage stability of the grid. IEEE 9 bus system is considered to study the voltage stability of the system by varying the wind speed of a squirrel cage induction generators (SCIG) connected at different busses in the system[3]. Here, the authors particularly addressed the issue of increasing wind energy share in total generation of the network, also it's impact on voltage stability of the network and finally concluded that the increase in the generation of SCIG-based wind farms will have an undesirable effect on voltage stability of whole network and it will decrease the voltage stability margin.

IEEE 14 bus system was studied for voltage stability by varying load in the system after placing the wind driven SCIG at appropriate locations using continuous power flow technique to reduce the real and reactive power losses in the system[4]. IEEE 26 bus system is used to know the margin of loading at every load bus before the voltage collapse at one of the buses in the system after placing a fixed speed pitch regulated wind turbine coupled SCIG at one of the buses in the system[5]. In order to do this study, the authors have developed a probabilistic voltage stability algorithm of wind turbine generating units interconnected with utility grid and power flow analysis has played major role to develop this algorithm.

In this paper IEEE 118 bus system[6] is considered to study the effect of wind energy penetration on steady state voltage stability of the system for various penetration levels. This paper is organized in sections, Section 2 explains the modelling of the system, initial conditions considered for load flow studies and modelling of the wind generators with and without reactive power compensation. Case studies of voltage stability for the basic system, with wind penetration, and with wind and shunt compensation are presented in Section 3. Finally conclusions on the voltage stability analysis and future scope of work are discussed at the end of the paper.

2. Modelling of the System

The standard IEEE 118-bus system is modelled on PSSE software for steady state voltage stability analysis. The system contains 19 synchronous generators, 35 synchronous condensers, 177 lines, 9 transformers, 14 fixed shunt reactive power compensating devices and 99 connected loads. In the load flow studies, the generator bus is modelled as PV bus with constant active power P and constant voltage V. The reactive power limits of synchronous generators are fixed. The maximum and minimum reactive power limit is assumed as 0.5 P_{Gen} and o -0.25 P_{Gen} respectively, where P_{Gen} is the active power rating of the synchronous generator. Load bus is modelled as PQ bus with constant active and reactive power. Synchronous condenser is modelled as generator delivering no active power and supplying only reactive power within the limits. Transmission lines in the system are modelled as PI sections. Fixed shunt capacitors and reactors are modelled as shunt elements at the corresponding buses. The total generation in the system is 4374MW+j531MVAR and load is 4242MW+j1438MVAR. The shunt capacitor and reactors present in the system are 153MVAR and 65 MVAR respectively. Basic load flow/power flow analysis of the system is carried out by assuming the voltage at all buses as 1pu. Power Flow analysis is performed using Newton-Raphson(NR) method for voltage stability analysis. Then the system is analyzed for voltage stability by replacing the wind generators for different wind penetration levels.

Almost all wind turbines installed up to now use either one of the following types: (a) fixed Speed Induction Generator (SCIG) (b) Doubly Fed Induction Generator (DFIG) (c) Direct Drive Synchronous Generator (DDSG). Out of these, Direct drive synchronous generator is rarely used in wind farms and as a result most of papers consider fixed speed induction generator (type a) and doubly fed induction generator (type b)[7]. Practically these two types of Wind Generators(WG) are installed in such a way that under steady state condition they will operate at unity power factor.

Every Synchronous Generator (SG) in the IEEE 118 bus system is replaced by combination of SG and WG. The power ratings of both SG and WG are indicated in the Figure 1. The percentage of wind penetration into system is given by the wind capacity penetration factor (i.e. k) and the value of k is set by the expression 1. Wind generators are compensated by 50% reactive power for unity power factor operation with respect to point of coupling. Wind generator is modelled as an active power source with unity power factor.

$$k = \frac{\text{Total Wind Power Generation in the system (MW)}}{\text{Total Power Generation in the system (MW)}} \quad (1)$$

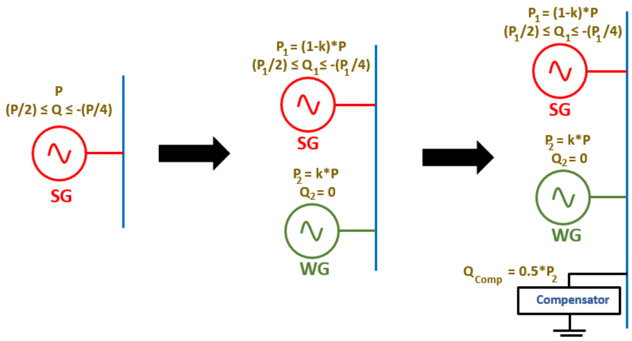

Figure 1. Modeling of Wind penetration

Table 1. Voltage Profile with varying L

Bus No/L	1.0	1.05	1.1	1.15	1.2	1.25	1.3
51	0.951	0.938	0.914	0.878	0.838	0.787	0.704
52	0.942	0.928	0.903	0.866	0.825	0.772	0.686
53	0.935	0.921	0.896	0.859	0.817	0.762	0.673
54	0.948	0.934	0.912	0.877	0.837	0.785	0.701
55	0.948	0.934	0.912	0.878	0.838	0.786	0.703
56	0.947	0.934	0.911	0.877	0.837	0.785	0.701
58	0.947	0.933	0.910	0.874	0.834	0.782	0.697
76	0.932	0.924	0.913	0.902	0.888	0.872	0.851

3. Case Studies

3.1 Case 1: Voltage Stability of the IEEE 118 Bus System

Initial load flow studies are carried out for the system and found that voltage at buses 51, 52, 53, 54, 55, 56, 58 and 76 are less than 0.95pu. So these buses were taken as candidate buses to observe the voltage profile for voltage stability analysis. The total loading on the system of 4242+j1438MW is uniformly increased with constant power factor from initial load to the load at which NR-Power flow method is diverged, which indicates that any further increase in the load leads to voltage collapse of the system. This process is implemented by varying the loading parameter(L) in steps of 0.05, starting from initial load for which L=1. So increase in load for L= 1.05 is 5%. The voltage profile for L=1 to L=1.3 in steps of 0.05 is provided in Table 1 and same is plotted in Fig. 2 after conducting the load flow studies for each case. Further increase in L is resulted in non-convergence of load flow. As the voltage profiles of bus no 51, 54, 56 and 58 are similar, out of these four, only bus no. 54 voltage profile is considered to plot in the Figure 2. Even though the voltage profile at bus No 53 for initial loading condition is 0.935pu with increase in load it is dropping to 0.673pu and going towards instability. It is observed that the voltage profile at all buses is in the same trend except for bus no 76. The voltage profile at the bus no 76 is better than the remaining buses and the worst voltage profile is observed for bus no 53.

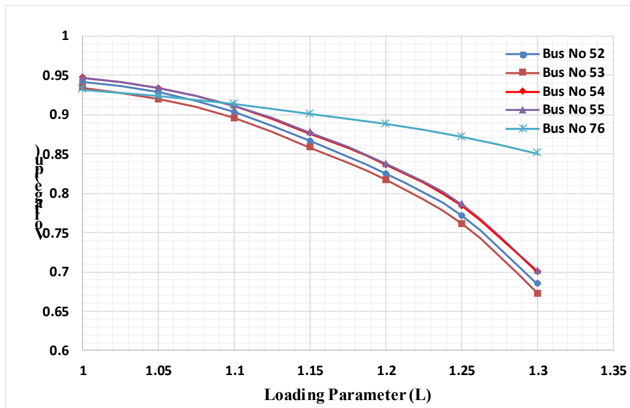

Figure 2. Voltage profile with increase in loading.

3.2 Case 2: Voltage Stability of the IEEE 118 Bus System with Wind Generators

Load flow analysis of the IEEE 118 bus system is carried out by replacing the conventional synchronous generators with wind generators as explained in Figure 1 of section II. The wind penetration is increased to 40%, 50% and 60% by setting the value of 'k' to 0.4, 0.5 and 0.6 respectively with increase in loading. The loading parameter 'L' is increased from 1, in steps of 0.05 till NR Power flow method is diverged in a similar way to Case 1 as explained in detail in section IIIA. Same assumption of voltage and load are used while carrying the load flow studies for comparing the results. The voltage profile at the candidate buses is plotted without the compensation at the wind generator terminals in Figures 3 to 5 for 40%, 50% and 60% wind penetration. Voltage instability is observed for greater than 120% of system loading for

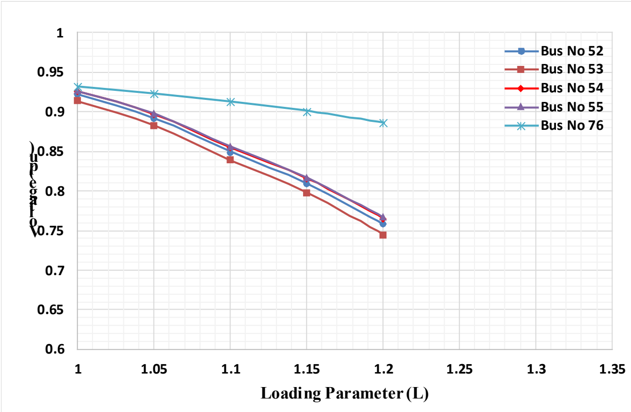

Figure 3. Voltage profile with 40% wind penetration without compensation.

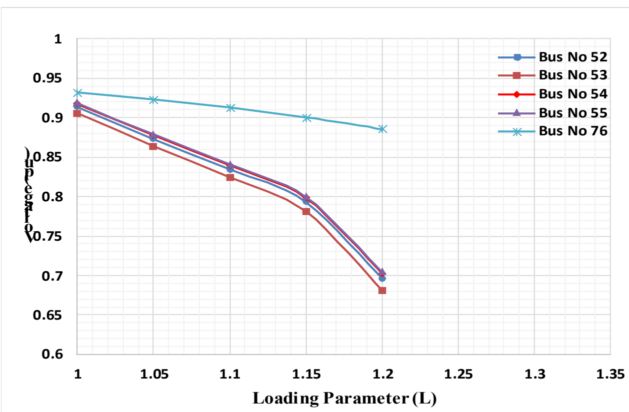

Figure 4. Voltage profile with 50% wind penetration without compensation.

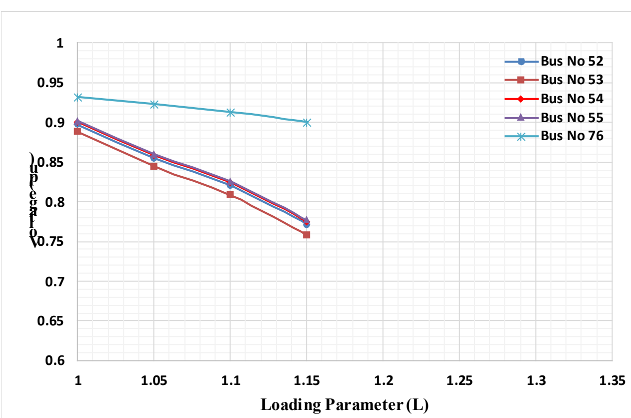

Figure 5. Voltage profile with 60% wind penetration without compensation.

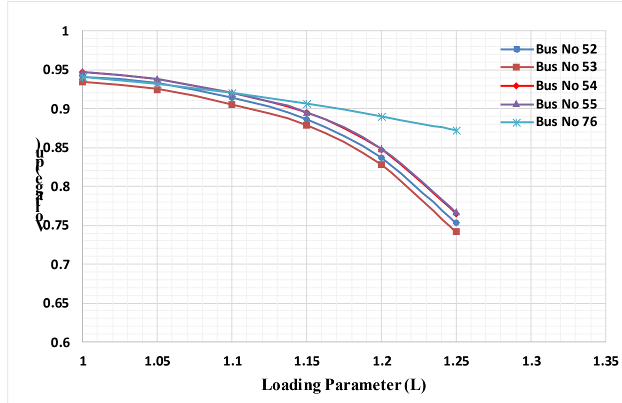

Figure 6. Voltage profile with 40% wind penetration with compensation.

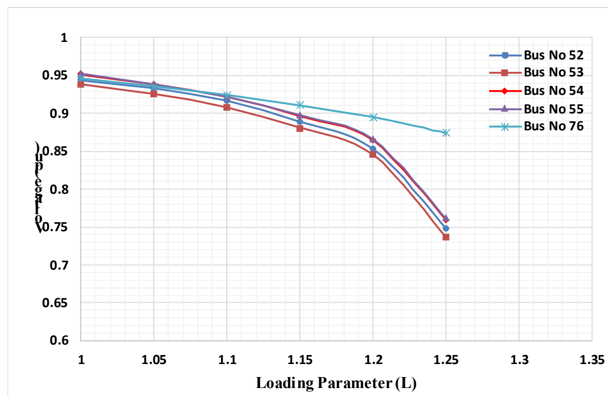

Figure 7. Voltage profile with 50% wind penetration with compensation.

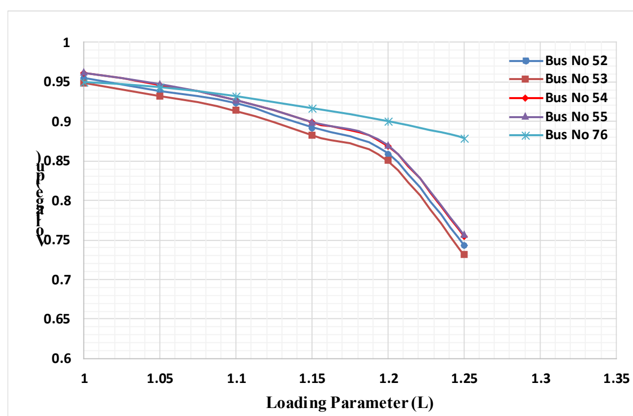

Figure 8. Voltage profile with 60% wind penetration with compensation.

40% and 50% wind penetration. The minimum voltage is 0.745pu at the bus no 53 for 40% penetration and 0.681pu for 50% wind penetration. Even though the voltage at basic loading condition is almost same, due to addition of wind, voltage profile is decreasing. The voltage instability is observed for more than 115% for wind penetration of 60%. The minimum voltage at bus no 53 is 0.758pu for this case. The system is experiencing voltage instability as the wind penetration increases. The voltage magnitudes at the busses are decreasing and the slope of the PV curve increases towards the nose point of instability.

3.3 Case 3: Voltage Stability of the IEEE 118 Bus System with Wind Generators and with Shunt Compensation

The voltage profile of the system is studied through load flow studies by providing the shunt compensation at the wind generator terminals as shown in Figure 1. The amount of compensation is selected as 50% the power generated by the wind generator. The voltage profile is plotted in Figures 6 to 8 for 40%, 50% and 60% wind penetration. So with compensation the voltage profile of the system is improved and the system stable at 120% loading in contrast to no compensation case. Voltage instability is occurring at 125% of system loading for all studied wind penetration levels. Even though the bus voltage at bus no 53 for initial loading condition is around 0.94pu, with increasing in penetration the voltage is decreasing up to 0.74pu.

4. Conclusion

The voltage stability analysis is carried out for IEEE 118 bus system with and without wind penetration. The standard loading of the system is increased in steps to find the loading limit of the system and voltage profile is analyzed through PV curves. The voltage instability is observed if the load is increased beyond the 130% without wind generation.

Analysis is carried out by replacing synchronous generators with wind generators for various penetration levels. From the analysis it is observed that, wind penetration reduces the loading limit of the system. The voltage instability is observed if load is increased beyond 120% and 130% for the wind penetration of 50% and 60% respectively. The simulation of wind generators with reactive power compensation resulted in better voltage stability and improved the system loading limit to 125%. Hence, it is observed that wind generators with suitable reactive power compensation will aid the voltage stability of power system.

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