REVIEW PAPER ON METHODS OF VOLTAGE STABILITY ANALYSIS OF WIND BASED DISTRIBUTED GENERATION SYSTEM

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ABSTRACT

Generation of electrical energy is greatly being contributed by wind farm. Thus, researchers are finding various optimizing techniques in order to utilize it at its optimum. The voltage stability serves a key role in operation of power system when large-scale wind energy system is connected to grid. In contrast with the past, Integration of large scale wind power has severe impacts on the power system operation. Under the large integration wind power, maintaining stability and reliability of supply is a big challenge to power system operators. In this paper, methods of voltage stability analysis of wind integration to the power grid has been studied. As wind flow is having random nature, it affects the stability of the system especially Voltage Stability. An attempt is made to identify the impact of integration of renewable energy into grid on voltage stability.

Keywords— Wind Power, Voltage Stability, Grid Integration.

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 glance 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]. It has become a key part of the solution to the nation's energy needs. Therefore, commissioning of wind 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. Wind 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 wind power system in many countries around the world. Its benefits include:

- No emissions of harmful gasses like CO_2
- Significant economically viable resource potential
- No impact on generation cost due to fuel supply price fluctuations.
- Increased security of supply
- Can be used as distributed generation Source
- Cost-effective energy production
- Improves sustainability
- Reduces global warming
- Improves energy security
- Requires no waste storage.

The below table shows the installed capacity of various generation systems of India.

Table 1: Installed capacity of various generation systems in India

Sr. No	Resources	Cumulative Achievements (in MW) till 31.03.2018
Grid connected renewable electricity		
1	Biomass Power	8701
2	Waste to energy	138
3	Solar PV power plants	21651
4	Wind Power	34046
1) Off-grid renewable energy		
5	Biomass Cogeneration	661.4
6	Solar PV system	539.13
7	Biomass Gasifiers	163.37
8	Waste to Energy	175.45
9	Hybrid Systems / Aero Generators	3.29

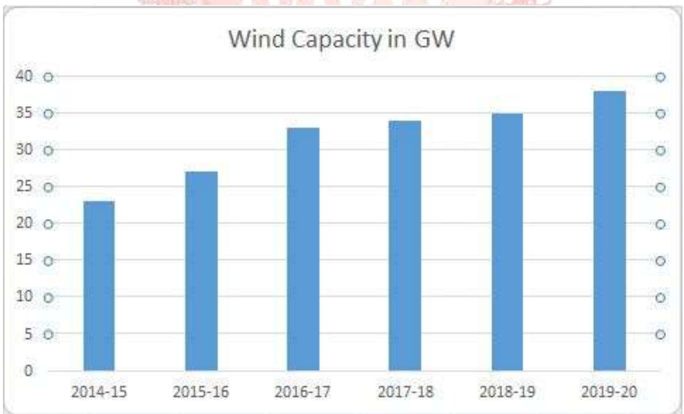

Fig. 1 Development of wind industry over the years

The most difficult challenge in utilizing the wind power in harnessing the energy is their random changing nature. The first element in harnessing this green energy is the wind turbine followed by electrical generator. The main function of these generators is to convert mechanical energy into electrical energy. Some of the electrical machines that can perform this operation are: doubly fed induction machines, induction machines, PMSM etc. Some special features of PMSM are:

- Simple construction
- Small size
- High efficiency
- Low Maintenance

- No need of DC excitation
- No need of brushes and slip rings

Because of the changing nature of the wind, the generator fails to produce a constant electrical voltage resulting in grid imbalance. To overcome this problem, maximum power point trackers are employed. Three phase ac supply coming out of the wind farm can be supplied to a matrix converter after suitable filters. This matrix converter will convert the input three phase supply into a variable voltage variable frequency supply. This variable supply can be used to drive an induction motor and PMSM.

II. WIND TURBINE SYSTEM

Wind turbine system [8] like generator, turbine rotor, gearbox, power electronic system, and a transformer for grid connection are illustrated in figure below. Wind turbines obtain the power from wind through turbine blades and it's converted to mechanical power. It is required to control and limit the converted mechanical power during higher wind speeds. The general way to convert the low-speed, high-torque mechanical power to electrical power is using a gearbox and a generator with standard speed. The gearbox connects the low speed of the turbine rotor to the high speed of the generator. Then the generator converts the mechanical power into electrical power, which is fed into a grid by processed by means of power electronic converters, and a transformer with required protection & metering equipment. Generally induction generators & synchronous generator are used in wind turbines.

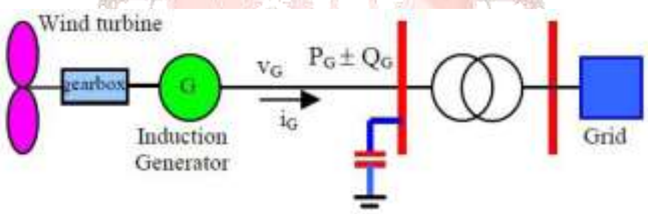

Fig. 2 Wind Turbine System Connected to Grid

Induction generators [8] produce electrical power when its shaft is rotated faster than the synchronous frequency of the induction motor. As these generators can produce power at varying rotor, this makes it capable to use in wind turbines. Induction generators are simple in construction. They are also more rugged in construction; hence it doesn't required brushes or commutators. They require an external supply to produce a rotating magnetic flux, as these types of generators are not self-exciting. The external supply can be provided from the electrical grid [9] or from the generator itself, when it starts producing power. The magnetic field is produced due to current induce in the rotor. If the rotor turns slower as compare to rate of the rotating flux, the machine will behave like an induction motor & when rotor is run faster; it acts like a generator, producing power at the synchronous frequency. In this type of generators the magnetizing flux is set through a capacitor bank connected to the machine in case of standalone system where as in case of grid connection it draws magnetizing current from the grid. It is most suitable for wind generating [10] stations as in this case speed is always a mutable factor.

Induction machines are widely in the electrical power system as induction motors but are not widely used as generators. Inspite of their simple construction, they are not preferred as much as synchronous generators. This is mainly due to the defined relationship between the export of active power [P] and absorption of reactive power [Q]. However, induction generators have the benefits of providing large damping torque in the prime mover, which makes it suitable for the application in fixed speed wind turbines. The fixed speed wind turbine uses a squirrel cage induction generator which is coupled to the power system through a connecting transformer as shown in Figure 3. To match the different operating speeds of wind turbine rotor & generator, a gearbox is used. The generator slip little bit varies with the amount of generated power and is therefore not entirely constant.[11]

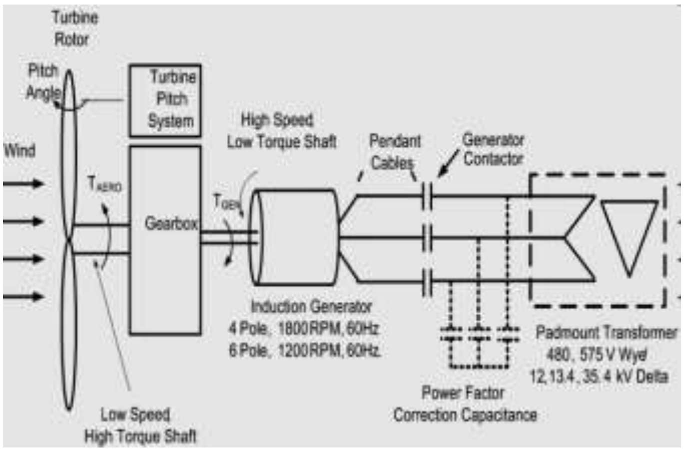

Fig. 3 Self-excited Induction Generator

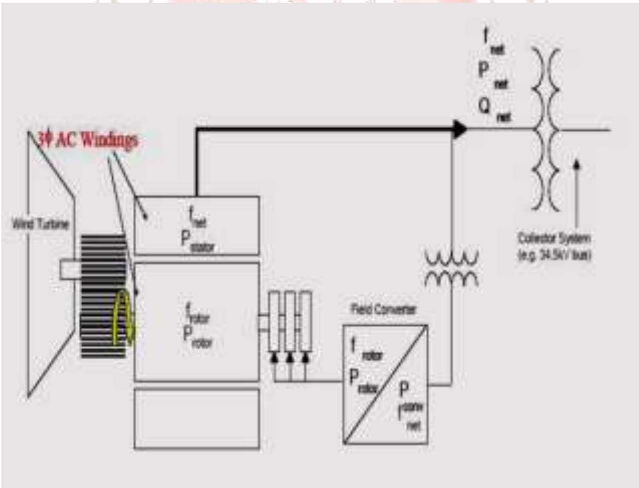

Fig. 4 Doubly-fed Induction Generator

However, because these speed variations are in the order of 1 % this wind turbine is normally referred to as constant speed. Nowadays, this type of wind turbine is nearly always combined with stall control of the aerodynamic power, although pitch-controlled constant speed wind turbine types have been built in the past. These types of machines consume reactive power and consequently, it is present practice to provide power factor correction capacitors at each wind turbine. These are typically rated at around 30 per cent of the wind farm capacity. As the stator voltage of most wind turbine electrical generators is quite low, the connecting transformer of the wind turbine is essential for connection to the distribution network and should be considered when modeling the electrical interaction with the power system.[12]

III. VOLTAGE STABILITY IN POWER SYSTEM

A power system's operating quantities should meet all operational criteria, stability at any time, and it must satisfy the security against any credible abnormality. Present practice is to operate the power system closer to the stability limit, taking economic and environmental restrictions into consideration. Thus to maintain the operation of power system stable and secure is a very important and challenging task. Modern analytical tools are used for voltage stability analysis such as:

A) PV Curves for Voltage Stability Analysis

These curves are used for the analysis of steady state voltage stability which is the stability of the system in normal operation. The 'nose or bending point' of the PV curve shows the maximum load that can be fed (Power Limit) and the corresponding bus voltage. Part of the PV curve beyond the knee point is considered unstable while upper part of the PV curve is considered stable. [4]

The relationship between active power transferred (P) and corresponding receiving end voltage (V) has the most significance while analysing voltage stability. The voltage stability analysis process includes the transfer of active power from one location of a system to another, and observing the effects to the system voltages. This type of analysis is commonly referred as a PV study.

Below figure shows a general PV curve that shows how the voltage V is varying for a particular specified bus with respect the total active power P delivered to load areas. When load demand crosses the bend point of the curve, the voltage falls rapidly and system becomes unstable. Load flow solutions fail to converge beyond this knee point, which shows that instability has occurred. This knee point is called the "Critical point". Therefore, the PV curve can be used to calculate the system's "critical operating voltage". When the operating points are below the critical point, the system is treated to be in an unstable condition.

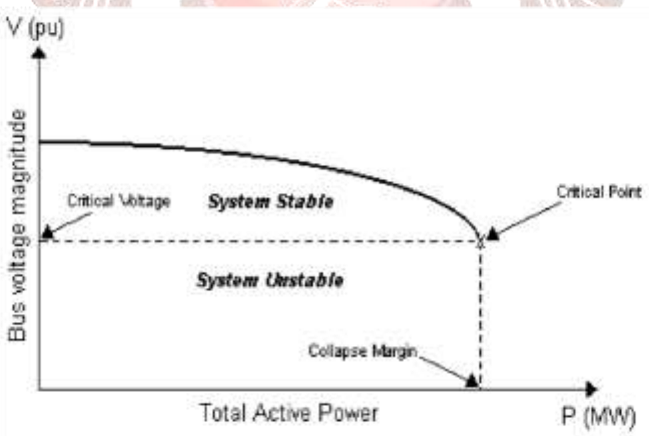

Fig. 4 PV Curve

B) QV Curves for Voltage Stability Analysis

The loading margin is an index to roughly calculate the voltage stability of power system. It is the difference between actual operating point of the system and critical loading point of the system. The voltage collapse points must be assessed to make sure secure operation at the normal operation point.

Under steady state conditions, the voltage (V) of a particular bus increases as reactive power Q is injected at the same bus. No matter how, when voltage of any of the buses decreases with the increase in reactive power for that same bus, the system is said to be unstable. Voltage stability is dependent on how a slight difference in active and reactive power affect the voltages at different buses. It indicates how much bus voltages are sensitive with respect to reactive power operations.

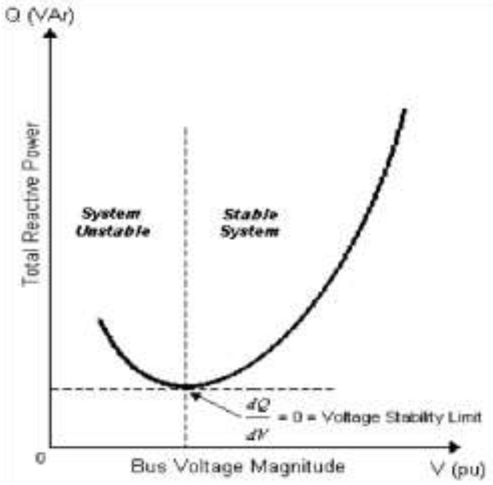

Fig. 5 QV Curve

A typical QV curve is shown in fig.5 below. Voltage stability limit occurs at the point where the ratio of change in voltage magnitude to the change in reactive power equates to zero. The minimum requirement of reactive power for a stable operation is also found at this point. During normal operating conditions, increase in reactive power injection results in increased voltage stability. If the operating point is on the right hand side of the QV curve, system is perceived to be stable. Whereas when operating points is in the left side of the graph system is considered to be unstable.

The maximum allowable loading on the system, inside the range of voltage stability limit, is firmly decided from the well-known *Q-V* curve or *P-V* curve. To generate a family of these curves series of computer simulations is required.

C) Optimal Power Flow

An indicator termed as L –indicator which is derived from Kirchhoff's law to determine voltage instability[6]. This voltage stability indicator predicts the voltage stability margin of current operating point. The value of L-indicator lies in between 0 and 1. Lower the value of L - indicator greater is the stability margin. By using L-indicator it is used to find the impact of loads, area and power transaction. Optimal power flow is carried out by using Newton-Raphson method in PSAT. This Indicator predicts the voltage stability problem accurately and properly.

Load curtailment is one of the methods for voltage stability margin criteria of the power system. Steady state voltage stability indicator in conjunction with an optimal power flow is used for the computation of load curtailment. The effect of this algorithm is evaluated on the composite system. The Expected Energy Not Served (EENS) and downtime is calculated analytically and also by Monte Carlo simulation. Load curtailment values are discussed with and without indicator. The EENS increases when system is operated with larger voltage stability margin. Down time has not much variation but in a larger system it will have a significance.

Results obtained from the Monte Carlo Simulation matches closely.

D) Continuation Power Flow

At voltage stability limit, the Jacobian matrix of power flow equations becomes singular. 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 used in order to estimate next solution for a defined pattern of load increase. The corrector step then determines the exact solution using Newton- Raphson

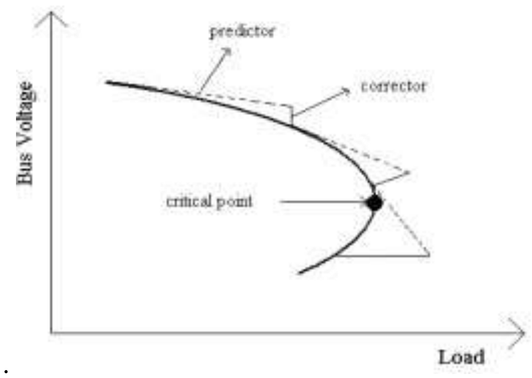

Fig. 6 Illustration of prediction-correction steps

technique employed by a conventional power flow. After that a new prediction is made for a defined increase in load based upon the new predictor. Then corrector step is applied. This process goes until critical point is reached. The critical point is the point where the tangent vector is zero. The flow chart of predictor-corrector scheme is illustrated in Figure 7.

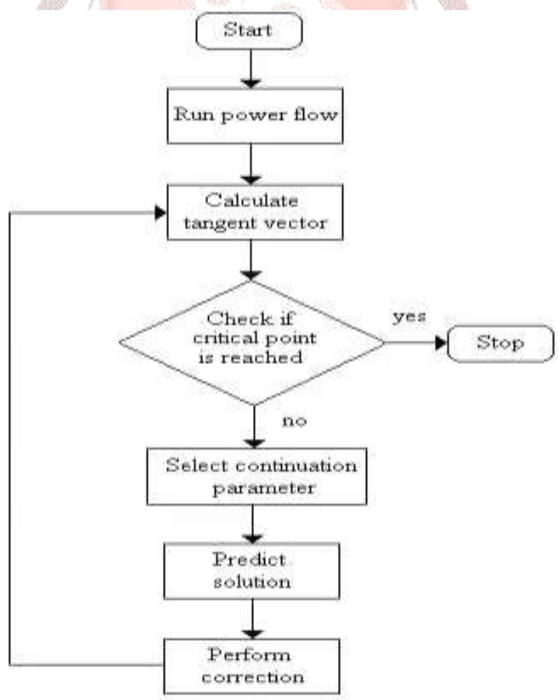

Fig. 7 Flow chart of CPFLOW

- Parameterization: The arc length parameterization is used to eliminate ill-conditioning near the nose point.
- Predictor: The tangent method is employed as the predictor when the solution curve is flatter. When the
- Solution curve exhibits pronounced curvature, the secant method is used instead.
- Corrector: The power flow algorithm for PV power systems proposed in 6 is chosen as the corrector.

- Step-length control: An adaptive scheme is applied to control the step length. A larger step length is chosen when the solution curve is relatively flat. As the solution curve gains more curvature, a smaller step length is chosen instead.

V. IMPACT OF SOLAR PV SYSTEM INTERCONNECTION ON VOLTAGE STABILITY

It is hard to argue the advantages of being able to use photovoltaic for power generation, however, research and power flow studies on large-scale PV cell integration show that there will be significant problems when replacing current fossil fuel based power plants with PV generation plants [7].

The main problem with PV integration include problems with: voltage stability, frequency stability, and overall power quality.

These three problems will be summarized in their own section below.

A) Power Quality Issues

Generation of power near the point of load centre is known as distributed generation. The decrease in amount of transmission and distribution cost make these systems very appealing to researchers since systems that control these distribution are expensive and technically challenging. Distributed generation has some power quality problems depending upon the size of the connected load. A distributed system is considered large–scale when loading on the system is greater than 10MW. Systems under this limit fails to qualify as commercial applications and usually do not have many power quality issues. However, large-scale systems experience power quality problems [5]. Renewable sources are usually considered distributed generation and are usually controlled locally which emphasizes the need to develop a grid that is flexible and adaptable.

Power generation plants that use the conventional method to spin a turbine benefit from having complete control over generation. Using a fossil-fuel based generation technique allows the power company to feed abundant resource fuel to the boilers at any time allowing a plant to produce power at will. Photovoltaic generation does not have the luxury of producing power on demand. A system of rolling clouds has the ability to take a 10MW fully producing PV plant and reduce the power output to a fraction of its full power potential. Assuming the solar generation is not intermittent and acts as a constant reliable source of power, we can focus on the analysis of PV integration when it is fully active.

B) Voltage Stability

The inherent non-dispatchable characteristics of PV systems allow voltage generation fluctuations that have not previously been present in the grid. In order to combat these voltage issues, storage solutions along with other instantaneous power producing solutions are on the forefront of current PV research and development. Alongside the intermittency of PV generation itself, there are also grid-connected voltage quality issues that must be considered. Power plants must have the capability to ride-though various voltage level sags in order to operate without outages. This requires that PV systems must be just adaptable to voltage sags just as conventional power plants are used to be.

VI. CONCLUSION

Recent trends in the power generation technologies shows that integration level of wind based Distributed Generation into the Grid has increased extensively. End user appliances are becoming much sensitive to the power quality condition. Integration of wind based distributed generation system may have severe impacts on the system operation and overall performance power system. For the past few years focus on performance of wind plant and its functional requirements has increased. Hence new grid codes are defined by regularity board which specifies the dynamic and static requirements that wind plants must meet in order to be remain connected to the grid. As per these Grid codes, it is required for wind systems to remain stable and connected to the system without tripping of any of the generators of the grid during faults & abnormal condition in the transmission system and the ride through fault capabilities must be met. It can be concluded that voltage stability is major point of concern while integrating a wind plant into the grid. When this integrated system is subjected to abnormal condition all the crucial parameters like bus voltage magnitude, the power angle, active power & reactive power gets affected & this results in voltage stability problems. So while integrating wind power plant into grid we have to take voltage stability in concern by the measurement of bus voltages & other essential parameters

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