Analysis of Wind Power Integration for Power System Transient Stability

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Abstract— Many developing nations are currently undertaking huge electric power generation and transmission expansion to meet the modern consumer power demand. This has been necessitated by the increased power activities and the need for stable power supply. In this paper, Doubly-Fed Induction Generators (DFIGs) are utilized to analyze wind power integration on power system transient stability. Short-circuit fault and intermittent wind power characteristics can be ruinous especially with diverse mix of power being injected to the electricity grid. Wind power is the fastest growing source of renewable energy after hydro generation. As such, wind power integration to the grid has raised concern as to how much more wind power can the grid accommodate and ensure that system transient stability is maintained. This concern has also extended to power system operators and regulators thereby necessitating further analysis. The aim of this paper is to draw some conclusions on what would happen with large-scale wind penetration to the grid on transient stability. The results indicate that as the wind energy integration increases, transient stability improves. However, the level of wind power penetration is only possible to a limit before the system goes unstable.

Keywords— Doubly-fed induction generator, Short-circuit fault, Power system transient stability, Wind power integration.

I. INTRODUCTION

Wind energy generation has been in existence since the ancient times; however its penetration into the conventional grid has continued to attract a lot of interest from researchers worldwide. Currently, many developing countries have a huge energy capacity deficit whereby at peak periods especially when most industrial plants are running, there is insufficient power generation necessary to meet the users demand and retain the reserve capacity. As such, the power system is at risk of collapse especially under fault when the energy reserve is inadequate to maintain the power system transient stability.

The situation is made worse by the generation mix that includes the hydro power, geothermal, nuclear, thermal and the wind power which all have different characteristics. The latter is there today and tomorrow is unavailable.

Wind power integration to the grid has been there for a long time and researchers have been trying to unravel what amount of wind energy can be integrated to the electricity grid without negatively affecting the power system transient stability. Some of the factors that determine wind integration to the utility electricity grid are: The national energy mix (availability of flexible generation sources -hydro, geothermal), demand for electricity in the country, distribution of wind generation sources, capacity of the grid and wind regime of the different sites contribute to a great role in ensuring there is higher wind penetration in the grid. Further, for greater wind penetration it is important that further studies be carried out to understand the technical challenges that might arise when integrating large wind power to the grid.

Wind integration studies have advanced from whether it is possible to add wind generation to focusing on how it will be done and at what cost [1]. The wind energy generated will address the power shortage capacity, the cost of power and maintain the desired energy reserve. This will in turn stabilize the power system. However, concerns have been raised as to how much wind power should be integrated to the power grid and maintain the power system stability. Many countries have focussed on wind power generation and integration to their conventional generation because it is cheap and environmentally friendly even so, some countries are reluctant to integrate large wind power plants. Therefore, it is crucial to achieve a balance between environmental effects and power performance on grid. Further, it is important to study these new aspects that the integration wind power brought to the conventional system, including the aspects of the transient stability and the maximum amount of wind power that can be utilized to a given system [2]. Several researchers have carried out work on the impacts of wind energy on power system stability based on real systems. We can learn from countries with large-scale wind integration experience such as Tasmania, Iberian Peninsula, South Australia, Ireland and US which are at an advanced stage of wind integration into their electricity grid. According to the report on large scale wind integration,
an improved forecasting, reduced perception of wind variability and better understanding of the requirements for frequency balancing is crucial [3]. The report further indicates that greater wind penetration is possible with better system control, good government policies and enhanced network. The extent to which the wind power can be integrated into the power system without affecting the overall stable operation also depends on the technology available to mitigate the possible negative impacts such as loss of generation, voltage flicker, and voltage and power variations due to variation in speed of the wind design [4].

II. EFFECTS OF WIND ENERGY INTEGRATION ON TRANSIENT STABILITY

A stable grid integrated with wind energy should be able to respond to abnormal conditions such as voltage disturbance and faults. Wind farms plays a crucial role in voltage stability of the electricity grid under faults because they have better management for reactive and active power. Wind farms have the potential to absorb and supply reactive power on demand. Researchers such as Ch. Eping et al [5] focused on transient stability issues and analyze the impact of various aspects like location of wind generators, connection points and distributed generation. The actual generator technology has a considerable impact on transient stability.

In this study, DFIGs with various penetration levels were analyzed. The results shows that this technology improves transient stability margins, when being equipped with low voltage ride-through capability, reactive current boosting and ideally with fast voltage control. In terms of connection point it was shown that integration of wind generation into sub-transmission and distribution systems has a negative impact on transient stability, because the reactive contribution is highly limited due to reactive losses in sub-transmission and distribution systems. They concluded that, in actual cases, there will always be a superposition of the above mentioned aspects, including a variety of generator types and voltage levels to which wind generators are connected. So, there is no general statement possible that state with certainty, if wind generation improves transient stability margins or if the impact is rather negative.

M. El-Sayed and Effat Moussa [6] investigated the effects of wind farms of different sizes on the Egyptian power system. For simplicity and accuracy of the Egyptian system analysis, the wind farm was aggregated into minimal set of equivalent wind generator models combining all turbines with the same mechanical nature frequency into single equivalent turbine. Power system dynamics simulation software is used to study the impact of increasing wind turbine penetration on system performance. The study was also carried out considering different contingencies i.e. transmission line outages, loss of generation units and finally a combination loss of generation and transmission lines. The result shows that the Egyptian system with a total installed capacity of 20400MW can withstand wind farms of size up to 900 MW.

Clemens Jauch et al [7] looked at the effect of wind power on the transient fault behaviour of the Nordic power system. The Nordic power system is the interconnected power system of the countries Norway, Sweden, Finland and Denmark. Here the wind turbines installed in eastern Denmark were used in the investigation. The simulations yielded the information such as how the faults impact on the wind turbines and how the response of the wind turbines influences the post fault behaviour of the Nordic power system.

III. METHODOLOGY

As per our earlier discussion, concerns have been raised as to how much wind energy should be integrated to the conventional grid without negatively affecting the transient stability. To address the above, this study analyzed a standard IEEE 9 bus of which the results can be extended to any power system depending on the stability of the existing network, location of the wind farm and capacity of the grid.

The fig. 1 shows an IEEE 9 bus system used for the analysis while figure 2 shows a one line diagram of figure 1 connected with a wind farm. The IEEE 9 bus has 3 generators; the generators are replaced with a wind power plant at various levels. A short circuit fault is initiated in a transmission line and the effects of wind integration to the power system are investigated.

Critical clearing time is used to study system stability under initiated system fault. In this paper, critical clearing time is used to determine the longest fault duration allowable for power system transient stability to be maintained. It is the measure used in this paper to analyse the effectiveness of greater wind penetration to the grid. Many questions have been raised about whether greater wind penetration to the grid is secure. This depends on many factors such as the control of the central power plants and on the control applied to other units connected to the grid and also on the topology and the strength of the transmission system itself [8]. The integration levels also depends on generation and demand balance, both real and reactive power through an electricity grid and must be maintained on an almost instantaneous basis to ensure system reliability [9]. This almost real time balance is at the heart of the challenges that exist when integrating any form of generation or demand into an electricity grid.

IV. SIMULATION RESULTS

In this study two scenarios were looked at. The first involves the study of the effects of transient stability with conventional generation. The 2nd involves analysis of a system with both the conventional generation and wind power plant at different wind integration levels. The two cases are detailed below:
A. Without Wind Integration

Here the system has no wind farm and therefore G3 is still a synchronous generator. In this case, the transient response of active and reactive power, excitation current, and rotor angle and voltage magnitude are shown. A three phase short circuit was created at 1 sec and cleared at 1.123 sec respectively.

Fig. 1: A test model of IEEE 9 bus system integrated with wind farm.

Fig. 2: One line diagram of grid connected wind farm.

Fig. 3: Behaviour of active power parameter for a fault at 1 s cleared at 1.123s.

Fig. 4: Behaviour of Reactive power parameter for a fault at 1 s cleared at 1.123s.
B. With Wind Farm Integration

With wind farm integration at 22%

With wind farm integration at 44%

Fig. 5. Behaviour of excitation current parameter for a fault at 1 s cleared at 1.123s.

Fig. 6. Behaviour of rotor angle parameter for a fault at 1 s cleared at 1.123s.

Fig. 7. Behaviour of voltage magnitude parameter for a fault at 1 s cleared at 1.123s.
Fig. 8. Behaviour of various SG parameters for a fault at 1 s cleared at 1.123s
Fig. 9. Behaviour of voltage magnitude parameter for a fault at 1 s cleared at 1.12s.

Fig. 10 Behaviour of various SG parameters for a fault at 1 s cleared at 1.12s.
Fig. 11 Behaviour of various SG parameters for a fault at 1 s cleared at 1.118s.

Fig. 12 Behaviour of various SG parameters for a fault at 1 s cleared at 1.118s
V.DISCUSSION

The figures 3-13 shows the effects of wind power integration. They clearly indicate that as the amount of wind power to the grid is increased, the transient stability improves however; this is only possible to a certain limit before the system goes unstable. It should be noted that wind integration to the conventional generation is crucial and has been a success in other countries where wind penetration is enormous. The same can be replicated in other power system. However, it will depend on the following factors:

i. The design limits of the transmission line
ii. Infrastructure standard-this deal with power quality issues.
iii. The firm capacity of the wind farm and the associated wind power dispatch issues.
iv. Fast response to abnormal conditions
v. Active and reactive power management to keep the frequency and voltage within the stable limit
vi. The energy mix. The distribution sources

Therefore, the degree of success and the level of wind penetration to the system greatly depends on the implementation of the above five factors. Further, more benefits of greater wind penetration can be accrued by investing in the state of the art forecasting equipment thereby improving the reliability of wind.

VI. CONCLUSION

It has been shown that it is possible to integrate large amount of wind power successfully to the power grid. The degree of this success and the level of wind penetration vary largely on various factors such as those highlighted earlier. Also, knowing what will happen in the future will make it easier to operate power system and even be more economical. Therefore, investment in reliable wind forecasting devices is crucial in wind integration levels. The results also indicate that as the wind energy integration increases, the transient stability improves. The critical clearing time reduced from 1.123s to 1.118s as the wind power is integrated to the grid. This is a confirmation that greater wind integration is possible if the power network is stable.

It is also crucial to point out that if the grid connection is weak there are possibilities that it will limits the wind power penetration levels. Therefore, for proper planning and operation of the grid with wind farm and to accrue more benefits of greater wind penetration it is vital to ensure that the key factors discussed are implemented in the network.

Similarly, for greater power system transient stability, the conventional generation should be increased significantly to caution against the variability and intermittent wind characteristics. Under such scenario the wind energy is used as the base load supplying large load as compared to conventional generation. However, the controls for both the wind farm and the conventional generation shall be automatic so that under wind variation the latter can automatically be switched on and continue to supply the load with no noticeable interruption. By so doing the power grid will stand a better prospect of allowing greater wind power integration and transient stability improvement.
REFERENCES


