Electrical Power Quality and Utilisation, Journal *Vol. XII, No. 2, 2006*

Mitigation of the Wind Generation Integration Related Power Quality Issues by Energy Storage

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Summary: **The wind power which has been expected to be a promising alternative energy source can bring new challenges when it is connected to the power grid due to the fluctuation nature of the wind and the comparatively new types of its generators. This paper illustrates a possible solution to mitigate these integration issues of the wind power by application of the energy storage to the wind farm in power systems focusing on its short-duration perspective. The simulation model for the Energy Storage System (ESS) connected to the wind farm is implemented using the Power System Simulator for Engineering(PSS/E) which is one of the most widely used program for the power system analysis in US. Employing a sample power system, the control effect of the ESS for mitigating the wind generation related power quality issues by suppressing the power flow fluctuation of the wind farm, and improving power system stability is validated. The counteracting effect of the ESS in the wind farm to the disturbance on the grid is also shown.**

Key words:
Wind turbine generator (WTG),
wind farm,
Power Quality,
Energy storage system(ESS),
power flow fluctuation,
PSS/E,
Power System Stability

1. INTRODUCTION

As the wind power generation is increasingly considered as promising alternative from the aspect of the potential economy in the area with appropriate wind speed as well as the reduction of CO_2 emissions, its penetration level in power systems is expected to significantly increase in the future. The rated capacity of installed wind power reached nearly 46,000MW worldwide during 2004, and is expected to reach 175,000MW by 2012 [1].

Since the wind power generation has its own characteristics which are different from the existing generating unit such as the fluctuation nature of the wind and the comparatively new types of its generators, it would bring new challenges when it is connected to power systems. Although the integration of wind power into the power systems with penetration level of more than 30% may require a redesign of the existing power systems, dealing with a gradual increase of wind power in penetration level of less than 20% is the current main challenge for many power systems these days.[2] These challenges regarding the network integration of wind power mainly consists of keeping an acceptable voltage level, and the power balance of the system. In fact, the most important hitch of WTG in competing with the fossil-fuel generating units is the irregular stream of electricity from WTG caused by the unpredictable wind variations while conventional power plants yield a steady stream of electricity[3]. Especially when the wind power supplies a significant part of the load in the power systems, its intermittency can affect various aspects of power systems such as generation planning and grid operation, and bring integration related power quality issues.

To study these integration issues of wind power, this paper illustrates the possible solutions by the application of Energy Storage System (ESS). ESS has been studied as a high-tech solution for managing power flows from Wind Turbine Generator (WTG) as well as keeping a voltage level at the connection point of the wind farm, and making them be competitive energy sources without putting power systems at risk. However, most studies conducted so far has mainly focused on the ESS connected to WTG itself, and a study on how the ESS can mitigate the network integration issues of wind power from the aspect of power system is badly needed to technically evaluate its feasibility.

This paper implements the simulation model for the ESS connected to wind power using the Power System Stimulator for Engineering (PSS/E) software which is the most widely used program for power system analysis in US, and analyzes the control effect of the ESS to mitigate various integration issues of wind farm employing a sample power system. The ESS with fast output power control is expected to suppress the wind power fluctuation, improve the power system stability, and counteract to the disturbance on the grid. However, a study of economy of the ESS is out of the scope of this paper.

This work was sponsored by the DOE Energy Storage Program, managed by Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

2. SIMULATION MODEL

In this section, a system consisting of WTG and ESS connected to a power grid is modeled using the Power System Simulator for Engineering (PSS/E) software. The control strategy for this system is also studied.

In most commercial tools for the bulk power system analysis, the standard model for simulating the wind power generation connected to a power grid is not developed yet. In the case of PSS/E, its first version of the wind package for integrating the WTG in an electrical power system was issued in March 2005, but it is still implemented by an additional program such as *IPLAN* which is a programming language designed to be utilizes as an enhancement to PSS/E, and the user-defined models[4]. In this package, equivalent wind turbine units are added to the load flow case and appropriate

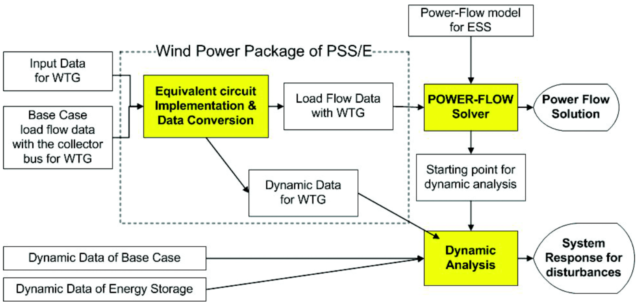

Fig. 1. Overview of the implemented WTG/ESS simulation using PSS/E

dynamic data are created by executing appropriate *IPLAN* program with given parameters of the WTG such as collector bus number, wind speed, displacement factor, the azimuth angle, desired voltage or power factor, machines parameters and etc.

For simulating the WTG and ESS connected to a power grid, this paper uses the wind package of PSS/E for integrating the WTG into power systems, and separately adds the ESS model in power systems as shown in Figure 1.

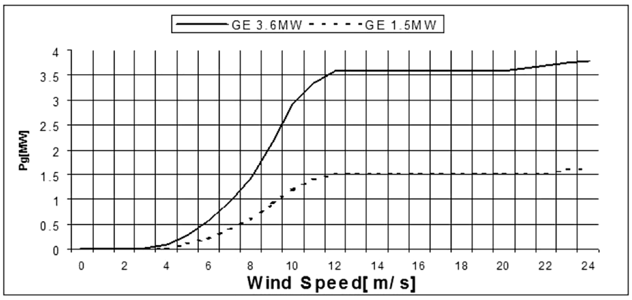

Fig. 2. Power Curve of GE WTG models

In this paper, the General Electric (GE) models are used for the the WTG simulation based on the manufacturer's recommendations [5]. Figure 2 shows the power curve of the WTG model of the GE used in this paper.

As shown in Figure 2, the WTG reaches the rated capacity at a wind speed of between 12–20[m/s]. So, in this paper, the initial wind speed is assumed to be 14m/s in case studies.

For the the ESS, CBEST battery model developed by Electric Power Research Institute(EPRI) is used for simulation in this paper. This model simulates power limitations into and out of the battery as well as ac current limitations at the converter, and assumes that the battery rating is large enough to cover all energy demand that occurs during the simulation for all short duration cases. However, energy limitations of the ESS can be also considered for long-duration applications [6].

The ESS is controlled to absorb the active power to be charged when wind power can generate the active power more than its specific level. When wind power can not generate the active power at its specific level, the ESS is controlled to be discharged and compensate the active power flow from the wind farm to the grid. Reactive power output of the ESS is controlled to keep the voltage at the connection point within its acceptable level.

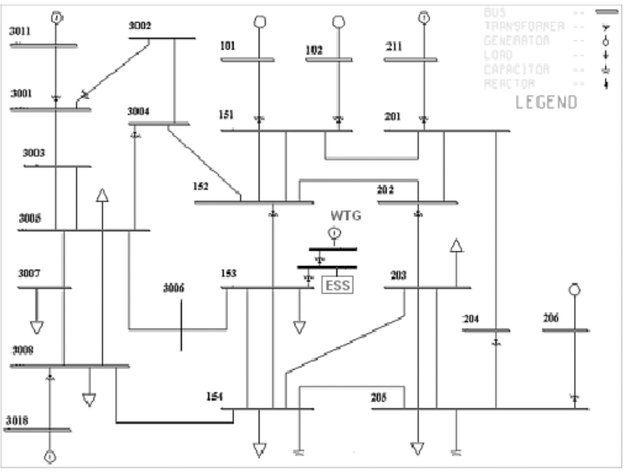

Fig. 3. Employed Power Systems

3. WIND POWER FLUCTUATION SUPPRESSION

In this section, the ESS is applied to suppress the power fluctuation from the WTG caused by the wind variations. As shown in Figure 3, the employed sample power systems consist of 23 buses, 6 generators, 8 loads, and 34 lines, with a total active load of 3200MW.

In this case study, it is assumed that the GE wind turbine generator of 1.5MW [4,5] is installed. For the simulation purpose, the collector bus of the wind farm is connected to power common connection (PCC) bus (153 bus) in the system, and the WTG is connected to the collector bus through a transformer. Multiple WTGs on the same collector bus can be aggregated in an equivalent unit, and they are assumed to be identical [4]. The ESS is connected to the connecting bus between PCC bus and the collector bus.

Figure 4 shows the proposed connection of the WTG and ESS with a power grid in detail. The EPRI CBEST battery is modeled for ESS (1.5MW+1.5Mvar) [5].

The ESS can be controlled to compensate the active power when the active power output of the WTG drops below a specified value, so that the total active power injected into power systems by the wind farm is kept constant regardless of the wind variations.

Figure 5 shows the simulation results of the WTG operating with wind variation before the ESS is connected. The wind is modeled as it is ramped up after a gust of 2 seconds. This variation is similar to one of the measured events [6]. As shown in Figure 5, the active power output of the WTG (Pg of the WTG) depends on the wind variation, so the active power injected into the power grid (a solid line) fluctuates even though the pitch angle of the WTG is controlled to keep its wind power generation constant. This power fluctuation can bring various power quality issues into power system operations such as the voltage and frequency.

Figure 6 shows the same simulation results of the WTG operation after the ESS is connected to the WTG.

As shown in Figure 6, the total active power injected into power systems by the wind farm(a solid line) can be kept constant by compensation of the ESS.

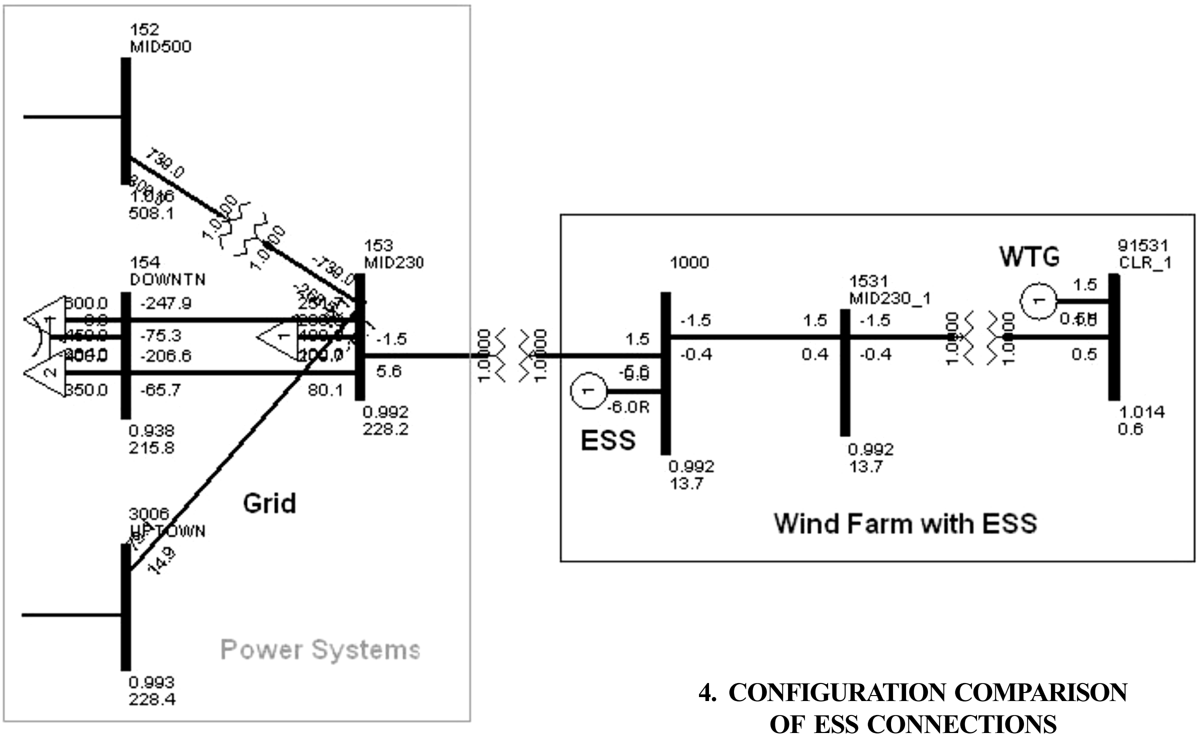

Fig. 4. Configuration of WTG and ESS connection

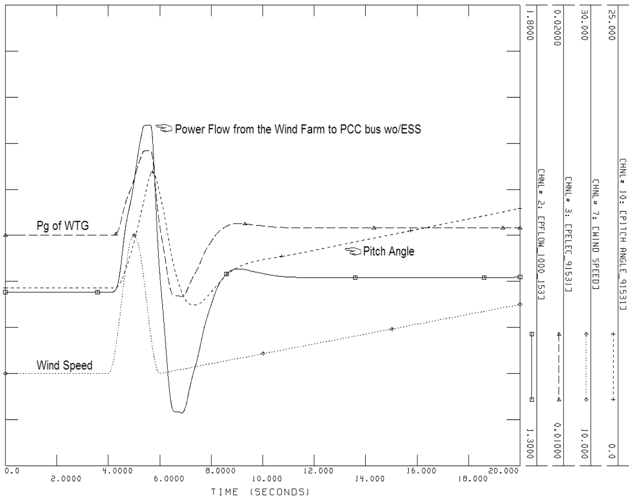

Fig. 5. Wind Power Simulation without the ESS

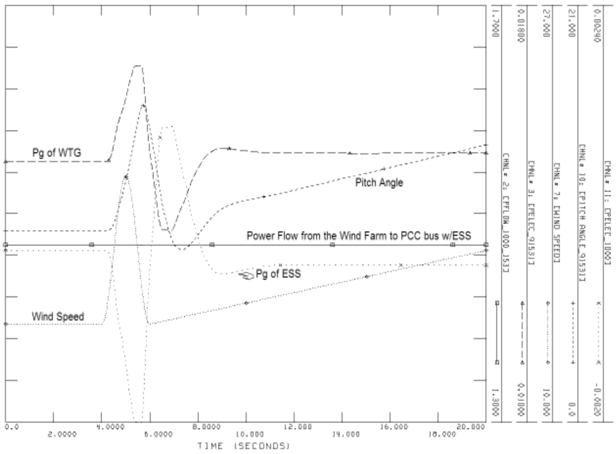

Fig. 6. Wind Power Simulation with the ESS

4. CONFIGURATION COMPARISON OF ESS CONNECTIONS

Because the wind farm usually consists of a large number of wind turbine generators in a wide area, the configuration of ESS connection is application dependent. In this section, two kinds of configuration for connecting the ESS to the wind farm are assumed, and their possible difference from the aspect of their control effect for suppressing the power flow fluctuations of the wind farm under a specific condition is analyzed. For doing this, the wind farm is assumed to consist of 10 units of the WTG, and the ESS is applied in either a distributed or concentrated configuration to suppress the power fluctuation of the wind farm. Each WTG is modeled as a GE unit of 3.6MW. The generating amount of the wind farm is about 1% of the system total load. Concerning the wind conditions, the constant wind (14meters/sec) is assumed for 5 WTGs, and the wind variation is assumed for the other 5 WTGs. The economic aspect of each configuration is not considered in this case study.

Figure 7 shows the distributed connection of the ESS to the wind farm, which is drawn by PSS/E software as it is modeled for the simulation purpose. The distributed the ESS is connected to each WTG, and each ESS is controlled to

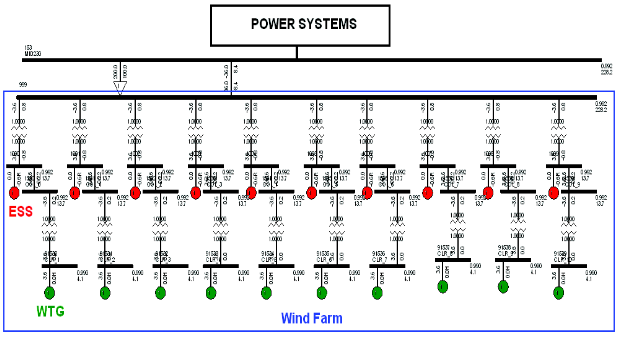

Fig. 7. The configuration of the wind farm with the distributed the ESS

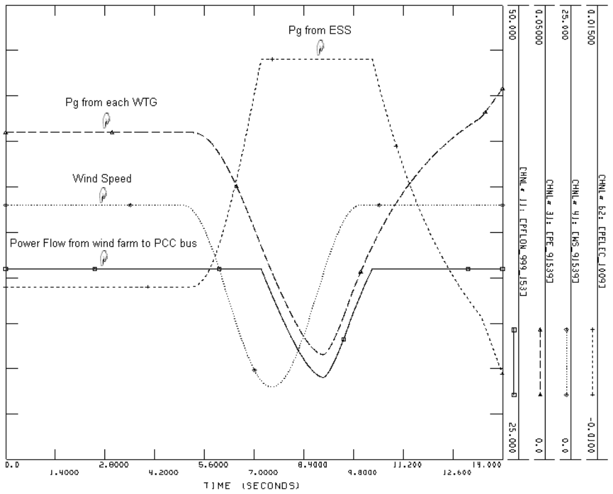

Fig. 8. Wind Power simulation with the distributed ESS

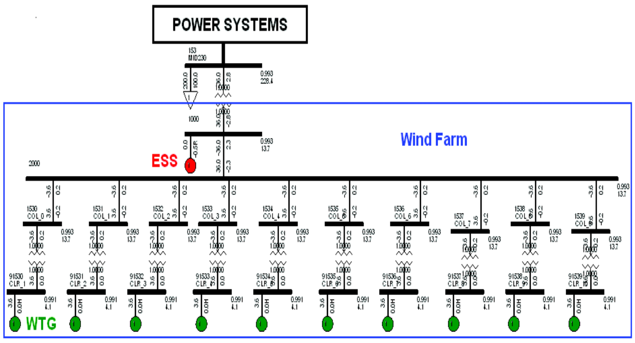

Fig. 9. The configuration of the wind farm with the aggregated the ESS

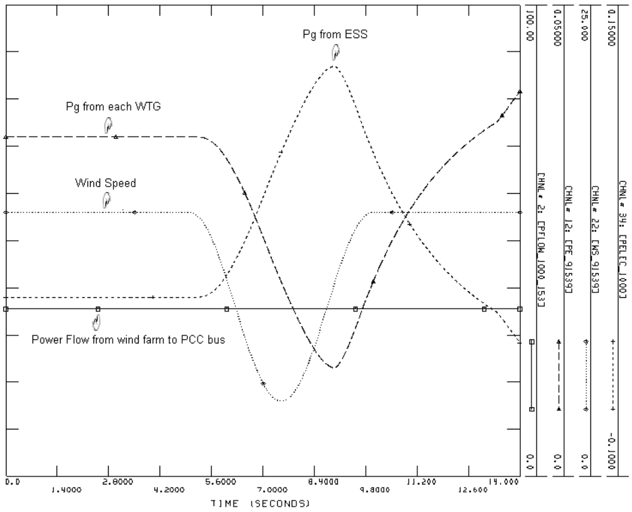

Fig. 10. Wind Power simulation with the concentrated the ESS

keep the active power output of individual WTG as a specified value regardless of the wind variations. ESS is also modeled as the EPRI CBEST battery of ±1.2MW, and ±1.2Mvar [6].

Figure 8 shows the simulation result of a group of WTG with wind variation, and the solid line indicates the total power flow from the wind power to PCC bus.

As shown in Figure 8, the active power output of WTG drops as the wind speed drops, and ESS compensates active power. However, the power flow from the wind farm to PCC bus could not be kept as a specified value because the capacity limit is reached at some of the distributed ESS.

At second, Figure 9 shows the different configuration for connecting ESS to the wind farm modeled for the simulation purpose. In this configuration, all ESS individually connected to each WTG in Figure 7 are aggregated as one ESS, and connected to the terminal of the wind farm. The aggregated ESS is modeled as the EPRI CBEST battery [5] of ±12MW, and ±12Mvar as same as the sum of all individual ESS in Figure 7.

Figure 10 shows the simulation result of a group of WTG with wind variation, and the solid line indicates the total power flow from the wind power to PCC bus.

As shown in Figure 10, the active power output of WTG depends on the wind variation, and the aggregated ESS compensates active power. However, in this configuration, the power flow from the wind farm to PCC bus could be kept at a specified value although all other conditions are same as the previous case.

In the aggregated configuration of ESS connection, all capacity of the aggregated ESS could be used for suppressing the power flow fluctuations. However, in the distributed configuration of the ESS connection, ESS connected to a group of WTGs with the constant wind could not contribute to suppress the power flow fluctuation of the wind farm so the capacity of the ESS connected to a group of WTG with the wind variation was not enough to suppress the power flow fluctuation. From these simulation results, we could see that some capacity of distributed ESS might be wasted under a specific condition because the wind variations at each WTG might be different even in the same wind farm.

5. IMPROVING POWER SYSTEM STABILITY

As the wind power begins to supply a significant part of the load in the power systems, the irregular stream of electricity from the wind farm caused by the turbulent gusts may even create stability problems in power systems. In this section, ESS is studied for mitigating these problems. The wind farm and ESS are connected as shown in Figure 3. Before the ESS is applied, the speed variations of the other generators in the system are analyzed when the wind farm faces the wind gust. And these effects are compared as the generating contribution of the wind farm is increased from 5% to 20%. Figure 11 shows the simulation results.

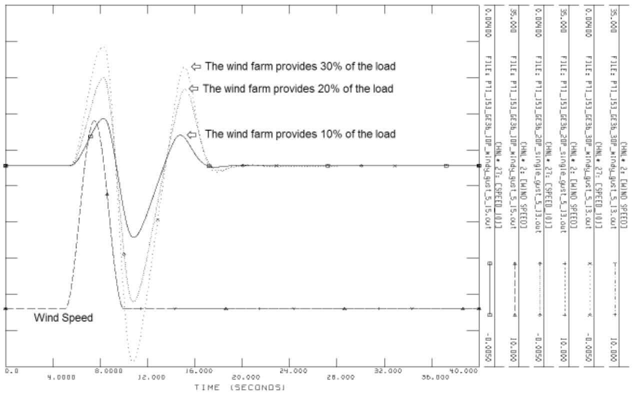

Fig. 11. The speed variation of the generator due to the wind gust

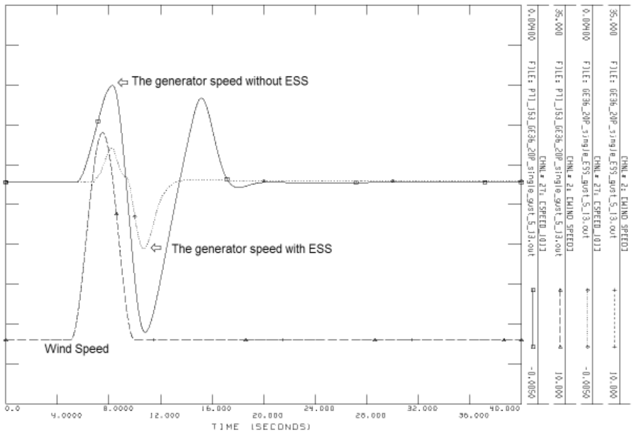

Fig. 12. The control effect of the ESS to the generator speed variation

As shown in Figure 11, the speed variation of the other generator in the system is drastically increased as the generating contribution of the wind farm is increased with the same wind gust. These kinds of situation may have a bad effect on the system stability because the wind farm is getting bigger these days. To these problems, the ESS can be a good solution by instantly releasing or absorbing power when the wind power output is suddenly changed. Moreover, the compensation of the ESS just during even a few minutes can be very effective to these problems.

Figure 12 shows the regulating effect of the ESS for the case that the generating contribution of the wind farm is up to 20% in the system. The capacity of the ESS is assumed to be about 16% of the capacity of the wind farm. In Figure 12, we can see that the speed variation of the generators can be mitigated by the control of the ESS connected to the wind farm.

6. COUNTERACTING TO THE DISTURBANCE ON THE GRID

The ESS can mitigate not only the fluctuations from the wind power but also the disturbances caused by any contingencies on the grid by a proper counteracting.

In this section, for the transient analysis of the system with the wind farm, a 3-phase bus fault cleared by a trip is applied as a disturbance in the grid as shown in Figure 13, and the response of the wind farm connected to the ESS is analyzed.

The wind farm is assumed to supply 20% of the system loads, and the wind speed is assumed to be constant (14 meters/sec).

Figure 14 shows the simulation results of the wind farm when a disturbance occurs in the grid before the ESS is connected.

As shown in Figure 14, a disturbance in the system causes the oscillations in the power flow from the wind farm although the wind speed is constant. In Figure 15, the counteracting effect of the ESS to this disturbance is shown. By regulating of the ESS, we can see that the power flow from the wind farm can be kept constant even when a disturbance occurs in the grid in Figure 15. The voltage profile on PCC bus is also improved.

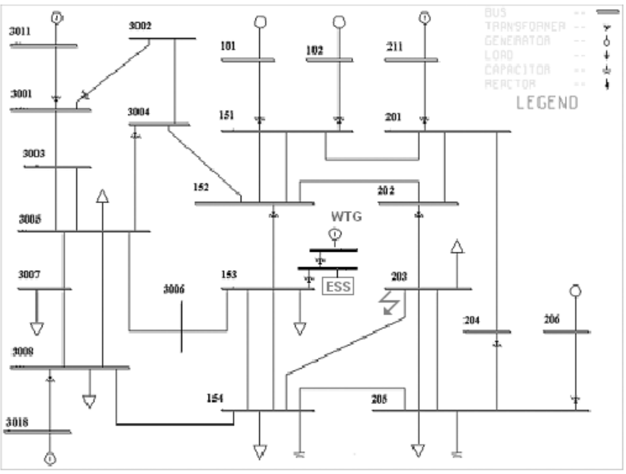

Fig. 13. The sample power systems

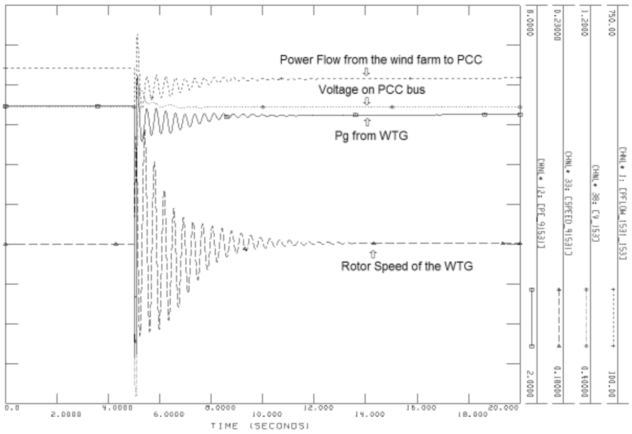

Fig. 14. Wind Power (without the ESS) Simulation with 3-phase bus fault

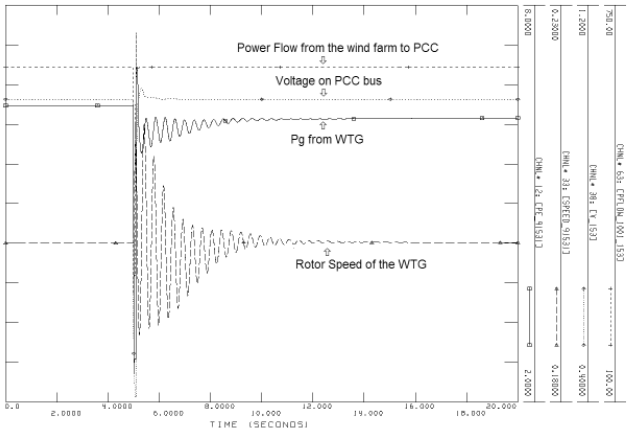

Fig. 15. Wind Power (with the ESS) Simulation with 3-phase bus fault

7. CONCLUSION

As a promising renewable alternative, the wind power is highly expected to contribute a significant part of generation in power systems in the future, but this also bring new integration related power quality issues caused by its comparatively new characteristics. The ESS seems to be a practical solution to these negative impacts of wind power especially with high penetration level. So, from the aspect of the power grid, various studies on the operations of the ESS connected to the WTG would be required. This paper implemented the simulation model for the ESS connected to wind power using PSS/E, and validated the possible applications of the ESS for mitigating the integration issues of wind power employing a sample power system. Case studies showed the preferable control effect of the ESS for suppressing the power fluctuation of the wind farm, and possible difference of the control effect between the distributed and concentrated configuration of ESS connection. This study also showed the preferable control effect of ESS for improving the power system stability with high penetration of wind power as well as for counteracting to a disturbance on the grid.

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