International Journal of Engineering Research and General Science Volume 2, Issue 3, April-May 2014
ISSN 2091-2730

Mixing Wind Power Generation System with Energy Storage Equipments

Mohammad Ali Adelian[1]

[1]Research Scholar, Email- Ma_adelian@yahoo.com

ABSTRACT – — with the advance in wind turbine technologies, the cost of wind energy becomes competitive with other fuel-based generation resources. Due to the price hike of the fossil fuel and the concern of the global warming, the development of wind power has rapidly progressed over the last decade. The annual growth rate of the wind generation installation has exceeded 26% since 1990s. Many countries have set goal for high penetration levels of wind generations. Recently, several large-scale wind generation projects have been implemented all over the world. It is economically beneficial to integrate very large amounts of wind capacity in power systems. Unlike other traditional generation facilities, using wind turbines present technical challenges. Electric power. The distinct feature of the wind energy is its nature of “intermittent”. Since it is difficult to predict and control the output of the wind generation, its potential impacts on the electric grid are different from the traditional energy sources. At high penetration level, an extra fast response reserve capacity is needed to cover shortfall of generation when a sudden deficit of wind takes place. However, this requires capital investment and infrastructure improvement. To enable a proper management of the uncertainty, this paper presents an approach to make wind power become a more reliable source on both energy and capacity by using energy storage devices. Mixing the wind power generation system with energy storage will reduce fluctuation of wind power. Since it requires capital investment for the storage system, it is important to estimate reasonable storage capacities for desired applications. In addition, energy storage application for reducing the output variation and improving the dynamic stability during the gust wind and severe fault are also studied.

Keywords— Wind Power Generation, Conversion System, Energy Storage , Batteries, Pumped Water, Compressed Air, Steady State Power Flow, Model of the Wind Turbine and Energy Storage .

IJERGS

INTRODUCTION

The development of wind power has rapidly growth over the last decade, largely due to the improving in the technology, the provision of government energy policy, the public concern about global warming, and concerned on the limited resource of conventional fuel based generation [1]. As the fossil fuel causes the serious problem of environmental pollution, the wind energy is one of the most attractive clean alternative energy sources. Wind power is one of the most mature and cost effective resources among different renewable energy technologies. Wind energy has gained an extensive interest and become one of the most promising renewable energy alternatives to the conventional fuel based power resources. Despite various benefits of the wind energy, the integration of wind power into the grid system is difficult to manage. The distinct feature of the wind energy from other energy resources is that its produced energy is “intermittent”. Due to the wind power is an unstable source, its impact on the electric grid are different from the traditional energy sources.

Challenge

Due to its intermittent in nature and partly unpredictable, wind power production introduces more uncertainty into operating a power grid. The major challenge to use wind as a source of power is that wind power may not be available when electricity is needed. the excess wind power has driven the wholesale electricity price to the negative territory in the morning while reduction of the wind generation has caused price spike in the afternoon. Thus uncertainty wind power may create the other issues for power system operation. For that reason, this paper studies the use of “Energy Storage Equipment” to reduce the uncertainty and negative impact of the wind generation. The integration of energy storage system and wind generation will enhance the grid reliability and security. Energy storage system can shift the generation pattern and smooth the variation of wind power over a desired time horizon. It is also be used to mitigate possible price hikes or sags. However, this requires significant capital investment and possible infrastructure improvement. It is important to perform cost benefit analysis to determine proper size of energy storage facilities for the desired operations.

Wind Power Generation

The amount mechanical power of a wind turbine is formulated as:

$$P = \frac{1}{2}\rho\pi R^2 v^3 C_P = \frac{1}{2}\rho A v^3 C_P \qquad (1)$$

Where ρ is the air density, *R* is the turbine radius, *v* the wind speed and *CP* is the turbine power coefficient which represents the power conversion efficiency of a wind turbine. Therefore, if the air density, swept area, and wind speed are constant, the power of wind turbine will be a function of power coefficient of the turbine.

Wind Generator Modeling

There are many different generator technologies for wind-power applications in use today. The main distinction can be made between fixed-speed and variable-speed wind-generator concepts.

Fixed Speed Wind Generator:

A fixed-speed wind-generator is usually equipped with a squirrel cage induction generator whose speed variations are only very limited (see figure 2.3). Power can only be controlled through pitch-angle variations. Because the efficiency of wind-turbines (expressed by the power coefficient *CP*) depends on the tip-speed ratio λ, the power of a fixed-speed wind generator varies directly with the wind speed. Since induction machines have no reactive power control capabilities, fixed or variable power factor correction systems are usually required for compensating the reactive power demand of the generator.

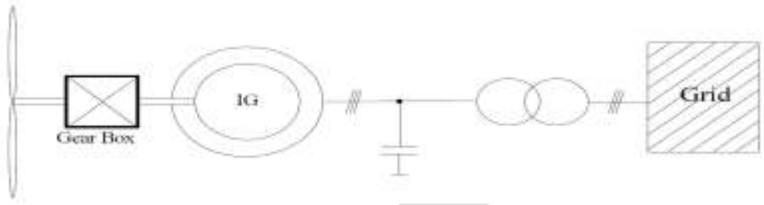


Figure 2.3 Fixed speed induction generator

Variable Speed Wind Generator: Doubly-Fed Induction and Converter-Driven Generator (DFIG)

In contrast to fixed-speed, variable speed concepts allow operating the wind turbine at the optimum tip-speed ratio λ and hence at the optimum power coefficient *CP* for a wide wind-speed range. Varying the generator speed requires frequency converters that increase investment costs. The two most-widely used variable-speed wind-generator concepts are the doubly-fed induction generator (figure 2.4) and the converter driven synchronous generator (figure 2.5 and figure 2.6). Active power of a variable-speed generator is controlled electronically by fast power electronics converters, which reduces the impact of wind-fluctuations to the grid. Additionally, frequency converters (self-commutated PWM-converters) allow for reactive power control and no additional reactive power compensation device is required.

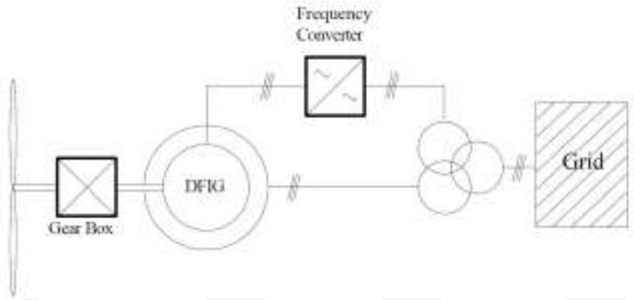


Figure 2.4 Doubly-fed induction generator

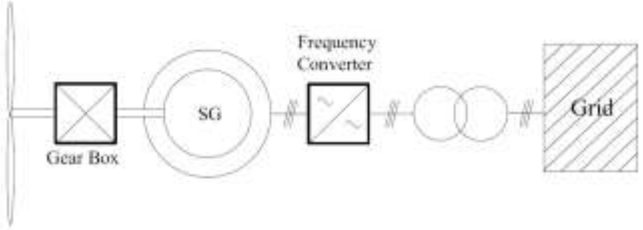


Figure 2.5 Converter-driven synchronous generator

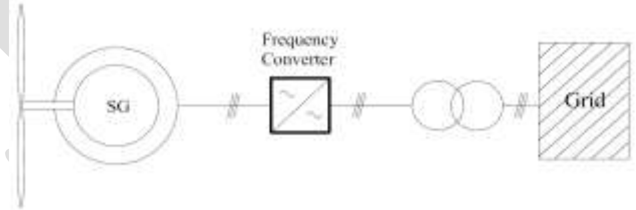


Figure 2.6 Converter-driven synchronous generator (Direct drive)

Figure 2.5 and figure 2.6 show two typical concepts using a frequency converter in series to the generator. Generally, the generator can be an induction or a synchronous generator. In most modern designs, a synchronous generator or a permanent magnet (PM) generator is used. In contrast to the DFIG, the total power flows through the converter. Its capacity must be larger and cost more compare to the DFIG with the same rating. Figure 2.6 shows a direct drive wind-turbine that works without any gear box. This concept requires a slowly rotating synchronous generator with a lot of pole-pairs [9].

Energy Storage

Energy storage is the storing of some form of energy that can be drawn upon at a later time to perform some useful operations. “Energy storages” are defined in this study as the devices that store energy, deliver energy outside (discharge), and accept energy from outside (charge). Energy storage lets energy producers send excess electricity over the electricity transmission grid to temporary electricity storage sites that become energy producers when electricity demand is greater. Grid energy storage is particularly important in matching supply and demand over a 24 hour period of time. Energy storage system can shift the generation pattern and smooth the variation of wind power over a desired time horizon. These energy storages, so far, mainly include chemical batteries, pumped water, compressed air, flywheel, thermal, superconducting magnetic energy, and hydrogen.

Batteries:

Battery storage has been used in the very early days of direct-current electric power networks. With the advance in power electronic technologies, battery systems connected to large solid-state converters have been used to stabilize power distribution networks for modern power systems. For example, a system with a capacity of 20 megawatts for 15 minutes is used to stabilize the frequency of electric power produced on the island of Puerto Rico.Batteries are generally expensive, have maintenance problems, and have limited life spans. One possible technology for large-scale storage is large-scale flow batteries. For example, sodium-sulfur batteries could be implemented affordably on a large scale and have been used for grid storage in Japan and in the United States. Battery storage has relatively high efficiency, as high as 90% or better.

Pumped Water:

In many places, pumped storage hydroelectricity is used to even out the daily demand curve, by pumping water to a high storage reservoir during off-peak hours and weekends, using the excess base-load capacity from coal or nuclear sources. During peak hours, this water can be used for hydroelectric generation, often as a high value rapid-response reserve to cover transient peaks in demand. Pumped storage recovers about 75% of the energy consumed, and is currently the most cost effective form of mass power storage. The main constraint of pumped storage is that it usually requires two nearby reservoirs at considerably different heights, and often requires considerable capital expenditure. Recently, a new concept has been reposed to use wind energy to pump water in pumped-storage. Wind turbines that direct drive water pumps for an 'energy storing wind dam' can make this a more efficient process, but are again limited in total capacity and available location.

Compressed Air:

Another grid energy storage method is to use off-peak or renewably generated electricity to compress the air, which is usually stored in an old mine or some other kind of geological feature. When electricity demand is high, the compressed air is heated with a small amount of natural gas and then goes through expanders to generate electricity.

Model of the Wind Turbine and Energy Storage:

A study system consisting of wind turbine and energy storage connected to a power system is modeled using the Power System Simulation for Engineering (PSS/E) software by Power Technologies Incorporation. In the PSS/E, the wind turbine model is equipped with an IPLAN program that guides the user in preparing the dynamic modules related to this model. The collection of wind turbines, wind speed information, wind turbine parameters, generator parameters, and the characteristics of the control systems are included [16]. This study uses the wind package of PSS/E to simulate and combine the wind power generation system with energy storage equipments integrated into a power grid.The dynamic model is shown in Figure 3.3. A user-written model can be used to simulate a wind gust by varying input wind speed to the turbine model. The GE 3.6 machine has a rated power output of 3.6 MW. The reactive power capability of each individual machine is ±0.9 pf, which corresponds to Qmax = 1.74 MVAR and Qmin = -1.74 MVAR, and an MVA rating of 4.0 MVA. The minimum steady-state power output for the WTG model is 0.5 MW. In this study, the GE wind turbine models are used for simulation following the manufacturer's recommendations [17].

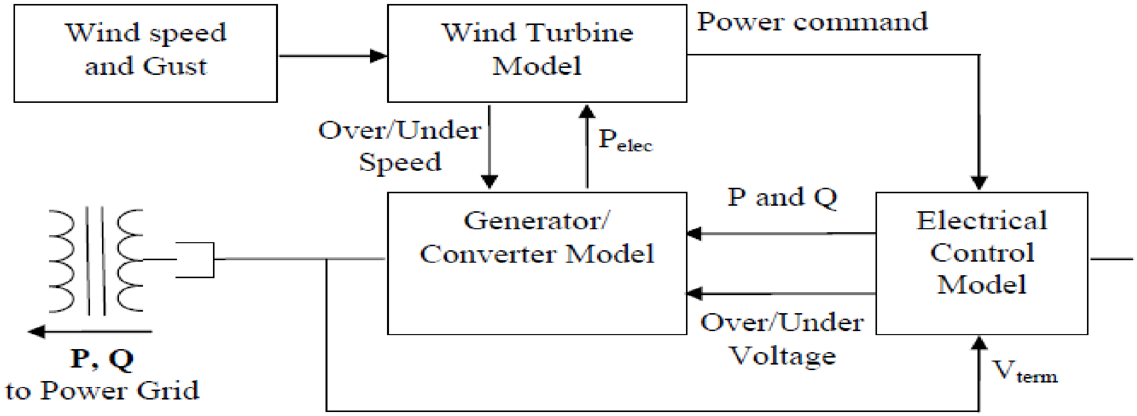


Figure 3.3 Dynamic model of GE 3.6 MW wind turbine

For energy storage model, EPRI battery model CBEST of PSS/E is used for simulation in this study. It simulates the dynamic characteristics of a battery. This model simulates power limitations into and out of the battery as well as AC current limitations at the converter. The model assumes that the battery rating is large enough to cover entire energy demand that occurs during the simulation [18].

Typical Variation of Wind Power:

Figure 4.1 to 4.4 show that storage capacity requirement to maintain the output of the wind farm as constant from one hour to one day under a typical variation of wind power. The storage capacities are 2.036MWh, 5.508MWh, 16.233MWh and 103.451MWh respectively. The maximum charging or discharging power ratings are 7.39MW, 10.66MW, 13.53MW and 17.58MW respectively for different desired operation scenarios. Summary of these estimated values relative to energy storage in typical variation of wind power scenario are shown Table 4.1.

Table 4.1 Estimated Values in Typical Variation of Wind Power

Desired Stable Power Output Time (hour)	Storage Capacity (MWh)	Max. Charging/ Discharging Power (MW)
1 H	2.036	7.39
2 H	5.508	10.66
6 H	16.233	13.53
24 H	103.451	17.58

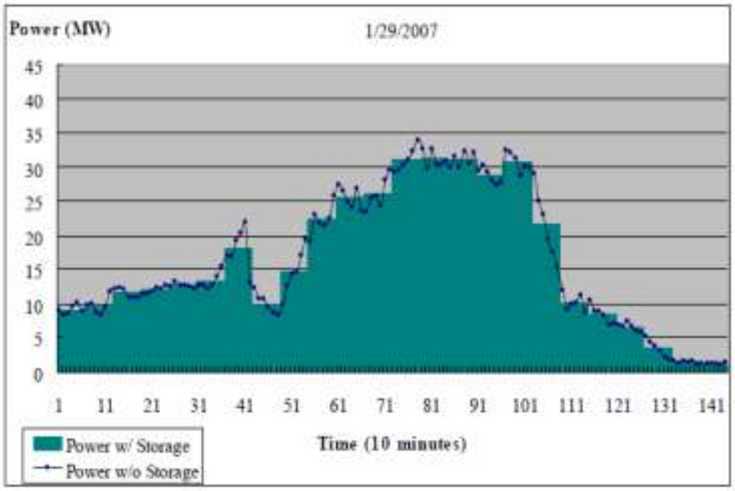


Figure 4.1 Storage Capacity and Time: 2.036 MWh, 1 hour

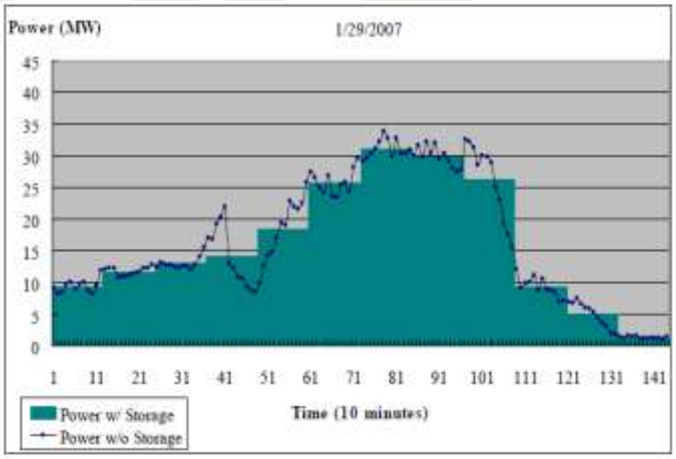


Figure 4.2 Storage Capacity and Time: 5.508 MWh, 2 hours

Figure 4.3 Storage Capacity and Time: 16.233 MWh, 6 hours

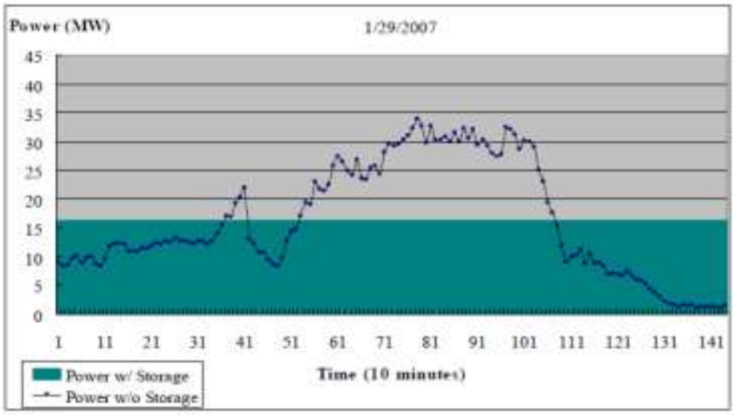


Figure 4.4 Storage Capacity and Time: 103.451 MWh, One Day

Smaller Variation of Wind Power:

As shown in Figure 4.5 to 4.8, they present simulation results for the combined system with storage capacity from one hour to one day when the wind speed is relative stable. As one can see, the required storage capacities and charging/discharging power ratings are smaller than the previous case. The storage capacities are 0.870MWh, 1.690MWh, 3.160MWh and 10.435MWh and the charging/discharging power ratings are 4.63MW, 4.69MW, 5.74MW and 6.26MW respectively. Summary of these estimated values relative to energy storage in smaller variation of wind power scenario are shown Table 4.2.

Table 4.2 Estimated Values in Smaller Variation of Wind Power

Desired Stable Power Output Time (hour)	Storage Capacity (MWh)	Max. Charging/ Discharging Power (MW)
1 H	0.870	4.63
2 H	1.690	4.69
6 H	3.160	5.74
24 H	10.435	6.26

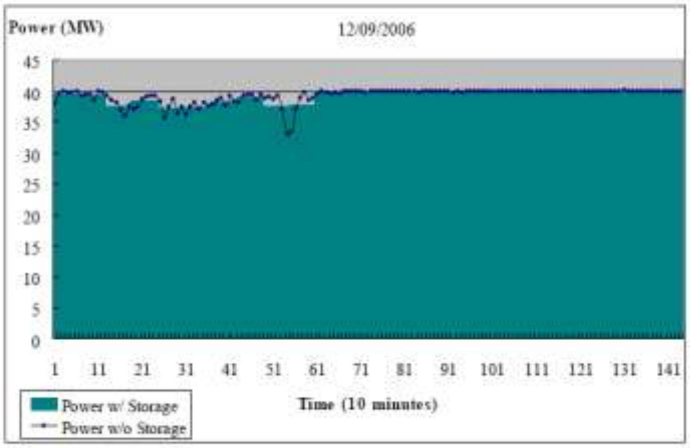


Figure 4.5 Storage Capacity and Time: 0.870 MWh, 1 hour

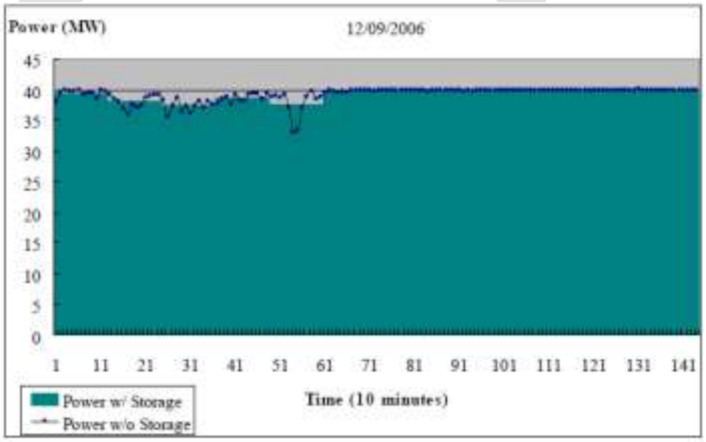


Figure 4.6 Storage Capacity and Time: 1.690 MWh, 2 hours

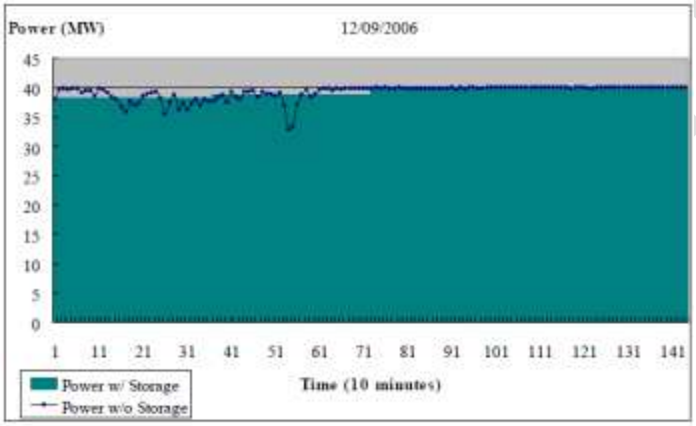


Figure 4.7 Storage Capacity and Time: 3.160 MWh, 6 hours

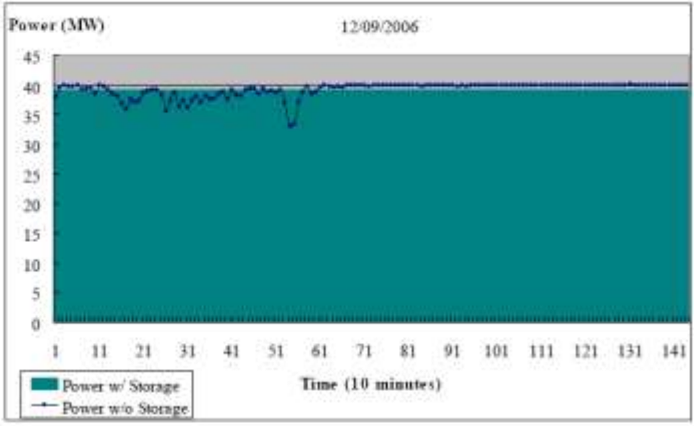


Figure 4.8 Storage Capacity and Time: 10.435 MWh, One Day

Larger Variation of Wind Power:

Figure 4.9 to 4.12 show that the behavior of the system for one hour to one day storage capacity when there is large variation of the wind speed. The required storage capacities are 5.164MWh, 10.524MWh, 22.819MWh and 137.863MWh respectively. Maximum charging/discharging power rating requirements are 16.20MW, 23.31MW, 27.94MW and 26.69MW respectively. Summary of these estimated values relative to energy storage in smaller variation of wind power scenario are shown Table 4.3.

Table 4.3 Estimated Values in Larger Variation of Wind Power

Desired Stable Power Output Time (hour)	Storage Capacity (MWh)	Max. Charging/ Discharging Power (MW)
1 H	5.164	16.20
2 H	10.524	23.31
6 H	22.819	27.94
24 H	137.863	26.69

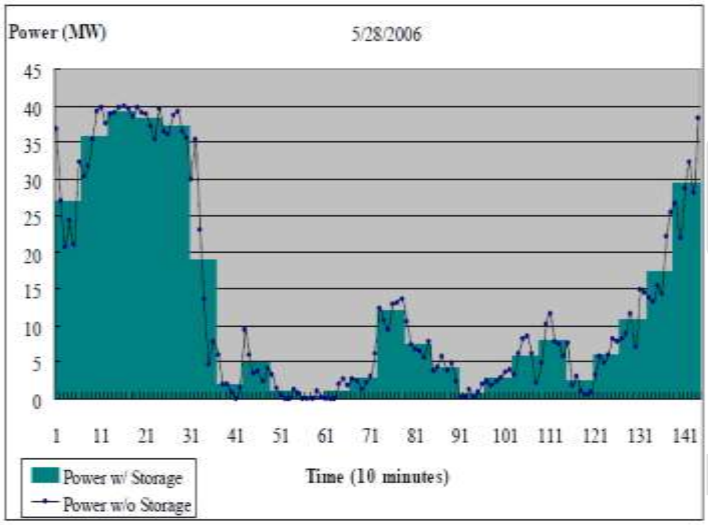


Figure 4.9 Storage Capacity and Time: 5.164 MWh, 1 hour

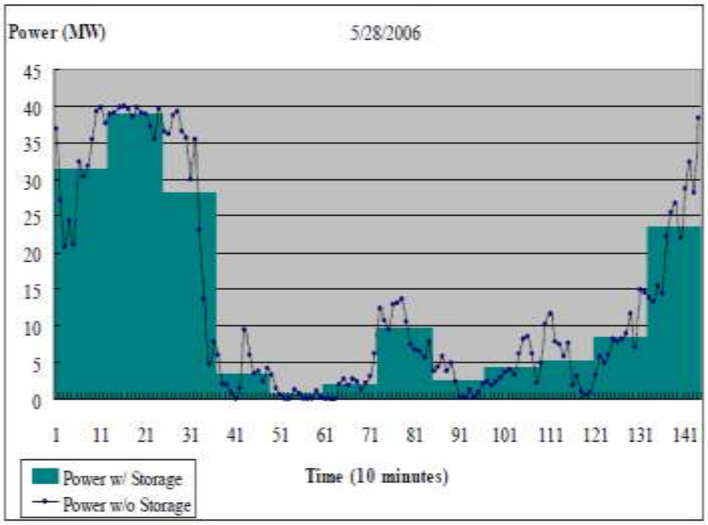


Figure 4.10 Storage Capacity and Time: 10.524 MWh, 2 hours

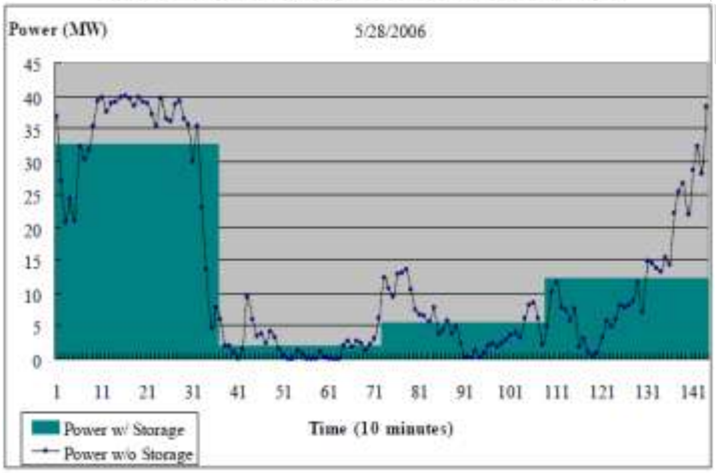


Figure 4.11 Storage Capacity and Time: 22.819 MWh, 6 hours

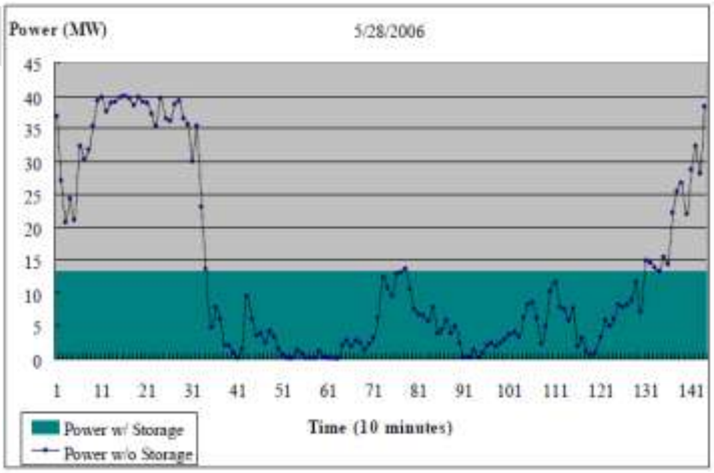


Figure 4.12 Storage Capacity and Time: 137.863 MWh, One Day

Steady State Power Flow Result:

The purpose of this power flow study is to observe the potential system impact during normal and contingency conditions after the 39.6 MW proposed wind farm is interconnected with the grid system. The contingency analysis considers the impact of the new wind power on transmission line loading, transformer facility loading, and transmission bus voltage during outages of transmission line and/or transformers. This study assumes that the energy storage systems is to keep 39.6 MW power output from wind collected bus 350 to grid. Therefore, the power flow result with energy storage equipments is the same as without them. To keep power system operates safely and reliably, the power flow result need to comply with the Taipower Grid Planning Standards [20]. The single line diagram of system near the wind farm is shown in Figure 4.14. Table 4.4 compares the steady state and single contingency (N-1) power flow results before and after the installation of the wind farm. All power flows in the list are expressed in MVA. For N-1 analysis, the obtained result showed no negative impact of the wind farm on the power system. The analysis indicated that an installation of the 39.6 MW wind power has very little effect on the grid system.

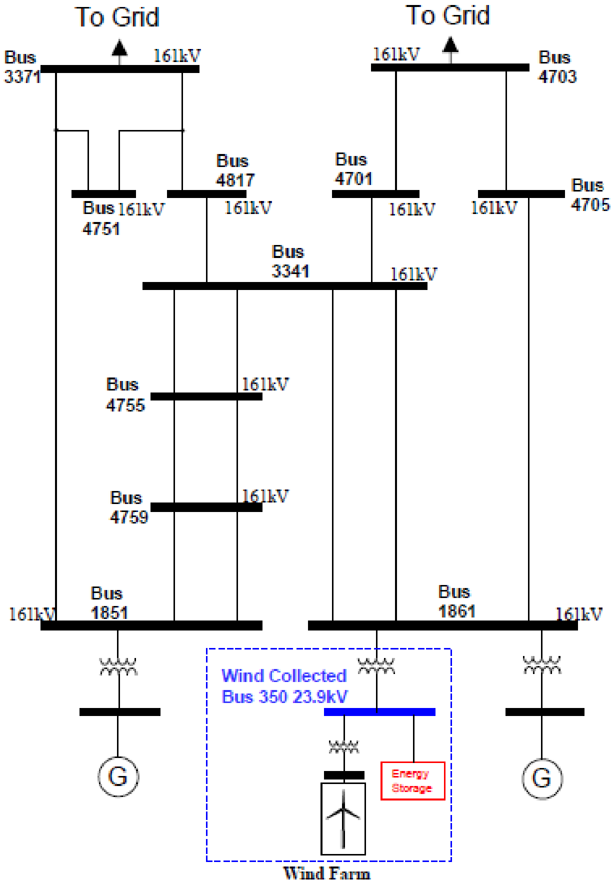
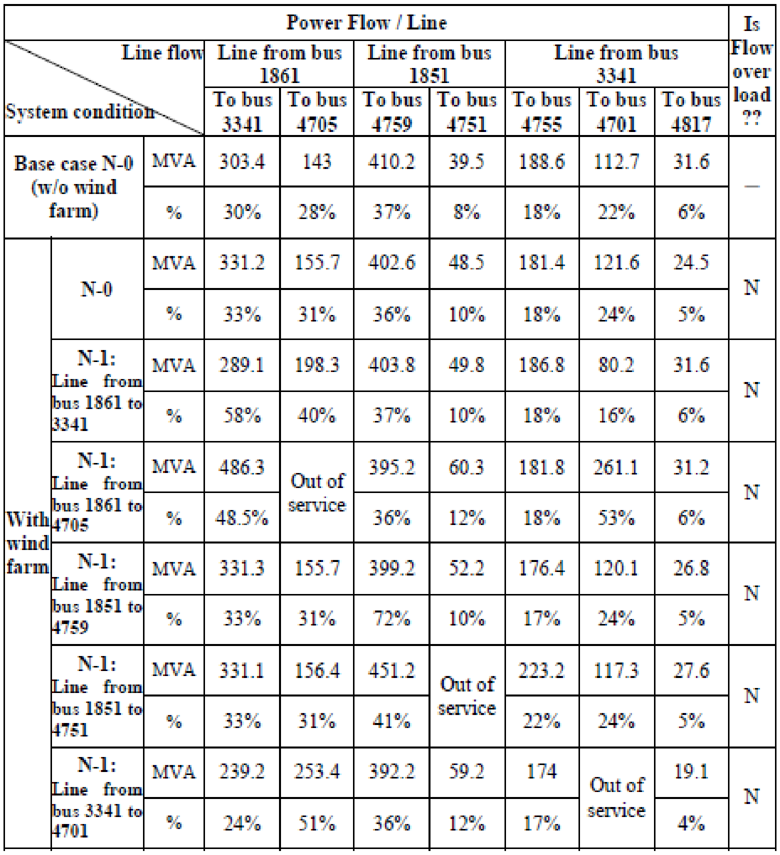


Figure 4.14 Single-line diagram of the power system near the proposed wind farm

Table 4.4 Steady State Power Flow Current and Percentage Level at Neighboring 161 kV Lines of New Proposed Wind Farm



			Power Flow / Line							Is Flow over load ??
Line flow / System condition			Line from bus 1861		Line from bus 1851		Line from bus 3341			
			To bus 3341	To bus 4705	To bus 4759	To bus 4751	To bus 4755	To bus 4701	To bus 4817	
Base case N-0 (w/o wind farm)		MVA	303.4	143	410.2	39.5	188.6	112.7	31.6	—
		%	30%	28%	37%	8%	18%	22%	6%	
With wind farm	N-0	MVA	331.2	155.7	402.6	48.5	181.4	121.6	24.5	N
		%	33%	31%	36%	10%	18%	24%	5%	
	N-1: Line from bus 1861 to 3341	MVA	289.1	198.3	403.8	49.8	186.8	80.2	31.6	N
		%	58%	40%	37%	10%	18%	16%	6%	
	N-1: Line from bus 1861 to 4705	MVA	486.3	Out of service	395.2	60.3	181.8	261.1	31.2	N
		%	48.5%		36%	12%	18%	53%	6%	
	N-1: Line from bus 1851 to 4759	MVA	331.3	155.7	399.2	52.2	176.4	120.1	26.8	N
		%	33%	31%	72%	10%	17%	24%	5%	
	N-1: Line from bus 1851 to 4751	MVA	331.1	156.4	451.2	Out of service	223.2	117.3	27.6	N
		%	33%	31%	41%		22%	24%	5%	
	N-1: Line from bus 3341 to 4701	MVA	239.2	253.4	392.2	59.2	174	Out of service	19.1	N
		%	24%	51%	36%	12%	17%		4%	

Acknowledgment

I want to say thank you to my family, specially my mother for supporting me during my study in M tech and all my friend which help me during this study. I have to also thanks for my college to support me during my m tech in electrical in Bharati Vidyapeeth deemd university college of engineering.

CONCLUSION

Wind generation is the fastest growing renewable energy source all over the world with an average annual growth rate of more than 26 % since 1990 [22]. Annual wind generation markets have been increasing by an average of 24.7% over the last 5 years. Global Wind Energy Council (GWEC) predicts that the global wind market will reach 240 GW of total installed capacity by the year 2012 [23]. Based on information from studies and operational experience, the report of European Wind Energy Association (EWEA) concludes that it is perfectly feasible to integrate the targeted wind power capacity of 300GW in 2030 – corresponding to an average penetration level of up to 20% [24, 25]. For high penetration levels of wind power, optimization of the integrated system should be explored. One has to establish strategies to modify system configuration and operation practices to accommodate high level wind penetration. For storage capacity option, our study reveals that more energy storage capacity and power rating are required if longer stable wind power output is desired. For simulation result during wind gust, combining the wind power generation system with proper energy storage equipments can reduce most of power system fluctuation.

REFERENCES

[1] Ming-Shun Lu, Chung-Liang Chang, and Wei-Jen Lee, “Impact of Wind Generation on a Transmission System,” Power Symposium, 2007 39th NAPS 2007.
[2] Chai. Chompoo-inwai, W.J. Lee, P. Fuangfoo, M. Williams, and J.Liao, “System Impact Study for the Interconnection of Wind Generation and Utility System,”IEEE I&CPS conference, Clearwater Beach, Florida, May 1-6, 2004, Industry Application, IEEE Transaction, Jan.-Feb. 2005.
[3] Energy Efficiency and Renewable Energy web site “ Wind energy topic” ttp://www1.eere.energy.gov/windandhydro/index.html
[4] ERCOT Report, “Analysis of Transmission Alternatives for CompetitiveRenewable Energy Zones in Texas”, December 2006.
[5] M. Hashem Nehrir, “A Course on Alternative Energy Wind/PV/Fuel Cell PowerGeneration,” IEEE PES General Meeting, June 2006.
[6] Debosmita Das, Reza Esmaili, Longya Xu, and Dave Nichols, “An Optimal Design of a Grid Connected Hybrid voltaic/Fuel Cell System for Distributed Energy Production,” IEEE IES, IECON 2005 31st Annual Conference, Nov 2005.
[7] Z. Chen, Y. Hu, “A Hybrid Generation System Using Variable Speed Wind Turbines and Diesel Units,” IEEE IES, IECON 2003 29th Annual Conference, Nov2003.
[8] W.J. Lee, “Wind Generation and its Impact on the System Operation,” Renewable Energy Course Presentation at UTA, August 2007
[9] Markus Pöller and Sebastian Achilles, “Aggregated Wind Park Models for Analyzing Power System Dynamics”.
[10] Wikipedia, the free encyclopedia, “Energy storage” http://en.wikipedia.org/wiki/Energy_storage
[11] Wind resource of Taiwan Map from Renewable Energy in Taiwan.http://re.org.tw/com/f1/f1w1.aspx
[12] Taiwan Power Company, “Tatan wind speed data between Feb 1, 2006 and May 31, 2007 ”.
[13] K. Methaprayoon, C. Yingvivatanapong, W.J. Lee, and J.Liao, “An Integration of ANN Wind Power Estimation into UConsidering the Forecasting Uncertainty,“IEEE Industrial and Commercial Power System Technical Conference, May 2005.
[14] Michael R. Behnke, and William L. Erdman, “Impact of Past, Present and FutureWind Turbine Technologies on Transmission System Operation and Performance,“PIER Project Report, March 9, 2006.
[15] Taipower Company 2006-2007 study planning No.006-2821-02, “The system study of the Taipower system with the rapid increased wind power generation capacity”, Middle report in 2007,3.
[16] “GE Wind 1.5 MW and 3.6MW Wind Turbine Generators, PSS/E Dynamic Models Documentation” PTI., Issue 3.0, June 10, 2004.
[17] Nicholas W.Miller, William W.Price, Juan J.Sanchea-Gasca, “Dynamic Modeling of GE 1.5MW and 3.6MW Wind Turbine-Generators”, October 27, 2003, Version3.0.
[18] PSS/E Power Operation Manual and Program Application Guide, PTI., August 2004.
[19] Ming-Shun Lu, Chung-Liang Chang, Wei-Jen Lee, and Li Wang, “Combining the Wind Power Generation System with Energy Storage Equipments” IEEE IAS 43thAnnual Meeting, October 2008.
[20] Taiwan Power Company, “TPC’s Grid Planning Standards”, Octorber , 2005.
[21] Kyung Soo Kook, McKenzie K.J., Yilu Liu and Atcitty S., “A study on applications of energy storage for the wind power operation in power systems,” IEEE PES General Meeting, June 2006.
[22] Global Wind Energy Council (GWEC), “Global Wind 2005 Report”, August, 2005.
[23] Global Wind Energy Council (GWEC), “Global Wind 2007 Report”, Second Edition, May , 2008.
[24] EWEA, “Large scale integration of wind energy in the European power supply: analysis”, December, 2005. ttp://www.ewea.org/
[25] First results of IEA collaboration “Design and Operation of Power Systems with Large Amounts of Wind Power”, Global Wind Power Conference September 1821,2006, Adelaide, Australia.

IJERGS