THE IMPROVEMENT OF POWER SYSTEM RELIABILITY WITH ENERGY STORAGE IN WIND GENERATION SYSTEM

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ABSTRACT

The reasons to shift the generation system from conventional fuel oil generating system to clean energy sources are now based on the increase of fuel cost, climate change and environmental issues in reducing the greenhouse gas emission and also pollution. Wind is one of the renewable energy that has many advantages and the level of the penetration has increased now. Despite the abundance amount of wind, the fluctuation and the intermittent make wind generation system can affect the reliability of the power system. One of the solutions to the problems above is the use of electrical energy storage system. Power that stored in the electrical energy storage system can be used later when the wind is not strong enough to generate electric power. This research intends to investigate more on li-ion battery as one of the promising means in enhancing the reliability of power system when connecting to wind generation system in order to enhance the power system reliability. This work should contribute significantly in wind energy generation stability improvement with the storage system and there will be an advantage in battery storage system application. The results show the stability improvement of the simulation system connected to the wind generation with the battery.

Keywords: wind, li-ion battery, stability improvement,

1. INTRODUCTION

The increase of fuel cost, climate change and environmental issues in reducing the greenhouse gas emission and pollution are the reasons to shift the generation system from conventional fuel oil generating system to clean energy sources (Olaofe & Folly, 2012). There are many kinds of renewable energy-based power generation. One of the renewable energy that has many advantages is wind. As a clean energy sources, wind now become more exposed and the level of the penetration has increased all over the world (Mohod & Aware, 2008).

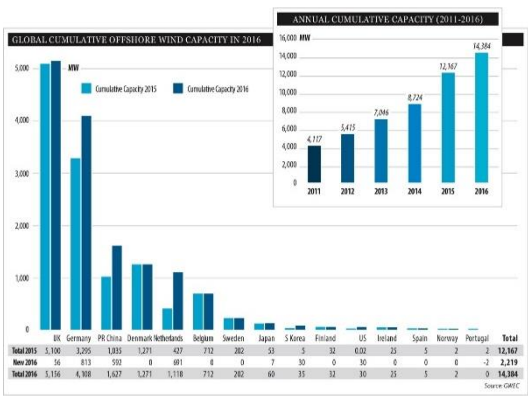

Figure 1.Global Cumulative Installed Wind Capacity 2011-2016.

Despite the abundance amount of wind, the fluctuation and the intermittent make wind generation system can affect the reliability of the power system. The wind speeds for every time the whole year cannot be 100% accurately predicted so the continuity of wind power generation is hard to be maintained. One of the solutions to the problems above is the use of electrical energy storage system. Power that stored in the electrical energy storage system can be used later when the wind is not strong enough to generate electric power. There are many kinds of energy storage system, some are divided based on power rating, low scale, medium and large scale, and some are divided based on the form of the storage system, Electrical Energy Storage (EES), Mechanical Energy storage (MES), Thermal energy storage (TES) and Chemical Energy Storage (CES) including Battery Energy Storage System (BESS) (Chen et al., 2009).

This research focuses on making the Lithium-ion battery as one of the battery energy storage system to be considered as an electrical energy storage system to be proposed to connect with a wind generating system in order to enhance the power system reliability. By taking the advantages of the Lithium-ion battery, connect to the wind power system that has some weaknesses, this research will also investigate the drawbacks of the battery and design the control to minimize them.

2. LITERATURE REVIEW

A. Wind Power

The rise of fossil fuel cost, the increase of energy consumed and environmental issues in reducing the greenhouse gas emission and pollution are the reasons to shift the generation system from conventional fuel oil generating system to clean energy sources (Olaofe & Folly, 2012). There are many kinds of renewable energy-based power generation that being developed now namely wind power, solar energy, geothermal, bio-mass energy, small hydro and ocean based energies. Brief explanation of those types is followed.

Solar power is one of the inexhaustible resources, clean renewable energy and has very low ghg pollution. The technology is flexible and can be used as widely array of applications. Another source is Geothermal. As one of the clean energy, Geothermal is also liberating almost zero emission, although there is some bad nontoxic smell. This energy has a large resource base all over the world and unlike the other sources; it is constantly available and not subject to alter much (Smith & Taylor, 2008).The benefits of biomass energy are potentially sustainable and relatively friendly environment. But a variety of biomass fuels like ethanol, biodiesel, alcohol and vegetable oil combination can be a significant source of greenhouse gases. Despite some advantages of this energy, the issue of the use of biomass as energy sources is sometimes collision with the function as food sources. Another potential energy sources is hydro power. Small hydro, usually considered as distributed generations (DG), it is low cost, simplicity gives a long–lasting reliability and can serve multiple purposes such as a source for irrigation, drinking water, recreation and flood protection. Due to the voltage control issues, DGs cannot get their maximum powers. The other clean energy is ocean based energy, more predictable and reliable compared to other renewable energy but 10–15 years later than wind energy in technology but it is not impossible to expect rapid progress. And lastly wind power as research interest to be developed here, as one of the clean energy sources that have been broadly developed in recent years. It has many advantages such clean, low capital cost and short gestation period and now wind power is the fastest growing energy source in the world. (Smith & Taylor, 2008; Zobaa & Bansal, 2011).

Based on the brief explanations above, the advantages of wind energy are deniably greater than any other renewable energy technology, it has the lowest environmental effects compare to those of any other renewable energy and because it becomes the most exposed and the level of the penetration has increased all over the world (Mohod & Aware, 2008; Smith & Taylor, 2008). Despite the abundance amount of wind, the fluctuation and the intermittent make wind generation system can affect the reliability of the power system. The wind speeds for every time the whole year cannot be accurately predicted so the continuity of wind power generation is hard to be maintained. One of the solutions to the problems above is the use of electrical energy storage system. Power that stored in the electrical energy storage system can be used later when the wind is not strong enough to generate electric power.

B. Battery Energy Storage System

One of the solutions to the problems above is the use of electrical energy storage system. Electrical Energy Storage (EES) can be defined as a storing process of electrical energy from a power network into any form that can be stored and then converting back to electrical power for later use. Based on the size of power rating in system management, EES can be classified as Low scale (under 10 MW), Medium scale (10 – 100 MW) and Large scale (above 100 MW). Based on form, there are four classification of energy storage. They are Electrical Energy Storage (EES), Mechanical Energy storage (MES), Chemical Energy Storage (CES) and Thermal energy storage (TES) (Chen et al., 2009).

The pumped hydroelectric storage (PHS), compressed air energy storage (CAES), fly wheel storage are including in mechanical energy storage and usually used for large scale storage. Chemicals energy storage is divided into electrochemical energy storage (battery), chemical energy storage (hydrogen fuel cells) and thermo chemical energy storage (solar fuel). Sodium sulphur batteries, advanced lead acid batteries, nickel-cadmium storage, lithium-ion batteries, redox-flow energy storage are classified to batteries energy storage systems (Chen et al., 2009; Mahlia, Saktisahdan, Jannifar, Hasan, & Matseelar, 2014; Olaofe & Folly, 2012).

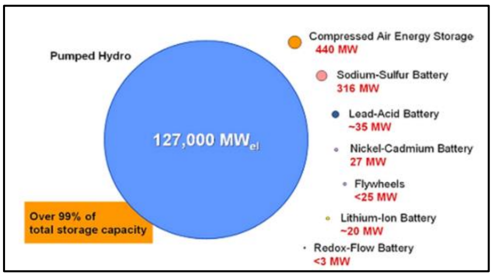

Figure 2.Worldwide installed storage capacity for electrical energy.

Adapted from "A review of available methods and development on energy storage; technology update" by Mahlia et al., 2014, *Renewable and Sustainable Energy Reviews, 33, p.533*

The comparison of the most common worldwide used energy storage is presented in Fig. 1. This figure shows that PHS is the most commonly used with overall rating 127 GWAt the second level is CAES with 440 MW and follow by sodium-sulphur battery is 316 MW and other battery technologies (Mahlia et al., 2014).

The other smaller capacities installed are battery energy storage system and there are many researches have been done and shown many benefits to be explored more. To choose the best storage system to connect with the wind generating system is a challenge. There are many factors and application's parameters to be considered. Parameters like the application, the requirements, the cost, the size, the energy density, the capacity, cycling capability, life time, Depth of Discharge (DoD), environmentally safe, reliable and efficient and operating constraints are the factors to be counted before making the decisions (Mahlia et al., 2014).

Vanadium redox battery, Zinc-bromine (Zn/Br) battery technology, nickel battery and sodium sulphur (Na-S) battery are also under investigated and have some disadvantages like rather poor in energy density and also environmental unfriendliness (Chen et al., 2009; Ghofrani, Arabali, Etezadi-Amoli, & Fadali, 2013; Olaofe & Folly, 2012). One type of the battery energy storage system that already discussed is the Lead-Acid. As an older, mature technology for small to large application and the most developed battery, this type of battery has some advantages such as cost effective option, simplicity in manufacturing. It also has some drawbacks such as low in energy density, limited life span and environmental unfriendliness (Mahlia et al., 2014; Olaofe & Folly, 2012).

This research focuses on making the battery energy storage system particularly lithium-ion battery to be considered as an electrical energy storage system to be proposed to connect with the wind generating system in order to enhance the reliability of the power system.

C. Lithium-Ion Battery

One of the newest technology from the battery energy storage system and is becoming the research interest here is lithium-ion battery. This type of battery has some advantages such as it can be in small size and light weight, safe, abundant, low cost of the cathode material, low maintenance needed, high efficiency and have a long life and better depth of discharge. So it is suggested to be used as wind smoothing. There are some disadvantages though. It has a high capital cost because of the need of special packaging and high charging management system due to closely defined operational limit and need internal overcharge protection circuit (Mahlia et al., 2014; Olaofe & Folly, 2012).

Basically there are three components of the lithium battery, two electrodes, anode and cathode, and the third part is a membrane that allows the electrolyte to penetrate and prevent shorting between the two electrodes called the separator or electrolyte. This battery can work as the storage for energy by converting the electric to electrochemical energy. In discharged status, all the ions are in the cathode sides initially and in charge status, ions are extracted from the cathode, move through the electrolyte into the anode. Electrons move from cathode to anode at the outside current collectors forming an electric circuit. The electric energy will be stored in electrochemical energy when the chemical potential in anode is higher. This process will be starting again once the electrochemical energy is released in the form of electric energy as described in Figure 3. Currently, cathode material determines the cell voltage and capacities, therefore make this material is important to be explored more and to find the new structure that has many advantages with the least cost included (Xu, Qian, Wang, & Meng, 2012).

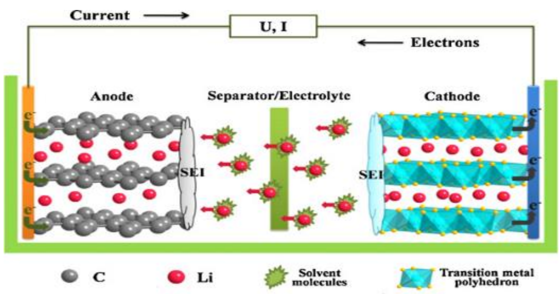

Figure 3.Charging working principles of Lithium-ion battery

Adapted from "Recent progress in cathode materials research for advanced lithium ion batteries" by Bo Xu et al., 2012, Material Science and Engineering R, 73, p.51-65

Some researchers have been done in answering these drawbacks and come up with some solutions but still need to be investigated more. Development of the cheaper cathode materials in order to reduce the expensive drawbacks of the Lithium-ion battery is reviewed by Fergus who investigates the recent improvements in cathode materials needed to reduce the capital cost and extend the life time of the battery. After some comparisons made, some performance characteristics are reviewed and which promising cathode materials and how the solution in improving their performances. It comes to conclusion that for some metal based cathode materials, they can provide high voltages and good capacities. But still with a challenge to make fully utilize the materials for numerous recharging cycles and at high discharge currents since the prevention action of reaction with the electrolyte is significant for long operational life (Fergus, 2010).

Another issue with the lithium ion battery is the protection from overcharged problem. From the various ways of control design for overcharging protection of the lithium ion battery, Iwayasu et al. do research on the connection of the overcharge protection and aromatic compound structure using the overcharge protection agents such as cyclohexylbenzene, isopropyl benzene and toluene. And the result shows that cyclohexylbenzene is the most effective overcharge protection compared to the other agents (Iwayasu, Honbou, & Horiba, 2011). Other researchers have done investigation on the lithium-ion battery packs through relay switches for controlling film growth. The control design has been considered a model of electrochemical battery cell with anode high fidelity model and make approximate film growth rate depends on the cell SOC and applied current (Moura, Forman, Bashash, Stein, & Fathy, 2011).

Control design proposed by Sarrias-Mena et al. in order to enhance the power system reliability has been done under several operating conditions such as wind speed fluctuating input for active and reactive power grid needed, voltage maintained at certain value, three-phase fault and overvoltage or under voltage. This research also proposed supervisory control system design that enable lithium ion battery perform based on the account of the state of charge (SOC) of the battery(Sarias-Mena, Fernandez-Ramirez, Garcia-Vazquez, & Juroado, 2014).

Through the literature review, it is observed that the design and the configuration are introduced in different way, from chemical and engineering side, and this research will propose a new design and configuration that will be simpler with consideration of the cost and the simple circuit design.

3. RESEARCH BENEFITS AND SIGNIFICANCE

Taking the advantages from Lithium-ion battery, this research intends to investigate more and making this battery as one of the option to be with a wind generation system in enhancing the reliability in connecting with the power system.

This research proposed a new investigation on design of Li-ion as a higher energy density, attractive cycle life, and low maintenance cost as an energy storage to strengthen the energy generated from wind turbines by increasing the reliability and good quality of voltage. Battery design will be based on battery energy storage system model inside the MATLAB/Simulink and it will be modified as desired to simulate the best energy storage technology to reduce the capital cost of these batteries without interfering the high performance. Therefore, it is important to know the percentage of the improvement of the reliability with the addition of system energy storage to one particular system with the wind generating system.

Design of Study

1. Modelling of power system with wind power generation and Li-ion battery
   a. Modelling the simple power system using MATLAB / Simulink
   b. Modelling the wind turbine connected to the power system using Induction Generator connected to power system (grid) through transformer and capacitor bank to help with the reactive power needed by the wind turbine
   c. Modelling the lithium-ion battery connected to the system point and analyse the quality of voltage.

   Lithium-Ion Model:

   Discharge Model (i* > 0)

$$f_1(it, i^*, i) = E_0 - K\frac{Q}{Q - it}.i^* - K.\frac{Q}{Q - it}.it + A.exp(-B.it)$$

   Charge Model (i* < 0)

$$f_2(it, i^*, i) = E_0 - K\frac{Q}{it + 0.1Q}.i^* - K.\frac{Q}{Q - it}.it + A.exp(-B.it)$$

2. Research conclusion on reliability performance enhancement. This will be based on simulation run in MATLAB/Simulink of the lithium ion battery performance added to the existing wind power system to improve the reliability and the results of the simulation will be presented. The percentage changes of reliability enhancement in reliability performance will be analysed from various operating conditions. The conditions simulated will be under wind speed fluctuating input for active and reactive power

grid needed, voltage maintained at certain value, three-phase fault and overvoltage/ under voltage.

4. RESULT AND DISCUSSION

Wind power system connected to the power system is modelled with 3MVA squirrel cage induction generator (SCIG). Providing the reactive power compensation, 400kVAR is installed with the addition of 3MVAR STATCOM for maintaining the system voltage. SCIG Wind turbine is connected to the grid and simulated under several conditions such as different loading level, different grid transformer capacity and different fault time. Regulation of the system voltage through reactive power compensation is done by connecting static synchronous compensator (STATCOM). Under several bad conditions (heavy loading level, weaken the grid transformer capacity or longer fault time), the STATCOM cannot work properly as a voltage regulator and reactive power compensator.

The proposed battery is then connected to the system. the results are shown with the active power output (P), system voltage (v), wind turbine rotor speed (wr) and synchronous generator rotor speed (wr) observed to show the reliability performances.

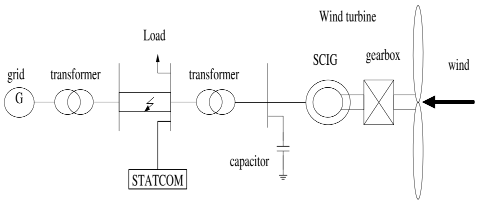

Figure 4. Single line diagram of the simulation system

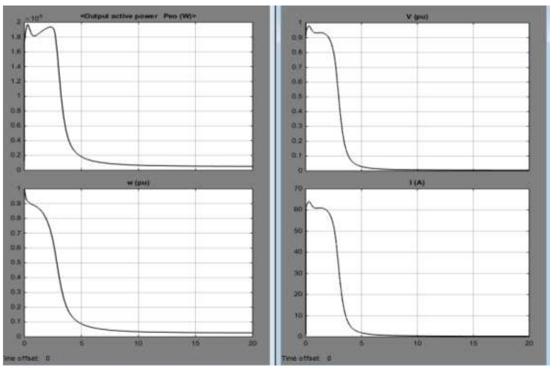

Figure 5. Simulation result when the system cannot maintain its stability because of the fault

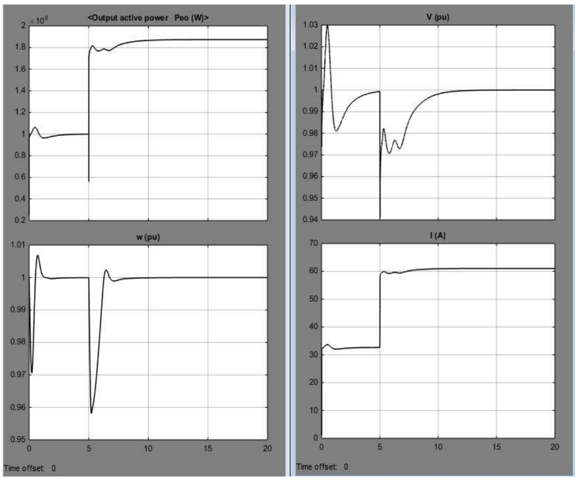

Figure 6. The system can maintain its stability when the proposed battery is connected

For the same total load, compare to the first model that the generator supply the heavy load from the beginning and the fault, the system will lose its stability because the torque exert to near the full capacity from the starting time of simulation (Figure 5).

But in this second model, the system still can maintain its stability and can keep supplying up to 96% of the generator capacity (Figure 6).

5. SUMMARY

This research use the software MATLAB/Simulink in modelling the power system with wind power and the lithium-ion battery connection and to investigate the reliability and stability enhancement through voltage, current, active and reactive power signals. Also the modification of the protection circuit inside the battery will be simulated.

Model for the wind is Induction Generator with three phase fault simulated after the system reached its steady state value.

This work should contribute significantly in wind energy generation stability improvement with the storage system and there will be an advantage in battery storage system application. Also the protection circuit inside the battery will be improved. The research take the advantages of the lithium-ion, minimize the drawbacks and apply to the power system connected to the wind generation system in order to improve the reliability of the power system.

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