Overview of Storage Energy Systems for Renewable Energy System Application

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Abstract— **The integration of renewable energy system into modern power grids has significantly increased during the last decade. Solar and wind energy are the most popular renewable energy sources recently. Solar energy has reached about 17,3 GW in 2010 whilst about 340 TWh of wind energy source has been installed worldwide. In this paper, the overview of updated information regarding proposed storage energy systems for renewable energy is presented. It is useful information for practitioners in considering the possible options of storage energy technologies to be connected with renewable energy sources.**

I. INTRODUCTION

Solar and wind energy resources are today's two most popular renewable energy resources. They are both environment-friendly and sufficiently available naturally, so their utilization continues to show a significant growth worldwide. Germany currently has 43.5% of the world's solar peak capacity, with an installed capacity of 17.3 GW by the end of 2010. This is four times more than that of its nearest rivals, Spain and Japan. Despite overall rapid capaci ty growth around the globe, the PV's power generation share globally is still low, contributing only 0.1% of the world's total power generation. The total installed peak capacity of wind power generation, on the other hand, has shown immense growth by a record 39.4 GW, reaching 200 GW by the end of 2010. Wind power's total installed capacity in 2010 was estimated at around 340 TWh. This indicates that about 1.6% of the total electricity generation worldwide is supplied by wind power generation [1]. In this paper, some well-known storage systems that are pervasive in current power systems will be presented. The chapter will also explain their advantages and limitations as well as their applications to renewable energy resources such as PV and wind. Finally, a short summary and comparison will appear in the last section.

II. STORAGE SYSTEMS FOR RENEWABLE ENERGY SOURCES

The inherent intermittent behavior of renewable energy sources will result in inconsistent power output. Meanwhile, the customer needs the voltage output to be stable, at least within the range of the equipment's safety margin, and the customer must be able to access power immediately. These needs have made diesel and other conventional constant power output generators the dominant supplies ever sinc e the power generator was introduced in the nineteenth century. After the Kyoto Protocol in 1997 [2], the demand for flexible renewable energy sources has skyrocketed as countries wish to mitigate the adverse environmental effects of conventional energy sources. In response to this demand, all sustainable energy systems must limit their reliance upon conventional resources and increase the engagements of renewable energy resources over the next 20-30 years. Overcoming the uncertain behavior of the renewable energy resources would make this goal feasible. Developers have been revising EST for a few decades, and the technology has become so mature that its storage capacity worldwide is currently the equivalent of about 125 GW. Energy storage in a power syste m can be defined as any installation or method, usually subject to independent control, which is capable of storing energy and using it in the power system when required. Energy storage devices are intended to supply energy when the system is under high demand; they are also designated to save energy during low energy demand. These devices are very important to maintaining the continuity of power supply when the main source of power cannot meet all the power demands. On account of this role, energy storage devices are also considered as back-up power systems. Therefore, devices such as solar panels and wind turbine generators not only run on renewable resources, but also increase the value of electricity generated by backing it up during peak demand periods or during the fluctuations of energy resources. With the proper controller, the natural intermittent characteristic of renewable resources can be smoothed out through energy storage devices .

A. Battery Energy Storage System (BESS)

The BESS stores energy in a chemical form. When BESS is connected to the power system, it releases energy back into the network whenever there is a demand. Then, BESS recharges when the grid returns to its normal operation. Batteries are considered as very old storage technologies as they were invented roughly one hundred years ago. Therefore, they are well utilized, explored, and tested and have been a highly popular form of energy storage solution since the early twentieth century. Many types of batteries are available in the market, but this chapter focuses on the batteries that store energy in electric power utility applications, and it pays particular attention to their application in renewable energy sources. Unlike other storage systems, BESS has no significant effect on the environment. The efficiency of this storage system is around 60% to 80% depending on how often the batteries cycle and how often the electrolytes are used. The lead-acid battery is still the most commonly used battery because of its relatively economic power density, especially in the automotive industry. However, it is not designed for deep discharge applications and its charging state should always be kept at the maximum charge level through constant voltage. Thus, the common lead-acid battery is not suitable as a storage device for distributed generations (DG), such as small PVs and wind distributed generators that must repeatedly discharge as much as 80% of their capacity.

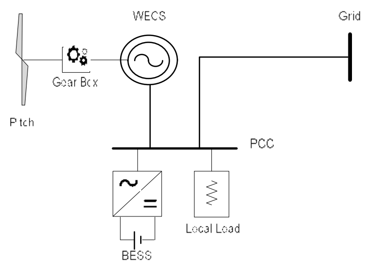

Figure 1. Typical configuration of a WECS-grid connected with BESS

Many studies have presented the application of BESS in conjunction with wind power generation. Some studies have simulated, analyzed, and discussed the hybrid system of energy storages between battery and capacitor [3-6], with flywheel [7] and thermal energy storage [8]. A dual battery scheme is introduced in Ref [9]. This method utilizes two BESSs where the power generated by the wind turbine charges one BESS while concurrently, the second BESS discharges power into the grid. In addition, there are some publications presenting introductory information on the types of batteries that may be directly connected to the DC-link of the variable speed WECS such as the PMSG [10, 11]. Refs [12, 13] have successfully simulated the small capacity of a wind-diesel hybrid system (WDHS) that is backed up by a 240 V Ni-Cd battery during load and wind variations. Refs [12, 13] provide discussions on batteries that work in conjunction with the static synchronous compensator (STATCOM) to achieve better charging/discharging process with the grid. Finally, the application of a battery as a mature storage technology in a hybrid renewable system of wind and PV panels connected to the grid is studied in Refs [14, 15]. The combination of two or more types of EST might result in a system that performs better. However, one must note that any addition or combination of an EST will increase the cost of the system and make the control system more complex. Therefore, reliable control algorithms must be applied to the combined systems. BESS is the most common and most suitable storage system for photovoltaic (PV) solar panels, because there are enough BESS in the market niche to match the size of most PV systems. There are many reports on various applications of BESS with PV systems. For example, Ref [16] demonstrates BESS supplying a standalone PV system with a rather simple controller. Ref [17] provides details of a multi-objective capacity hybrid power system with PV-wind-diesel-battery. Ref [18] presents a model to assess the economic and environmental impact of PV with diesel-BESS for remote villages. Although the battery has proven to be proficient at smoothing and backing up the wind and PV output power, the main drawbacks of batteries are their maintenance costs and relatively short life cycles. Manufactures consider these drawbacks carefully, and they often choose alternative energy storage systems. Moreover, for large wind farm systems, relatively large battery banks must be connected, which consequently increases the maintenance costs and replacement costs as mentioned above.

B. Ultracapacitor

UC has the characteristics of both a capacitor and a battery. However, UC undergoes no chemical reaction as does a battery, so the UC's cycling capacity is significantly higher. UC is also referred to as supercapacitor or electrochemical capacitor, but the term ultracapacitor seems to be more familiar in the power industry. As can be seen in Fig. 2, the energy density of UC is lower than the energy density UC has several advantages over BESS, including higher cycle capacity (more than 100,000 cycles) with efficiency greater than 90%. UC has been used for peak shaving purposes with a power range of hundreds of kilowatts in just one second (faster than battery).

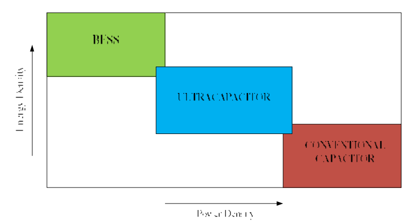

Figure 2. Comparison of energy and power density of UC, BESS, and conventional capacitor

UC has often been characterized as being somewhere between a battery and a conventional capacitor but UC's energy density is higher than that of a conventional capacitor. Inversely, in terms of power density, UC has less power density than a conventional capacitor has but more power density than BESS. A presentation has been included in [19] of an application of UC with a battery to improve the power dispatch of WECS during low wind speed. Installing UC instead of a conventional capacitor on PMSG based WECS is discussed in [20] and UC's combination with fuel cells is introduced in Ref [21]. The advantages of connecting UC with a large PV system over connecting a battery or a shunt capacitor to stabilize the large PV systems is presented in Ref [22], along with comparisons of connecting UC with hydro and thermal power systems. Study that tested UC's ability to meet load demands when connected to a standalone PV system is in Ref [23] and the studies that examined UC's ability to match the power demand of a micro-grid when connected to an integrated PV are listed in Refs [24, 25]. The new, composite energy storages of UC and BESS, which are designed to manage dynamic energy on a micro-grid, are discussed in Ref [26] and a composite of UC, BESS, and PV for electric vehicles is designed and modeled in Ref [27]. Unlike BESS, UC has sufficient efficiency for grid application and achieves about 90%. UC's estimated cost/kW is also more competitive than BESS's. However, UC has low power density, so the size of UC remains in the wattage scale. Recent prototypes have increase UC's kW range, but its scalability is still incompatible for large-scale WECS and for PV system applications.

C. *Superconducting Magnetic Energy Storage (SMES)*

Superconducting coil stores energy within a magnetic field created by the flow of direct current in a coil that should be maintained within a superconductive state through immersion in liquid Helium at 4.2 K in a vacuum-insulated cryostat. SMES is the only storage system known to store electrical energy directly based on electric current.

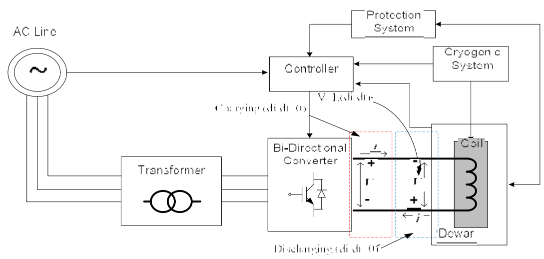

Figure 3. Typical schematic diagram of a SMES unit [28]

The suitability of the SMES unit for renewable energy-based power systems has been demonstrated in many studies. SMES can regulate the natural intermittence of most renewable energy resources with its high efficiency, quick response, and long life duration. While it is true that the solar power system provides a fairly constant energy resource with relative ease compared to wind energy systems, it simply cannot provide enough power for large-scale operations without being enormous and expensive. Thus, the SMES unit may be a competitive choice as an ETS candidate compared to other ETS. The main purpose of applying SMES to wind WECS is to stabilize the system in order to compensate for the WECS's fluctuating output power. The suitability of the SMES unit for renewable energy-based power systems has been demonstrated in many studies. SMES can regulate the natural intermittence of most renewable energy resources with its high efficiency, quick response, and long life duration. While it is true that the solar power system provides a fairly constant energy resource with relative ease compared to wind energy systems, it simply cannot provide enough power for large-scale operations without being enormous and expensive. Thus, the SMES unit may be a competitive choice as a ETS candidate compared to other ETS. An early SMES's application to renewable energy is presented in Ref [29], In this study, SMES is used to steady the output power of PV arrays. Ref [30], then describes an advanced system design of PV/SMES. This reference includes three main objectives for applying SMES to PVs connected to a distribution system. The first objective is to smooth the output power of the PV due to the insulation fluctuation. In addition, the SMES system can also support an active and reactive power demand fluctuation in a power distribution system. This hybrid system is also designed to reduce the transient influence caused by a sudden change in the effective and reactive load demand. Ref [30] also introduces the concept of the I/V (current/voltage) converter that uses IGBT, and allows energy to transfer from the SMES coil to the utility system and vice-versa. A new type of dispersed system is introduced in [31]. In this reference, the system consists of a PV, Fuel Cell (FC), and SMES. Both the PV and FC use a boost chopper to transfer power. Meanwhile, the SMES is connected to an I/V converter that uses GTO to allow the charging and discharging process with the grid, as illustrated in Fig. 4.

The main purpose of applying SMES to wind WECS is to stabilize the system in order to compensate for the WECS's fluctuating output power. Some papers have been published regarding this objective, and a few are listed in Refs [32]-[37]. In Ref [32], the study tests a squirrel cage induction generator and then presents a comparison of the results of the STATCOM and SMES connected to the system. However, this study does not work out the detailed model control of the SMES unit. The application of SMES that is controlled by fuzzy logic and connected to a wind farm is presented in Ref [33]. In this reference, the study uses a 6-pulse CSC. The CSC consists of 6-GTO to allow the transfer and absorption of energy from the SMES coil to the power system and vice-versa. However, the fuzzy logic, only consists of one input to control the level degree of CSC's firing angles in order to allow transfer or absorb energy which is unrealistic to apply because the capacity of the SMES coil, on the other hand, has to be taken into consideration to make it closer in a realistic application as described in Chapter 5 of this thesis. In addition, using 6-GTO in SMES application might cause harmonic distortion. Therefore, the 6-GTO should be more robust when it is applied to a 12-pulse CSC with the appropriate transformer connection in order to eliminate the 5th, 7th, 17th,and 19th harmonics in the system [38]. The focus of Ref [34] is to enhance the transient stability of the system by using SMES under various wind fluctuations. This SMES unit consists of an AC/DC converter that is controlled by regulating the modulation index and the phase angle. However, the result for the transient response of active power output (P_{IG}) with or without SMES does not seem very significant, whereas the transient response of active power in a tie line is quite significant.

The enhancement of the transient stability of a wind-SMES connected to the grid is also studied in [35]. The system studied in Ref [35] is similar to the one studied in Ref [33]. However, the SMES configuration used in [35] consists of a VSC and a DC-DC chopper, which both use IGBTs. The controller of VSC is using PWM while conventional PI controller is used to control the DC-DC chopper. The same system as well as a SMES configuration are also presented in [36], and the only difference in this study is its application of fuzzy logic to determine the duty cycle of the DC-DC chopper. Refs [33], [35], and [36] all ignore the capacity of the SMES coil while determining the optimal energy transfer/absorbance of the SMES coil, even though this capacity must be taken into consideration in real applications.

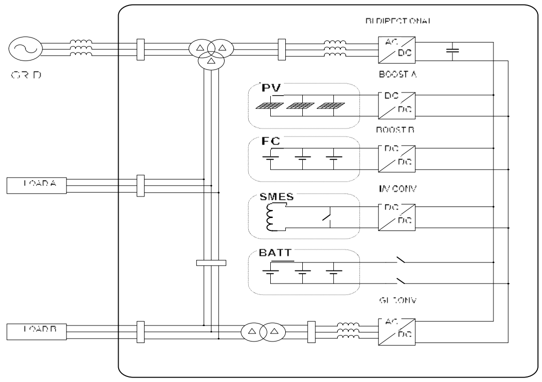

Figure 4. New type dispersed power system that uses SMES unit [31]

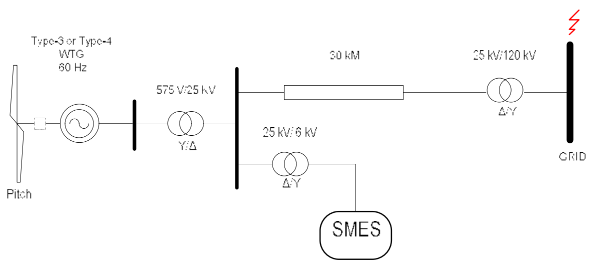

Figure 5. Application of SMES unit on variable speed WECS during grid disturbances [39]

The application of SMES on DFIG WECS is discussed in [37]. This study aims to improve the voltage stability of the wind turbine generator system during any short circuit in the transmission line, while Ref [40] discusses the SMES unit's proficiency at reducing the high voltage profile at the PCC during a swell event on the grid side. The application of SMES on WECS equipped with Type D system is firstly discussed in Refs [41] and [42], SMES is employed on a variable speed WECS, after which the authors compare the transient responses during a voltage sag event on the grid side, as depicted in Fig. 5.

D. Flywheel Energy Storage System (FESS)

A flywheel operates by storing energy in a spinning mass. Through a coupled electric machine, the system can store power by accelerating the shaft and then retrieve the power by slowing the shaft. The flywheel's overall efficiency will drop to 78% after 5 hours and then to 45% after one day; therefore, long term storage is not foreseeable for this device [43]. Numerous studies have discussed the feasibility of flywheels for renewable energy systems, particularly the WECS system. In Refs [44]-[47], the FESS is connected directly to the DC-link of the Type D WECS (the full converter WECS). It is proven that this setup can improve the quality of power delivered by a wind generator. However, since the FESS is applied inside the converter station of the WECS, this concept is only applicable to the new design and can be included only in new connections to the grid. A combination of STATCOM with FESS is introduced in [48]. This concept's objective is to improve the quality of the power output of a fixed speed WECS. The combination of the two devices requires high-performance power electronics, therefore, its installation and operating costs might become high and its proposed control algorithm is very complicated due to the multiple levels of control used in this study. A typical model of an FESS is shown in Fig.6.

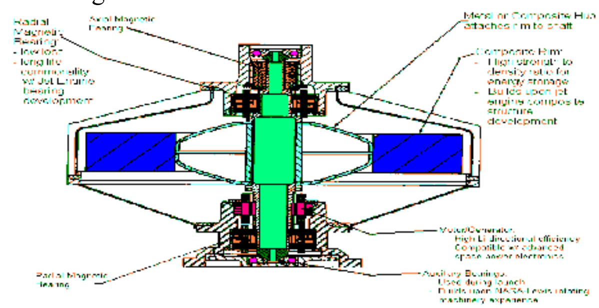

Figure 6. Typical model of a FESS [44]

E. Compressed Air Energy Storage (CAES)

Compressed air energy storage (CAES) works based on conventional gas turbine generation concept. CAES decouples the compression and expansion cycles of a conventional gas turbine into two separate processes and stores energy in the form of compressed air, which is elastic potential energy. During low demand, CAES stores energy by compressing air into an airtight space. To extract the stored energy, CAES draws the compressed air from the storage vessel, heats the air and then expands it through a high-pressure turbine, which captures some of the energy in the compressed air. The air then is mixed with fuel and combusted with the exhaust that is expanded through a low-pressure turbine. Both the high and low-pressure turbines are connected to an electrical generator [49]. This storage technology burns about one-third of the premium fuel that a conventional, simple-cycle combustion engine burns and produces one-third of the pollutants that the conventional engine produces per kWh generated [50]. Typically, CAES is shown in Fig. 7. The literature has also extensively studied CAES in collaboration with WECS. In Ref [52], the researchers have utilized a stochastic electricity market model to estimate the impact of significant wind power generation on system operation and on the economic value of investment in CAES. Given the results of this study, one can conclude that decentralized CAES installation at or close to a large wind generation site may underestimate the economic value of the CAES investment option. The security constraints for CAES along with its connection to WECS and the optimum schedule of generating units for minimizing the cost of supplying energy are studied in Ref [53]. Then, Ref [54], further studies the ancillary services that are constrained by CAES's security requirements.

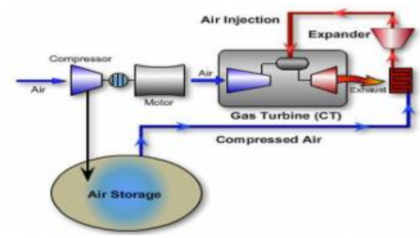

Figure 7. Typical model for a CAES [51]

The study and comparison of different types of wind -diesel and CAES (WDCAS) configurations are described in [55]. This WDCAS arrangement not only increases the penetration rate of wind energy but also improves the star t up speed of the diesel engine. Although CAES is technically approved to be effective with renewable energy systems, it must still be combined with other functions before one can economically justify its operation [56]. In order to improve its efficiency or to remove the need for an additional conventional fuel generation, CAES must be combined with other EST which, in turn, increases the cost and makes the control system more complicated. Generally speaking, the main dis advantages of CAES [57] include its need for high energy input during the power production process and the greenhouse gases emissions that result from CAES's reliance on natural gas. However, this shortage will be overcome in the future with the advent of a third generation of CAES that does not use natural gas in the generation process. The new system will store heat during compression, which it can be reused during generation to warm the compressed air [58]. These ambitions, however, are still under research, and the new system might need considerable time before it is ready for implementation. The other drawback that researchers may need to take into account is CAES's location limitation. This system requires a location with a suitable underground reservoir where a power plant can be constructed [59].

III. CONCLUSION

Various storage energy systems commonly equip renewable energy resources recently. It plays pivotal role in storage the excessive energy while deliver it when required. The intermittent sources of renewable energy can also be solved with the proper selecti on of storage energy technology. In this paper, the current use of storage energy technologies is discussed and provided for practitioners in renewable energy application.

REFERENCES

[1] www.bp.com, accessed: 22 February, 2012

[2] F. A. Farret and M. G. Simoes, "Integration of Alternative Sources of Energy", New Jersey: Wiley-Interscience. 2006

[3] L. Wei, G. Joos, and J. Belanger, "Real-Time Simulation of a Wind Turbine Generator Coupled with a Battery Supercapacitor Energy Storage System", *IEEE Transactions on Industrial Electronics,* vol. 57, pp. 1137-1145. 2010

[4] Y. Yoshida, W. Guohong, and T. Minakawa, "Mitigating Fluctuation of Wind Turbine Power Generation System by Introduction of Electrical Energy Storage with Combined Use of EDLC and Lead Acid Storage Battery", in *International Conference on Power System Technology (POWERCON), 2010*, pp. 1-7. 2010

[5] A. M. Gee and R. W. Dunn, "Novel Battery / Supercapacitor Hybrid Energy Storage Control Strategy for Battery Life Extension in Isolated Wind Energy Conversion Systems", in *Universities Power Engineering Conference (UPEC), 2010*, pp. 1-6. 2010

[6] H. Jia, Y. Fu, Y. Zhang, and W. He, "Design of Hybrid Energy Storage Control System for Wind Farms Based on Flow Battery and Electric Double-Layer Capacitor", in *Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific*, pp. 1-6. 2010

[7] L. Barote, M. Georgescu, and C. Marinescu, "Smart Storage Solution for Wind Systems", in *PowerTech, 2009 IEEE Bucharest*, pp. 1-6. 2009

[8] M. Zamani, G. H. Riahy, N. Abdolghani, M. H. Zamani, and G. Shahgholian, "Utilization of Thermal Energy Storage for Reducing Battery Bank Size of Hybrid (Wind-PV) Systems", in *International Conference on Clean Electrical Power (ICCEP), 2011*, pp. 709-714. 2011

[9] D. L. Yao, S. S. Choi, K. J. Tseng, and T. T. Lie, "Determination of Short-Term Power Dispatch Schedule for a Wind Farm Incorporated With Dual-Battery Energy Storage Scheme", *IEEE Transactions on Sustainable Energy,* vol. 3, pp. 74-84. 2012

[10] X. Y. Wang, D. Mahinda Vilathgamuwa, an d S. S. Choi, "Determination of Battery Storage Capacity in Energy Buffer for Wind Farm", *IEEE Transactions on Energy Conversion,* vol. 23, pp. 868-878. 2008

[11] L. Barote, R. Weissbach, R. Teodorescu, C. Marinescu, and M. Cirstea, "Stand-Alone Wind System with Vanadium Redox Battery Energy Storage", in *International Conference onOptimization of Electrical and Electronic Equipment, 2008*, pp. 407-412. 2008

[12] S. Teleke, M. E. Baran, A. Q. Huang, S. Bhattacharya, and L. Anderson, "Control Strategies for Battery Ener gy Storage for Wind Farm Dispatching", *IEEE Transactions on Energy Conversion,* vol. 24, pp. 725-732. 2009

[13] A. Arulampalam, M. Barnes, N. Jenkins, and J. B. Ekanayake, "Power Quality and Stability Improvement of a Wind Farm Using STATCOM Supported with Hybrid Battery Energy Storage", *Generation, Transmission and Distribution, IEE Proceedings,* vol. 153, pp. 701-710. 2006

[14] F. Giraud and Z. M. Salameh, "Steady-State Performance of A Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage", *IEEE Transactions on Energy Conversion,* vol. 16, pp. 1-7. 2001

[15] V. Khadkikar, R. K. Varma, and R. Seethapathy, "G rid Voltage Regulation Utilizing Storage Batteries In PV Solar System; Wind Plant Based Distributed Generation System", in *Electrical Power & Energy Conference (EPEC), 2009 IEEE*, pp. 1-6. 2009

[16] S. G. Tesfahunegn, O. Ulleberg, T. M. Undeland, and P. J. S. Vi e, "A Simplified Battery Charge Controller for Safety and Increased Utilization in Standalone PV Applications", in *International Conference on Clean Electrical Power (ICCEP), 2011*, pp. 137-144. 2011

[17] A. Saif, K. G. Elrab, H. H. Zeineldin, S. Kennedy, and J. L. Kirtley, "Multi-Objective Capacity Planning of a PV-Wind-Diesel-Battery Hybrid Power System", in *IEEE International Energy Conference and Exhibition,* pp. 217-222. 2010

[18] R. W. Wies, R. A. Johnson, A. N. Agrawal, and T. J. Chubb, "Simulink Model for Economic Analysis and Environmental Impacts of A PV With Diesel-Battery System for Remote Villages", *IEEE Transactions on Power Systems,* vol. 20, pp. 692-700. 2005

[19] J. M. Miller, J. C. K. Yeung, Y. Q. Ma, and G. Sartorelli, "Ultracapacitors Improve SWECS Low Wi nd Speed Energy Recovery. Ultracapacitor and Battery for Low Wind Energy Harvesting", in *Power Electronics and Machines in Wind Applications, 2009. IEEE*, pp. 1-6. 2009

[20] G. Mandic and A. Nasiri, "Modeling and simulation of A Wind Turbine System with Ultracapacitors for Short-Term Power Smoothing", in *IEEE International Symposium on Industrial Electronics*, pp. 2431-2436. 2010

[21] N. Gyawali and Y. Ohsawa, "Effective Voltage and Frequency Control Strategy for A Stand-Alone System with Induction Generator/Fuel Cell/Ultracapacitor", in *Integration of Wide-Scale Renewable Resources Into the Power Delivery System, 2009 CIGRE/IEEE PES Joint Symposium*, pp. 1-11. 2009

[22] R. Shah and N. Mithulananthan, "A Comparison of Ultracapacitor, BESS and Shunt Capacitor on Oscillation Damping of Power System with Large-Scale PV Plants", in *Universities Power Engineering Conference (AUPEC)*, pp. 1-6. 2011

[23] C. Jae Hoon and H. Won-Pyo, "Power Control and Modeling of A Solar-Ultra Capacitor Hybrid Energy System for Stand-Alone Applications", in *International Conference on Control Automation and Systems,* pp. 811-814. 2010

[24] S. Manfredi and M. Pagano, "On the Use of Ultracapacitor to Support Microgrid Photovoltaic Power System", in *International Conference on Clean Electrical Power*, pp. 491-497. 2011

[25] P. J. Binduhewa, A. C. Renfrew, and M. Barnes, "Ultracapacitor Energy Storage for Microgrid Micro-Generation", in *4th IET Conference on Power Electronics, Machines and Drives, 2008*, pp. 270-274. 2008

[26] Z. Haihua, T. Bhattacharya, T. Duong, T. S. T. Siew, and A. M. Khambadkone, "Composite Energy Storage System Involving Battery and Ultracapacitor With Dynamic Energy Management in Microgrid Applications", *IEEE Transactions on Power Electronics,* vol. 26, pp. 923-930. 2011

[27] X. Jianming, K. Longyun, and Z. Yanning, "Design of a Hybrid PV/UC/Batteries System", in *IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems*, pp. 57-61. 2011

[28] A. M. Shiddiq-Yunus, M. A. S. Masoum, and A. A. Siada, "Application of SMES to Enhance the Dynamic Performance of DFIG During Voltage Sag and Swell", *IEEE Transactions on Applied Superconductivity*. 2012 (In Press)

[29] K. S. Tam, P. Kumar, and M. Foreman, "Enhancing the Utilization of Photovoltaic Power Generation by Superconductive Magnetic Energy Storage", *IEEE Transactions on Energy Conversion,* vol. 4, pp. 314-321. 1989

[30] I. Tsukagoshi, I. Takano, and Y. Sawada, "Transient Performance of PV/SMES Hybrid Dispersed Power Source", in *Power Engineering Society Summer Meeting, 2001,* vol.3, pp. 1579-1584. 2001

[31] T. Monai, I. Takano, H. Nishikawa, and Y. Sawada, "Response Characteristics and Operating Methods of New Type Dispersed Power Supply System Using Photovoltaic Fuel Cell and SMES", in *Power Engineering Society Summer Meeting, 2002*, vol.2, pp. 874-879. 2002

[32] F. Zhou, G. Joos, C. Abbey, L. Jiao, and B. T. Ooi, "Use of Large Capacity SMES to Improve the Power Quality and Stability of Wind Farms", in *Power Engineering Society General Meeting,* vol.2, pp. 2025-2030. 2004

[33] M. Hasan Ali, T. Murata, and J. Tamura, "Stabilization of Power System Including Wind Generator by Fuzzy Logic-Controlled Superconducting Magnetic Energy Storage", in *International Conference on Power Electronics and Drives Systems, 2005*, pp. 1611-1616. 2005

[34] C. Shiang-Shong, W. Li, C. Zhe, and L. Wei-Jen, "Power-Flow Control and Transient-Stability Enhancement Of A Large-Scale Wind Power Generation System Using A Superconducting Magnetic Energy Storage (SMES) Unit", in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century,* pp. 1-6. 2008

[35] M. R. I. Sheikh, S. M. Muyeen, R. Takahashi, T. Murata, and J. Tamura, "Transient Stability Enhancement of Wind Generator Using Superconducting Magnetic Energy Storage Unit", in *18th International Conference on Electrical Machines*, pp. 1-6. 2008

[36] M. H. Ali, P. Minwon, Y. In-Keun, T. Murata, and J. Tamura, "Improvement of Wind-Generator Stability by Fuzzy-Logic-Controlled SMES", *IEEE Transactions on Industry Applications,* vol. 45, pp. 1045-1051. 2009

[37] J. Shi, Y. J. Tang, L. Ren, J. D. Li, and S. J. Chen, "Application of SMES in Wind Farm to Improve Voltage Stability", *Physica C: Superconductivity,* vol. 468, pp. 2100-2103. 2008

[38] J. C. Das, "Power System Analysis: Short-Circuit Load Flow and Harmonies", New York: Marcel Dekker. 2002

[39] A. M. Shiddiq-Yunus, A. A. Siadah, and M. A. S. Masoum, "Improvement of LVRT Capability of Variable Speed Wind Turbine Generator Using SMES Unit", in *IEEE Power and Energy Society Innovative Smart Grid Technologies Conference (ISGT 2011)*, Perth, Australia. 2011

[40] A. M. Shiddiq-Yunus, A. A. Siada, and M. A. S. Masoum, "Application of SMES Unit to Improve the High Voltage Ride through Capability of DFIG-Grid Connected during Voltage Swell", in *IEEE Power and Energy Society Innovative Smart Grid Technologies Conference (ISGT 2011)*, Perth, Australia. 2011

[41] A. M. Shiddiq-Yunus, A. Abu-Siada, and M. A. S. Masoum, "Effects of SMES on Dynamic Behaviors of Type D-Wind Turbine Generator-Grid Connected During Short Circuit", in *Power and Energy Society General Meeting, 2011 IEEE*, pp. 1-6. 2011

[42] A. M. Shiddiq-Yunus, A. Abu-Siada, and M. A. S. Masoum, "Effect of SMES Unit on the Performance of Type-4 Wind Turbine Generator During Voltage Sag", in *IET Conference on Renewable Power Generation (RPG 2011)*, pp. 1-4. 201

[43] H. Ibrahim, A. Ilinca, and J. Perron, "Energy Storage Systems-Characteristics and Comparisons", *Renewable and Sustainable Energy Reviews,* vol. 12, pp. 1221-1250. 2008

[44] http://physics.oregonstate.edu/~hetheriw/projects/energy/topics/doc/storage/ flywheel/flyparts.gif, accessed: 20 January, 2012

[45] G. Cimuca, S. Breban, M. M. Radulescu, C. Saudemont, and B. Robyns, "Design and Control Strategies of an Induction-Machine-Based Flywheel Energy Storage System Associated to a Variable-Speed Wind Generator", *IEEE Transactions on Energy Conversion,* vol. 25, pp. 526-534. 2010

[46] K. Idjdarene, D. Rekioua, T. Rekioua, and A. Tounzi, "Direct Torque Control Strategy for a Variable Speed Wind Energy Conversion System Associated to a Flywheel Energy Storage System", in *Second International Conference on Developments in Systems Engineering (DESE), 2009*, pp. 17-22. 2009

[47] M. Khaterchi, J. Belhadj, and M. Elleuch, "Participation of Direct Drive Wind Turbine to the Grid Ancillary Services Using a Flywheel Energy Storage System", in *7th International Multi-Conference onSystems Signals and Devices (SSD), 2010*, pp. 1-6. 2010

[48] G. O. Suvire and P. E. Mercado, "Improvement of Power Quality in Wind Energy Applications Using A DSTATCOM Coupled with a Flywheel Energy Storage System", in *Power Electronics Conference, 2009. COBEP '09. Brazilian*, pp. 58-64. 2009

[49] H. Chen, T. N. Cong, W. Yang, C. Tan, Y. Li, and Y. Ding, "Progress in Electrical Energy Storage System: A Critical Review", *Progress in Natural Science,* vol. 19,pp. 291-312. 2009

[50] R. B. Schainker, "Executive Overview: Energy Storage Options for A Sustainable Energy Future", in *Power Engineering Society General Meeting, 2004. IEEE*, vol.2, pp. 2309-2314. 2004

[51] http://www.matternetwork.com/2010/8/2010-year-compressed-air-energy.cfm, accessed: 10 January, 2012

[52] J. S. Derk, "Compressed Air Energy Storage in an Electricity System with Significant Wind Power Generation", *IEEE Transactions on Energy Conversion,* vol. 22, pp. 95-102. 2007

[53] H. Daneshi, A. Daneshi, N. M. Tabari, and A. N. Jahromi, "Security-Constrained Unit Commitment in A System With Wind Generation and Compressed Air Energy Storage", in *6th International Conference on the European Energy Market, 2009.* pp. 1-6. 2009

[54] H. Daneshi, A. K. Srivastava, and A. Daneshi, "Generation Scheduling with Integration of Wind Power and Compressed Air Energy Storage", in *Transmission and Distribution Conference and Exposition, 2010 IEEE PES*, pp. 1-6. 2010

[55] H. Ibrahim, A. Ilinca, R. Younes, J. Perron, and T. Basbous, "Study of a Hybrid Wind-Diesel System with Compressed Air Energy Storage", in *Electrical Power Conference, 2007. IEEE Canada*, pp. 320-325. 2007

[56] M. Beaudin, H. Zareipour, A. Schellenberglabe, and W. Rosehart, "Energy Storage for Mitigating the Variability of Renewable Electricity Sources: An Updated Review", *Energy for Sustainable Development,* vol. 14, pp. 302-314. 2010

[57] B. R. Alamri and A. R. Alamri, "Technical Review of Energy Storage Technologies when Integrated with Intermittent Renewable Energy", in *International Conference on Sustainable Power Generation and Supply, 2009. SUPERGEN '09*, pp. 1-5. 2009

[58] J. Taylor and A. Halnes, "Analysis of Compressed Air Energy Storage," in *PCIC Europe 2010 Conference Record*, pp. 1-5. 2010

[59] W. Tong, "Wind Power Generation and Wind Turbine Design", Southarmpton, UK: WIT Press. 2010.