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Combination of SDBR and STATCOM to Improve Power Quality of Grid Connected Wind Farm in PSAT Environment

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Abstract:

The renewable energy sources such as wind and solar considered as promising alternative energy sources. The power from wind varies due to the different environmental conditions. The generated power from renewable energy sources is always fluctuating due to environmental conditions. The power arising out of wind turbine connected to grid system concerning the power quality measurements such as active power, reactive power, voltage sag, voltage swell, harmonics and electrical behavior of switching operations. This project presents a method to enhance the stability of a grid-connected wind farm composed of a fixed-speed wind turbine generator system (WTGS) using a combination of small series dynamic braking resistor (SDBR) and static synchronous compensator (STATCOM). The SDBR and STATCOM have active and reactive power control abilities, respectively, and a combination of these units paves the way to stabilize well the fixed-speed wind farm. In this project, a centralized control scheme of using an SDBR and a STATCOM together is focused, which can be easily integrated with a wind farm.

Different types of symmetrical and unsymmetrical faults are considered to evaluate the transient performance of the proposed control scheme, applicable to a grid-connected wind farm. The effect of a multimass drive train of a fixed-speed WTGS in fault analysis, along with its importance in determining the size of the SDBR to augment the transient stability of a wind farm, is investigated. Extensive simulation analyses are performed to determine the approximate sizes of both SDBR and STATCOM units. Dynamic analysis is performed using real wind speed data. A salient feature of this work is that the effectiveness of the proposed system to minimize the blade–shaft torsional oscillation of a fixed-speed WTGS is also analyzed. Simulation results show that a combination of a small SDBR and STATCOM is an effective means to stabilize the wind farm composed of a fixed-speed WTGS.

Keywords:

Induction generator, SDBR, stability, STATCOM, torsional oscillation, wind farm.

1. INTRODUCTION:

The industry worldwide is turning increasingly to renewable sources of energy to generate electricity. Wind is the fastest growing and most widely utilized of the emerging renewable energy technologies in electricity systems at present, with a total of 194.4 GW installed worldwide at the end of 2010 [1]. Variable-speed wind turbine generator systems (WTGS) are getting more attraction than the fixed speed nowadays. However, fixed-speed WTGS technologies still retain a sizeable share on the wind power market due to their superior characteristics such as brushless and rugged construction, low cost, maintenance free, and operational simplicity. The lifetime of a wind turbine is expected to be more than 20 years. Therefore, it is still a matter of interest to investigate the interaction of a fixed-speed WTGS with a power system [2].

The fixed-speed WTGS that uses an induction machine as a wind generator has the stability problem similar to a synchronous generator (SG) [3]–[6]. This study focuses on both transient and dynamic stability improvement issues of the fixed speed WTGS. Due to the huge penetration of wind power to the grid, wind farm grid codes have been developed recently in many countries in which fault ride through (FRT) is an important constraint to adopt with [7]–[11]. There are different techniques and compensating tools reported in power system literatures to augment the stability of the fixed-speed WTGS [6], [12]–[32]. Energy capacitor systems [12], [13], battery energy storage systems [14]–[16], superconducting magnetic energy storage systems [17]–[19], and flywheel energy storage systems [20] are very effective tools as having both active and reactive power control abilities.

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A static synchronous compensator (STATCOM) is also found to be a potential candidate to stabilize a fixed-speed WTGS [21]–[23]. The transient response of a pitch controller is comparatively slow, as reported in [24] and [25], compared with the flexible alternating current transmission system (FACTS) devices used in [12]–[23]. In addition to these, a dynamic braking resistor (DBR) can be used for wind generator stabilization [26]–[32]. As the DBR has only the active power control ability, it is good idea to incorporate a reactive power compensating device along with the DBR. For stability augmentation of a fixed-speed WTGS, a series DBR (SDBR) [29]–[31] is more effective than a DBR with a shunt-connected topology [26]–[28]. In [29] and [30], a simulation analysis is performed using only one fixed speed WTGS that connects the grid. That study is symmetrical to a distributed topology where each SDBR is connected close to the individual wind generators and differs significantly from the centralized topology using only one SDBR installed at the wind farm terminal. Incorporation of an SDBR with a dynamic voltage restorer increases the system cost due to the presence of a transformer and an LC filter [31].

In earlier works with the SDBR [29]–[31], the effect of other SGs that exist in a realistic power system is not evident. This study focuses on transient and dynamic stability augmentation of a grid-connected wind farm composed of fixed-speed WTGSs using a combination of an SDBR and a STATCOM, the purpose of which lies to reduce the overall cost of the compensating devices. Therefore, centralized SDBR and STATCOM are considered to be connected at the terminal of a wind farm that connects the power system to observe the effectiveness of the proposed system during normal and grid fault conditions, in this study. Instead of a representative wind farm model used in [29] and [30], where the components are expressed using a simple transfer function, realistic component modeling is considered in this study using the laboratory standard power system software package PSCAD/EMTDC [33]. The detailed six-mass drive train model is considered in a fixed-speed WTGS for the sake of precise analysis. The effect of a multi mass drive train of a fixed-speed WTGS for fault analysis and its importance in determining the size of an SDBR unit that sufficiently augments the FRT capability of a wind farm are investigated in detail.

2. MODEL SYSTEM:

Fig. 1 shows a model system used for the simulation analyses.

One SG representing the main power plant is connected to an infinite bus through transformers and transmission lines, respectively. Twenty wind generators in a wind farm are connected to the grid through an individual transformer and a common transmission line. A capacitor bank C has been used for reactive power compensation of each induction generator IG at steady state. The value of capacitor C is chosen so that the power factor of the wind generator during the rated operation becomes unity [6]. The automatic voltage regulator and Governor (GOV) control system models for the SG used in this study are available in [6]. A centrally controlled SDBR is considered to be connected at a wind farm terminal. The STATCOM is connected to point K in Fig. 1. The system base power is 100 MVA.

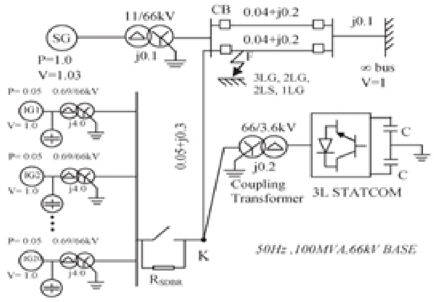

Figure .1 Model System

3. FLEXIBLE AC TRANSMISSION SYSTEM:

3.1 Introduction:

Flexible AC Transmission Systems, called FACTS, got in the recent years a well known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice.In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. The basic applications of FACTS-devices are: 1) Power flow control, 2) Increase of transmission capability, 3) Voltage control, 4) Reactive power compensation, 5) Stability improvement, 6) Power quality improvement, 7) Power conditioning, 8) Flicker mitigation, 9) Interconnection of renewable and distributed generation and storages.

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3.2 Static Synchronous Compensator (STATCOM):

The STATCOM is a solid-state-based power converter version of the SVC. Operating as a shunt-connected SVC, its capacitive or inductive output currents can be controlled independently from its terminal AC bus voltage. Because of the fast-switching characteristic of power converters, STATCOM provides much faster response as compared to the SVC. In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously; therefore, STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for STATCOM to inject capacitive power to support the dipped voltages.

Basically, STATCOM is comprised of three main parts as shown in figure 2: a voltage source converter (VSC), a step-up coupling transformer, and a controller. In a very-high-voltage system, the leakage inductances of the step-up power transformers can function as coupling reactors. The main purpose of the coupling inductors is to filter out the current harmonic components that are generated mainly by the pulsating output voltage of the power converters.

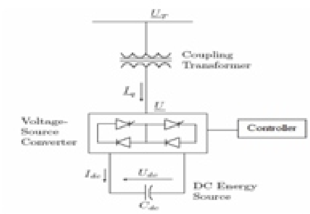

Figure .2 STATCOM

A. Operation:

There are two modes of operation for a STATCOM, inductive mode and the capacitive mode. The STATCOM regards an inductive reactance connected at its terminal when the converter voltage is higher than the transmission line voltage. Hence, from the system's point of view, it regards the STATCOM as a capacitive reactance and the STATCOM is considered to be operating in a capacitive mode. Similarly, when the system voltage is higher than the converter voltage, the system regards an inductive reactance connected at its terminal. Hence, the STATCOM regards the system as a capacitive reactance and the STATCOM is considered to be operating in an inductive mode.

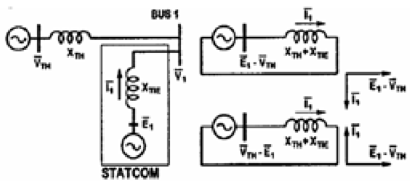

Figure .3 STATCOM operating in inductive or capacitive modes.

In other words, looking at the phasor diagrams on the right of Figure 3, when1I, the reactive current component of the STATCOM, leads (THVE−1) by 90º, it is in inductive mode and when it lags by 90º, it is in capacitive mode.This dual mode capability enables the STATCOM to provide inductive compensation as well as capacitive compensation to a system. Inductive compensation of the STATCOM makes it unique. This inductive compensation is to provide inductive reactance when overcompensation due to capacitors banks occurs. This happens during the night, when a typical inductive load is about 20% of the full load, and the capacitor banks along the transmission line provide with excessive capacitive reactance due to the lower load. Basically the control system for a STATCOM consists of a current control and a voltage control.

4. MODELING AND CONTROL SCHEME:

In this paper, a coordinated control scheme is adopted among the SDBR, STATCOM, and pitch controller to stabilize the wind farm under dynamic and network fault conditions. The coordinated control scheme is schematically shown in Fig. 4.

1) In normal operation, the wind farm terminal voltage deviates a lot due to the rapid wind speed fluctuations as the capacitor banks placed at the terminals of individual wind generators are designed to maintain a unity power factor under rated power conditions when the wind speeds are at rated values. The STATCOM will work during normal operation to maintain constant voltage at the wind farm terminal, and hence, the terminal voltage is set as the control input of the STATCOM in the coordinated control scheme. The STATCOM will also work during the grid fault condition when the terminal voltage falls below a threshold value.

2) The SDBR works only during the grid fault condition along with the STATCOM to enhance the FRT capability of the wind farm when the terminal voltage falls below the threshold value.

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3) The pitch controllers are attached with individual wind:

generators and activate when the power exceeds the rated values of the generators. Therefore, wind generator output power is set as the input of the pitch controller. During the grid fault condition, the pitch controller will also activate when the wind generator power exceeds the rated values, particularly when the fault occurs at high wind conditions.

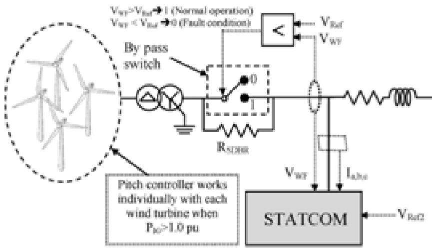

Figure .4 Proposed coordinated control scheme for a wind farm.

A. SDBR:

The concept of the SDBR to augment the FRT capability of the electric generator was first reported in 2004 [37]. The SDBR is used to balance the active power during network disturbance through electrical dissipation. A resistor is dynamically inserted in the generation circuit for a short time during the grid fault, which increases the voltage at the generating end and thus helps in balancing power and electromagnetic torque as well. In this paper, the SDRB is centrally placed to augment the FRT capability of the wind farm composed of fixed-speed WTGSs, as shown in Fig. 4. There are few ways to implement the switching of the SDBR during the fault condition. In this paper, the SDBR is switched on–off using a standard circuit breaker, which is simple to implement, but on–off conditions may lead to a limit cycle.

However, a soft switching scheme can easily be adopted using the insulated gate bipolar transistor (IGBT) or gate turn-off thyristor devices, where the limit cycle issue can be resolved. The wind farm terminal voltage is reasonably chosen as the control input of the centrally placed SDBR, as shown in Fig. 4. During the network fault condition, the wind farm terminal voltage, as well as the voltages at individual wind generators, suddenly reduces. The wind farm voltage is compared with the reference voltage VRef (in this study, a 0.9 per unit (p.u.) value is considered as reference), and the SDBR is switched on instantly.

The essence of the SDBR is that it has a current-squared relationship to the electrical power dissipation, and it quickly restores the wind farm voltage that eventually helps the wind farm to be connected with the power system, fulfilling the FRT requirement of wind farm grid code.

B. STATCOM:

Due to the limitation of the state-of-the-art semiconductor switch technology, the power voltage rating is generally around 6.0 kV, with a mainstream switch voltage rating at 4.5 kV. Therefore, in this paper, a three-level inverter-based STATCOM is used to increase the output voltage for suitable connectivity with the wind farm. The STATCOM total rating is considered as 50MVA. Considering the practical viewpoints and suitability of the simulation analysis, the overall solid-state power circuit combines four three-phase inverter modules, each with a nominal rating of 12.5 MVA, as shown in Fig. 5.

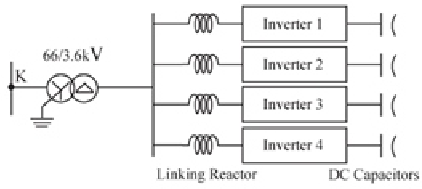

Figure .5 Schematic diagram of a STATCOM design.

The one-pole structure of a three-level IGBT inverter is shown in Fig. 6(a). The IGBT switching table and control methodology of the STATCOM are shown in Fig. 6(b) and (c), respectively. The aim of the control is to maintain the desired voltage magnitude (VRef2 in Fig. 4) at the wind farm terminal. For the control of the voltage source inverter (VSI), the well-known cascaded vector control scheme is used, as shown in Fig. 7.

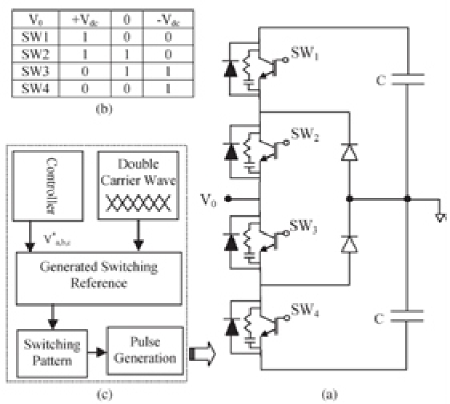

Figure .6 Schematic diagram of a STATCOM switching circuit. (a) One-pole structure. (b) Switching table. (c) Pulse generation system.

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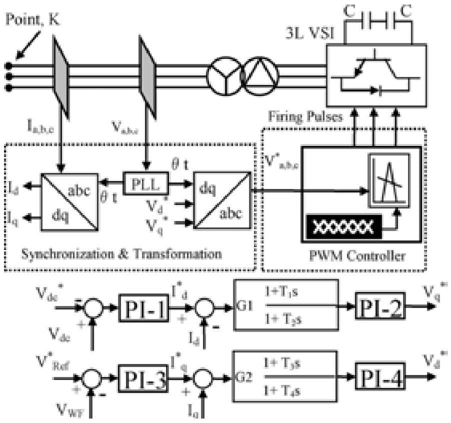

Figure .7 Control block diagram of a 3L VSI-based STATCOM.

5. SIMULATION RESULTS:

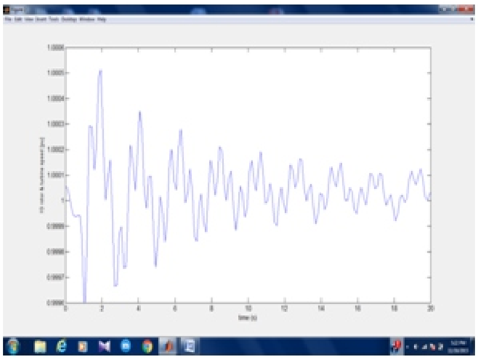

Figure.8 IG rotor and turbine speed of WTGS with a 50 MVA STATCOM and different values of SDBR

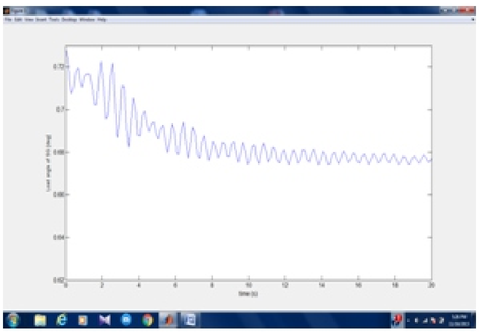

Figure .9 Load angle of the SG with a 50 MVA STATCOM and different values of SDBR

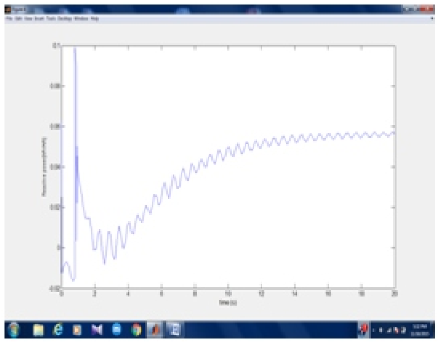

Figure .10 Reactive power of a STATCOM

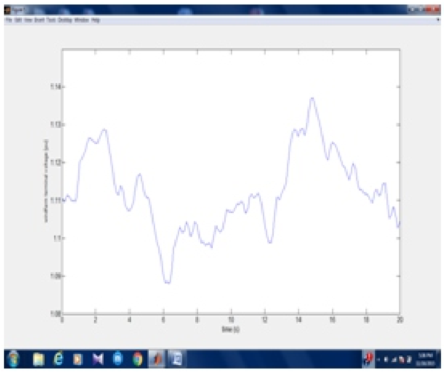

Figure .11 Voltage responses with a 25 MVA STATCOM and different values of SDBR.

6. CONCLUSION:

This paper has focused on the transient and dynamic stability augmentation of a grid-connected wind farm composed of fixed-speed WTGSs using a combination of the SDBR and the STATCOM in a cost-effective proportion. From the extensive simulation analyses, it is found that a 0.3–0.35 p.u. SDBR (based on the system base) and a 20–25 MVA STATCOM (40%–50% of the wind farm capacity) is a good proportion to stabilize the transient and dynamic stabilities of the wind farm.

This proportion is considered for analyzing all types of symmetrical and unsymmetrical fault conditions, and it is found that the wind farm FRT requirement is fulfilled as per recent grid code.

It is also investigated that this proportion can significantly minimize the blade–shaft oscillation of the fixed speed WTGS, which is one of the important observations from this study. Through the extensive simulation analysis, few more relevant observations are given below for further study on the SDBR and the STATCOM for stability augmentation of grid connected wind generators.

FRT requirement of the wind farm as per recent grid code when it is connected to the power grid, particularly for a longer duration of a fault case scenario. The other generators available in the power system may have some pessimistic impact during the FRT of the wind farm for a longer duration fault as the braking resistor is dynamically inserted in series in this configuration.

2) To precisely determine the size of the SDBR that is inserted at the terminal of the wind farm composed of fixed speed WTGSs, a multi mass drive train model should be considered in the analysis.

3) A pertinent proportion of the SDBR and the STATCOM is eventually related to active and reactive power balance, and thus, special attention should be given to determine the size of the SDBR and the STATCOM to augment dynamic and transient stability of a power system-connected wind farm.

Finally, it is concluded that if the capacity of the SDBR and the STATCOM can be chosen properly, the combination will be a cost-effective means to augment the dynamic and transient stability of a grid-connected wind farm composed of fixed speed WTGSs.

REFERENCES:

[1] GWEC publications, Global Wind 2010 Report, The Global Wind Energy Council. [Online]. Available: http://www.gwec.net/
[2] A. Sumper, O. G. Bellmunt, A. S. Andreu, R. V. Robles, and J. R. Duran, "Response of fixed speed wind turbines to system frequency disturbances," IEEE Trans. Power Syst., vol. 24, no. 1, pp. 181–192,Feb. 2009.
[3] C. L. Souza, L. M. Neto, G. C. Guimaraes, and A. J. Moraes, "Power system transient stability analysis including synchronous and induction generator," in Proc. IEEE Porto Power Tech., 2001, vol. 2, p. 6.
[4] J. Tamura, T. Yamazaki, M. Ueno, Y. Matsumura, and S. Kimoto, "Transient stability simulation of power system including wind generator by PSCAD/EMTDC," in Proc. IEEE Porto Power Tech., 2001, vol. 4, EMT-108, doi:10.1109/PTC.2001.964821.
[5] E. S. Abdin and W. Xu, "Control design and dynamic performance analysis of a wind turbine-inductiongenerator unit," IEEE Trans. Energy Convers., vol. 15, no. 1, pp. 91–96, Mar. 2000.
[6] S. M. Muyeen, J. Tamura, and T. Murata, Stability Augmentation of a Grid-connected Wind Farm. London, U.K.: Springer-Verlag, Oct. 2008.
[7] R. Zavadil, N. Miller, A. Ellis, and E. Muljadi, "Making connections [wind generation facilities]," IEEE Power Energy Mag., vol. 3, no. 6, pp. 26–37, Nov./Dec. 2005.
[8] Federal Energy Regulatory Commission (FERC), United States of America, Docket No. RM05-4-000 - Order No. 661, Interconnection for Wind Energy, Jun. 2, 2005.
[9] Wind Farm Power Station Grid Code Provisions, WFPS1, pp. 213–216, Jan. 2007.
[10] E.On Netz, Grid Code, High- and Extra-High Voltage, Apr. 2006. [Online]. Available: www.eon-netz.com/
[11] B. Singh and S. N. Singh, "Wind power interconnection into the power system: A review of grid code requirements," Elect. J., vol. 22, no. 5, pp. 54–63, Jun. 2009.
[12] T. Kinjo, T. Senjyu, N. Urasaki, and H. Fujita, "Output levelling of renewable energy by electric double-layer capacitor applied for energy storage system," IEEE Trans. Energy Convers., vol. 21, no. 1, pp. 221–227, Mar. 2006.
[13] S. M. Muyeen, R. Takahashi, M. H. Ali, T. Murata, and J. Tamura, "Transient stability augmentation of power system including wind farms by using ECS," IEEE Trans. Power Syst., vol. 23, no. 3, pp. 1179–1187, Aug. 2008.
[14] L. Zhang, C. Shen, M. L. Crow, L. Dong, S. Pekarek, and S. Atcitty, "Performance indices for the dynamic performance of FACTS and FACTS with energy storage," Elect. Power Compon. Syst., vol. 33, no. 3, pp. 299–314, Mar. 2005.
[15] S.W. Mohod andM. V. Aware, "Micro wind power generator with battery energy storage for critical load," IEEE Syst. J., vol. 6, no. 1, pp. 118–125, Mar. 2012.
[16] H. Takabayashi, S. Sano, Y. Hirose, K.Mitani, and H.Wakatabe, "The application of valve-regulated lead acid batteries to wind power generation system," in Proc. 31st Int. Telecommun. Energy Conf., Incheon, Korea, 2009, pp. 1–5.
[17] S. C. Tripathy, M. Kalantar, and R. Balasubramanian, "Dynamics and stability of wind and diesel turbine generators with superconducting magnetic energy storage on an isolated power system," IEEE Trans. Energy Convers., vol. 6, no. 4, pp. 579–585, Dec. 1991.
[18] S. Nomura, Y. Ohata, T. Hagita, H. Tsutsui, S. Tsuji-Iio, and R. Shimada, "Wind farms linked by SMES systems," IEEE Trans. Appl. Supercond., vol. 15, no. 2, pp. 1951–1954, Jun. 2005.
[19] S.-S. Chen, L. Wang, W.-J. Lee, and Z. Chen, "Power flow control and damping enhancement of a large wind farm using a superconducting magnetic energy storage unit," IET Renew. Power Gener., vol. 3, no. 1, pp. 23–38, Mar. 2009.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

[20] F. Islam, H. Hasanien, A. Al-Durra, and S. M. Muyeen, "A new control strategy for smoothing of wind farm output using short-term ahead wind speed prediction and flywheel energy storage system," in Proc. Amer. Control Conf., Montreal, QC, Canada, Jun. 2012, pp. 3026–3031.
[21] S. W. Mohod and M. V. Aware, "A STATCOM-Control scheme for grid connected wind energy system for power quality improvement," IEEE Syst. J., vol. 4, no. 3, pp. 346–352, Sep. 2010, Member, IEEE.
[22] S. M. Muyeen, M. A. Mannan, M. H. Ali, R. Takahashi, T. Murata, and J. Tamura, "Stabilization of wind turbine generator system by STATCOM," IEEJ Trans. Power Energy, vol. 126-B, no. 10, pp. 1073–1082, 2006.
[23] M. Aten, J. Martinez, and P. J. Cartwright, "Fault recovery of a wind farm with fixed speed induction generators using a STATCOM," Wind Eng., vol. 29, no. 4, pp. 365–375, Jun. 2005.
[24] P. M. Anderson and A. Bose, "Stability simulation of wind turbine systems," IEEE Trans. Power App. Syst., vol. PAS-102, no. 12, pp. 3791–3795, Dec. 1983.
[25] S. M. Muyeen, M. H. Ali, R. Takahashi, T. Murata, and J. Tamura, "Transient stability enhancement of wind generator by a new logical pitch controller," IEEJ Trans. Power Energy, vol. 126, no. 8, pp. 742–752, Aug. 2006.
[26] W. Freitas, A.Morelato, andW. Xu, "Improvement of induction generator stability using braking resistors," IEEE Trans. Power Syst., vol. 19, no. 2, pp. 1247–1249, May 2004.
[27] 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," IEE Proc.-Gener. Transmiss. Distrib., vol. 153, no. 6, p. 701–110, Nov. 2006.
[28] X.Wu, A. Arulampalam, C. Zhan, and N. Jenkins, "Application of a static reactive power compensator (STATCOM) and a dynamic braking resistor (DBR) for the stability enhancement of a large wind farm," Wind Eng., vol. 27, no. 2, pp. 93–106, Mar. 2003.
[29] A. Causebrook, D. J. Atkinson, and A. G. Jack, "Fault ride-through: Shifting the balance of power from blade to electrical resistance," in Proc. Eur. Wind Energy Conf., Athens, Greece, 2006.
[30] A. Causebrook, D. J. Atkinson, and A. G. Jack, "Fault ride-through of large wind farms using series dynamic braking resistors (March 2007)," IEEE Trans. Power Syst., vol. 22, no. 3, pp. 966–975, Aug. 2007.
[31] Y. Wei, L. Hong, Q. Jiang, and Z. Wang, "A new dynamic strategy for improved ride-through capability of wind turbine generator," in Proc. IEEE Power Energy Soc. Gen. Meet., Detroit, MI, USA, 2011, pp. 1–6.
[32] A. M. Hasan and B. Wu, "Comparison among stabilization methods of fixed-speed wind generator system," in IEEE Energy Conversion Congress and Exposition, ECCE09, San Jose, CA, USA, Sep. 2009, pp. 2667–2674.
[33] PSCAD/EMTDC Manual, Manitoba HVDC Research Center, Winnipeg, MB Canada, 1994.
[34] Heier, Grid Integration of Wind Energy Conversion System. Chichester, U.K.: Wiley, 1998.
[35] O. Wasynczuk, D. T. Man, and J. P. Sullivan, "Dynamic behavior of a class of wind turbine generator during random wind fluctuations," IEEE Trans. Power App. Syst., vol. PAS-100, no. 6, pp. 2845–2873, Jun. 1981.
[36] S. A. Papathanassiou and M. P. Papadopoulos, "Mechanical stresses in fixed speed wind turbines due to network disturbances," IEEE Trans. Energy Convers., vol. 16, no. 4, pp. 361–367, Dec. 2001.
[37] A. Causebrook, "Dynamic braking of electric generators for fault ride though control," U.K. Patent Appl. No. GB0526133.4, Dec. 22, 2005, Newcastle