Line-Fault Ride-Through (LFRT) capabilities of Wind DFIG Turbine

A.Khattara, A.Aboubou and M.Bahri
Laboratory of Energy Systems Modeling Biskra, Algeria
a.khattara@mselab.org; a.aboubou@mselab.org; m.bahri@mselab.org

M. Becherif
FCLab FR CNRS 3539
FEMTO-ST UMR CNRS 6174,
UTBM Belfort, France
mohamed.becherif@utbm.fr

M.Y. Ayad
Industrial Hybrid Vehicle Application
France
ayadmy@gmail.com

O. Akhrif
GREPCI Research Group, Ecole de Technologie Supérieure, Montréal, QC, Canada.
ouassima.akhrif@etsmtl.ca

Abstract—**The penetration of wind power into electrical grids is increased during the recent years. According to grid codes issued by utilities, tripping of wind turbines following power system faults is not allowed. Besides, to provide voltage support to the grid, reactive current supply is necessary. This paper studied the power flow (PF) of two different parts in one network, the first presents the transmission lines and the second presents the distribution lines, a wind DFIG turbine is connected to these different parts of network.A line fault right through (lfrt) is applied on each part of the network. The corresponding voltages are given and compared, then a new solution is proposed to connect the wind turbine to the distribution network and aiming to not disconnect the wind turbine during the line fault. The power system analyses toolbox (PSAT) are used in this work.**

Keywords- DFIG; distribution; line fault; power flow; PSAT

I. INTRODUCTION

In the last 15 years, the use of doubly fed induction machines in modern variable-speed wind turbines has increased rapidly. The scientific literature is rich in this research field. In [1], the aim was to present the complete modelling and simulation of wind turbine driven by doubly-fed induction generator which feeds AC power to the utility grid. The work in [2] attempts to identify some basic relations between damping of the oscillation modes and voltage stability through the analysis of a simplified yet realistic two-area test system. the studied system consists of four equivalent generators [2], which represent a sizeable wind farm connected to the transmission system through a weak radial. The approach chosen has been to perform different types of stability analyses on different power flows and system configurations. Both static and dynamic simulations have been performed. Authors in [3] present a procedure for developing an optimal FRT strategy relevant for upcoming wind farms. The simulation studies in [3], demonstrate that it is possible to increase the connectable wind farm capacity to a given grid configuration by optimising the FRT settings. The optimised FRT strategy is composed of two main requirements: The active power should instantaneously be as low as possible and the reactive power should instantaneously be as high as possible whenever a fault occurs. Both requirements increase the transient stability which is a serious concern during fault occurrences in weak networks. Other study presents the voltage stability in power systems when connected by wind farm generators. Two models of wind generator, namely squirrel cage induction generator and doubly fed induction generator are used and based on steady-state model. P-V curve is used to express maximum loading factor in power system when wind farm was installed. The test IEEE 14 bus system is selected to show the obtained performance. To improve the voltage stability, FACTS device is selected. The results show that STATCOM can improve maximum loading factor better than SVC for both types of wind farm generator. Therefore, this methodology can give direct advantage for organization that and built convincing of power system.the respond of setting wind turbine generator on voltage stability [4]. The behaviour of wind turbine equipped with a Doubly Fed Induction Generator (DFIG) under micro-interruption is dealt in [5]. A scheme tolerant micro-interruption was proposed. A control strategy of the Unified Power Flow Control (UPFC) using PI controller was presented. And finally fuzzy logic controller is illustrated and compared to PI controller. The dynamic analysis of a DFIG-based wind farm connected to a test system, and dynamic simulation to verify the influence of the crowbar resistance value and its operation time were performed and are shown in [6].

In most cases of wind power studying, the weibull wind speed modelling or the composite modelling are presented and chosen [7], [8], [9], [10], [11], [12] and [13]. The results obtained in this paper are with two different wind model types: weibull and composite.

Aspects of grid stability became more and more important due to the worldwide increase of installed wind power plants. In the past, wind power stations had to be disconnected in the case of grid faults. According to new grid code requirements, wind turbines must remain connected to the grid during grid disturbances. Moreover, they must also contribute to voltage support during and after grid faults.

In this paper a DFIG wind turbine is connected to two different lines, the first is equipped by up transformer and the second by a down transformer, where the first presents the transmission network while the second presents the distribution network. A line fault ride through is applied on these different grids and the voltages before, during and after the line fault is obtained and new solution is proposed to not disconnect the

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DFIG wind turbine during the grid fault. The results are given by the PSAT under MATLAB Simulink and two different wind models are tested to validate the results, weibull and composite.

II. Problem Formulation

Doubly-fed induction generators (DFIGs) are variable-speed machine and have seen a recent surge in popularity for wind turbine applications for several reasons [14]. The primary reason for this is their ability to vary their operating speed in order to gain optimum power extraction from the wind [15]. The basic scheme adopted in the majority of systems is showed in figure 1. The stator is directly connected to the grid, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG operating at a variety of speeds in response to wind speed changes. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator to other storage devices. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of the grid line-to-line voltage [16]. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor or stator-sides converter in both super and sub-synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes [17].

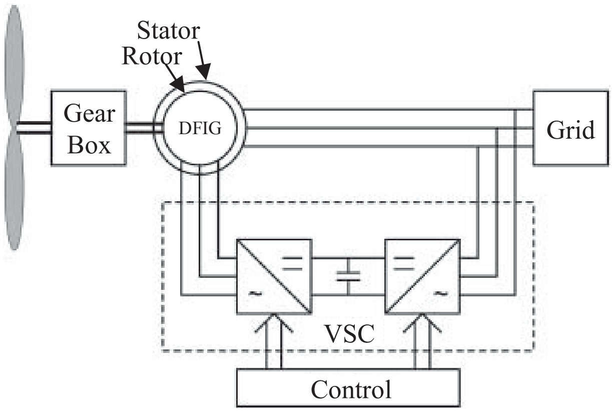

Figure 1. Doubly Fed Induction Genertor

A. *The Weibull wind speed probability density function [18]*

The Weibull wind speed distribution is a mathematical idealization of the distribution of wind speed over time. The function shows the probability of the wind speed being in a 1m/s interval centred on a particular speed (v), taking into account both seasonal and annual variations for the years covered by the statistics. The Weibull distribution function is given by[19] [20]:

$$P_{(v)} = \frac{k}{v}\left(\frac{v}{c}\right)^{k-1} \exp\left\{-\left(\frac{v}{c}\right)^{k}\right\} \quad (1)$$

Where $P_{(v)}$ is the frequency of occurrence of wind speed (v), c (in unit of m/s) is the scale factor which is closely related the wind speed for the location, and k is the dimensionless shape factor which describes the form and width of the distribution. The Weibull distribution is therefore determined by the two parameters c and k. The cumulative Weibull distribution $P_{(v)}$ which gives the probability of the wind speed exceeding the value v is expressed as:

$$P_{(v)} = exp\left\{-\left(\frac{v}{c}\right)^{k}\right\} \quad (2)$$

Equation (2) above suggests that both k and c could be obtained from a regression analysis of P(v) – v plot of the wind speed distribution data for a particular location. However, meteorologists have characterized the distribution of wind speeds for many of the World's wind regimes in terms of the speed distribution patterns. For example, in temperate climate (mid latitudes), a typical shape factor (k) of 2 offers a good approximation [20] [21]. For k = 2, equation (1) or (2) is called the Raleigh wind speed distribution. Hence, the Raleigh distribution is a special case of the Weibull function developed for estimation of wind potential in temperate climate locations. Wind characteristics are essentially location specific and the performance of wind power systems varies if actual wind conditions at the location differ from those standard speed distributions.

On the other hand, according to [20] [22], the shape (k) factor has been suggested to be obtainable using the mean wind speed data (v) and standard deviation (σ) for the location as:

$$k = \left(\frac{\sigma}{v}\right)^{-1.086} \quad (3)$$

While the scale factor has been given [23] as:

$$c = \frac{\mu}{\Gamma\left(1+\frac{1}{k}\right)} \quad (4)$$

Where (Γ) is the gamma function defined mathematically in general x-variable [24] as:

$$\Gamma x = \int_{0}^{\infty} x^{n-1} e^{-x}\, dx \quad (5)$$

B. *Composite wind model*

A composite wind model is as proposed in [25], [26]. This model considers the wind as composed of four parts, as follows:

- average and initial wind speed v_{wa},
- ramp component of the wind speed v_{wr};
- gust component of the wind speed v_{wg};
- wind speed turbulence v_{wt};

Thus, the resulting wind speed $_{w}$ is:

$$_{w}(t) = v_{wa} + v_{wr}(t) + v_{wg}(t) + v_{wt}(t) \quad (6)$$

Where all components are time-dependent except for the initial average speed v_{wa}.

C. *Voltage Stability Index Estimation*

Voltage Stability is defined as the ability of power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition [27]. Voltage stability is a problem in power networks, which are heavily load, faulted, or with insufficient reactive power supply. Although, voltage instability is essentially a local phenomenon, the problem of voltage stability concerns whole power system, and is essential for its operation and control. The main reason for voltage instability is the increased of load, for that reason, voltage stability is also called load stability problem. Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system [4].

The formulation of a voltage stability load index at a load bus uses voltage equations. The technique is based on measurements of voltage phasors and no-load voltage at the bus to calculate the voltage stability L-index. The complete mathematical derivation of the L-index is presented in the Appendix. The index gives the distance of the bus to the voltage stability limit. The voltage stability L-index is given by the equation:

$$L = \frac{4[V_0 V_L cos(\theta_0 - \theta_L) - V_L^2 cos^2(\theta_0 - \theta_L)]}{V_0^2} \quad (6)$$

Where, V_0 is the no load voltage at the node and V_L is the load voltage. When the value of L at every load bus in the system is less than 1.0, the system voltage is stable. As the value of L approaches 1.0 at any bus, the system approaches to its stability limit and becomes unstable when L exceeds 1.0 at the referred bus [28].

III. SIMULATION RESULTS

A. Characteristics

To show the solution for the problem studied in this paper, the simulation was performed using Matlab Simulink ™ PSAT (figure 2).

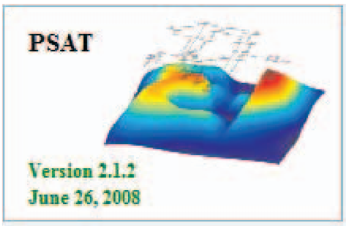

Figure 2. Power System Analysis Toolbox (Psat)

The DFIG power is of 5MW. Figure 3 shows the block diagram of the simulated system. the wind is modeled first by the Weibull, then by the composite methods, a typical network of 7 bus, one generators, tow transformers and four lines is chosen; the network is divided in two parts, the first is equipped by up transformer and presents the transmission network when the second is fed by down transformer and presents the distribution one.

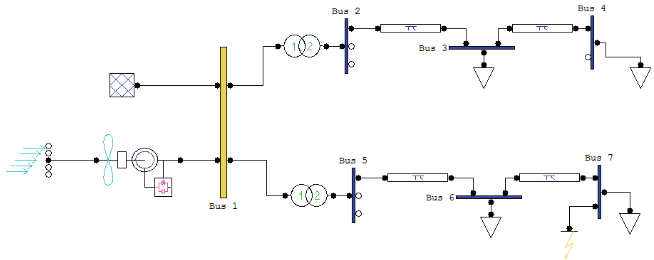

Figure 3. Simulation diagram of the studied DFIG.

B. Influence of the line fault on the DFIG turbine connected to the transmission network

In this work, the DFIG chosen is equipped in the first part by an up transformer 0.96/34.5 kV and are connected to the grid. At time 3s a three phases fault of resistance zero and at 0.5s fault clearing is considered in the transmission lines.

The figures 4 and 5 give the voltages in the slack bus and in the bus where the fault line is appeared before, during and after the fault.

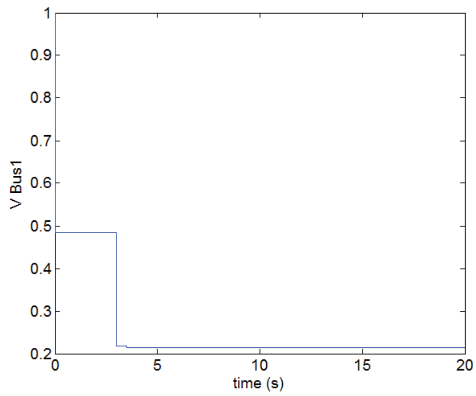

Figure 4. Voltages in bus 1 (fault located in transmission lines) before, during and after the fault.

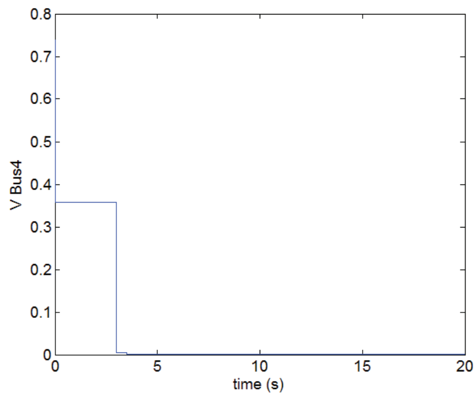

Figure 5. Voltage in bus 4 (fault located in transmission lines) before, during and after the fault.

According to the figures 4 and 5, the voltage in different buses before the grid fault is in standard ranges, but during the fault, a voltage dips is appeared and it remains after that the fault line disappeared. So, the DFIG have not a line-fault ride-through capability when it is connected to the transmission line.

The results given are done with the Weibull wind model and they are checked by the composite wind modeling (figure 6).

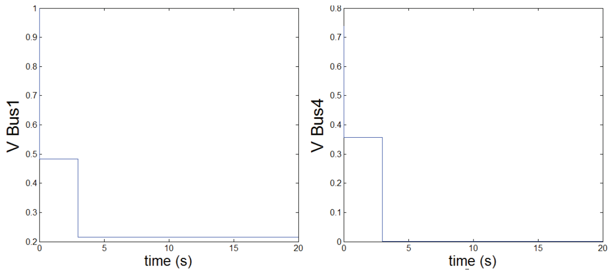

Figure 6. Voltages in the case of composite model (fault located in transmission lines) before, during and after the fault.

C. Influence of the line fault on the DFIG turbine connected to the distribution network

The DFIG is equipped in the second part by a down transformer 0.96/0.380 kV. At time 3s, a three phases fault of resistance zero and at 0.5s, fault clearing is applied in the bus 7 located in the distribution lines.

The figures 7 and 8 give the voltages in the slack bus and in the bus where the fault line is appeared before, during and after the line fault.

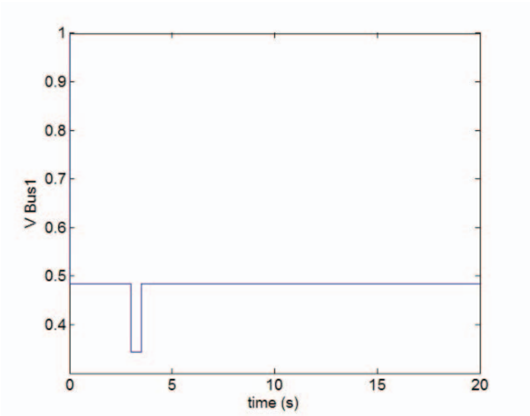

Figure 7. Voltage in bus 1 (fault located in distribution lines) before, during and after the fault.

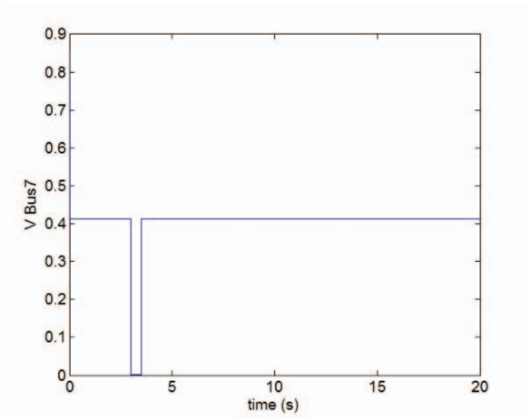

Figure 8. Voltage in bus 7 (Fault located in destribution lines) before, during and ater the fault.

According to the figures 6 and above, the voltage in different buses before and after the grid fault is in standard ranges, but during the grid fault, a voltage dips is appeared in some bus (bus 1 and 5) because the grid fault is between them then it disappeared. So, the DFIG wind turbine has a line-fault ride-through capability when it is connected to the distribution line.

The results given are performed with the Weibull wind model and they are checked by the composite wind modeling (figure 9).

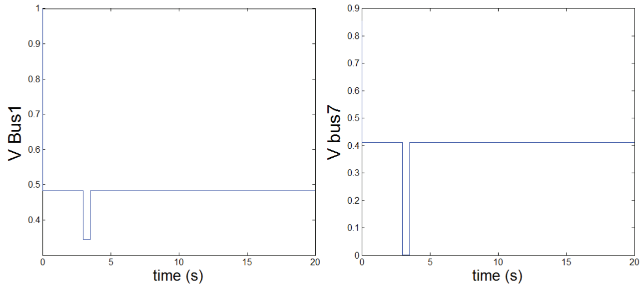

Figure 9. Voltages in the case of composite model (fault located in destribution lines) before, during and after the fault.

The figure 10 shows the reactive power synchronization of the DFIG wind turbine before, during and after the fault.

The DFIG reactive power increases during the line fault to contribute to maintain the voltage, than it decreases to its nominal value after the line fault disappears.

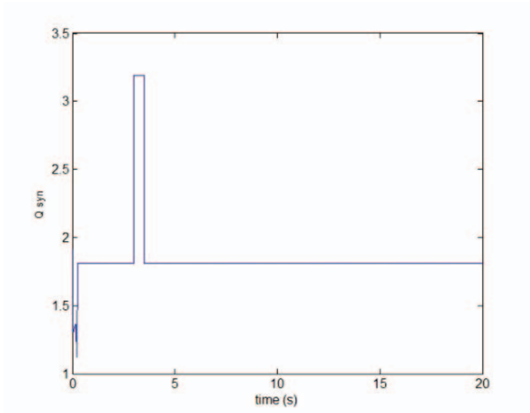

Figure 10. Reactive power synchronization of DFIG connected to the distribution network before, during and after the fault.

The DFIG wind turbine has the capability to contribute to maintain the voltage during a line fault when it is connected to the distribution network by a down transformer. However, it can't inject enough reactive power to maintain the voltage during the fault line when it is connected to the power system by an elevator transformer. As a solution now, the DFIG wind turbine should be connected directly to the distribution network by a down transformer to avoid the problem of disconnection from the network during a line fault, especially in the case of supply strategic points by the electrical energy.

IV. CONCLUSION

This paper has presented the line fault ride through capabilities of DFIG wind turbine. The DFIG has been integrated in two different parts of one network. The first presents the transmission lines, while the second presents the distribution lines. It has been equipped by transformers, a three phases fault has been applied in those different parts of network and at each time, the voltages in all grid bus and the reactive power synchronization of DFIG wind turbine results has been given before, during and after the fault line. The results have been given by the PSAT and the wind was modelled by Weibull then composite methods to validate the results. It has been demonstrated that the line fault ride through capabilities of DFIG wind turbine is done while DFIG wind turbine is integrated in the distribution network and equipped by a down transformer.

Finally, it has been demonstrated that to avoid the problem of disconnecting the DFIG wind turbine from the network during a line fault. It should connect the DFIG wind turbine directly to the distribution network by a down transformer, especially when it is desired to feed the strategic points.

References

[1] B. Chitti Babu , K.B. Mohanty, “Doubly-fed induction generator for variable speed wind energy conversion systems-modeling & simulation,” International Journal of Computer and Electrical Engineering, Vol. 2, No. 1, February, 2010; 1793-8163.

[2] Giuseppe Di Marzio, Olav B. Fosso, Kjetil Uhlen, Magni Þ. Pàlsson, “Large-scale wind power integration, voltage stability limits and modal analysis,” 15th PSCC, Liege, 22-26 August 2005, Session 16, Paper 3.

[3] David T. Johnsen, Willi Christiansen, Arne Hejde Nielsen, Kim H. Jensen, Jørgen N. Nielsen, Troels Sørensen, “Optimisation of the fault ride through strategy of a wind farm,” Paper Master Thesis.

[4] P. N. Boonchiam, A. Sode-Yome, N. Mithulananthan, K. Aodsup, “Voltage stability in power network when connected wind farm generators,” PEDS2009.

[5] M.A. Dami, K. Jemli, M. Jemli and M. Gossa, “Doubly fed induction generator, with crow-bar system, under micro-interruptions fault,” Revue des Energies Renouvelables Vol. 13 N°4 (2010) 653 – 668.

[6] Maurício B. C. Salles, Kay Hameyer, José R. Cardoso, Ahda. P. Grilo and Claudia Rahmann, “Crowbar system in doubly fed induction wind generators,” Energies 2010, 3, 738-753, ISSN 1996-1073.

[7] Zuwei Yu, Sr. and Akiner Tuzuner, “Fractional weibull wind speed modeling for wind power production estimation,” IEEE 2009, 978-1-4244-4241-6/09/$25.00.

[8] Tian Pau Chang, “Wind speed and power density analyses based on mixture weibull and maximum entropy distributions,” International Journal of Applied Science and Engineering 2010. 8, 1: 39-46.

[9] D. J. Lekou, P. Vionis, “Report on repair techniques for composite parts of wind turbine blades,” OPTIMAT BLADES, Repair_techn_1.doc, Last saved 13/08/2002.

[10] Arnab Sarkar, Sunita Singh, Debojyoti Mitra, “Wind climate modeling using Weibull and extreme value distribution,” International Journal of Engineering, Science and Technology, Vol. 3, No. 5, 2011, pp. 100-106.

[11] Ali Naci Celik, “Energy output estimation for small-scale wind power generators using Weibull-representative wind data,” Journal of Wind Engineering and Industrial Aerodynamics 91 (2003) 693–707.

[12] Anderson PM, Bose A, “Stability simulation of wind turbine systems,” IEEE Trans Power Apparat Syst 1983; 102(12):3791–5.

[13] E. G. Potamianakis, C. D. Vournas, “Modeling and Simulation of Small Hybrid Power Systems,” Paper accepted for presentation at 2003 IEEE Bologna Power Tech Conference, June 23th-26th, Bologna, Italy.

[14] J. Slootweg and W. Kling, “Is the answer blowing in the wind?,” IEEE Power and Energy Magazine, vol. 1, pp. 26–33, November–December 2003.

[15] American wind energy association, “AWEA Electrical guide to utility scale wind turbines,” Policy Department 1101 14th Street NW, Washington DC, 2005.

[16] B adrzadeh, S. K Salman and Babak, New Approach for modelling Doubly-Fed Induction Generator (DFIG) for grid-connection studies. School of Engineering, The Robert Gordon University : s.n.

[17] H oldsworth L, Wu XG, Ekanayake JB, Jenkins N, Comparison of fixed speed and doubly-fed induction wind turbines during power system disturbances. IEE Proceedings: Generation, Transmission, Distribution, 2003, 3: 343-352 : s.n.

[18] F. C. Odo1, S. U. Offiah and P. E. Ugwuoke, Weibull distribution-based model for prediction of wind potential in Enugu, Nigeria,Adv. Appl. Sci. Res., 2012, 3(2):1202-1208.

[19] J ohn Wiley & Sons, Chinchester. Walker, J. F. and Jenkins, S, “Wind energy technology,” 1997.

[20] Gipe, P, “Wind power: renewable energy for home farm and business,” Chelsea Green, USA.. 2004.

[21] Enibe, S. O, Nigerian journal of solar energy, 6, 14. 1987.

[22] Iheonu, E. E., Akingbade, F. O. and Ocholi, M, Nig. J. of Renewable Energy, 10, 43, 2002.

[23] Seyit, A. A. and Ali, D, Energy Conversion management, 50, 1761.. 2009.

[24] S. Chand & company Ltd, New Delhi, 1158. Dass, H. K, Advanced Engineering mathematics,. 1998.

[25] Wasynczuk, O., Man, D. T. and Sullivan, J. P, “Dynamic behavior of a class of wind turbine generators during random wind fluctuations,” IEEE Transactions on Power Apparatus and Systems 1981, 100(6), 2837–2845.

[26] Anderson, P. M. and Bose, A, “Stability simulation of wind turbine systems”, IEEE Transactions on Power Apparatus and Systems 1983, 102(12), 3791–3795.

[27] N.Mithulananthan, A.Sode-Yome, N.Acharya, S.Phi-chaisawat, “Application of FACTS controllers in thailand power systems,” RTG Budget-Joint Research Project, Fiscal-Year 2003, January 2005.

[28] 14 T. K. Rahman, G. B. Jasmon, “A new technique for voltage stability analysis in a power system and improved loadflow algorithm for distribution network,” Proceedings of 1995, International Conference on Energy Management and Power, Delivery, 1995. EMPD '95, Vol. 2, pp. 71 4 – 719.