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A Review Study on Small Signal Stability Enhancement in Power System with Integration of Distributed Wind Energy Sources

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Abstract— In this modern era, distributed energy like Photo Voltaic System (PV), Wind, Fuel Cell etc. are considered as a very small source of electric power conversion from non-conventional energy sources. Small signal stability analysis of a power system is correlated mainly with the inter-area and intra area oscillations. But, during small disturbance it leads to different types of unstable conditions. Usually, synchronous system mechanical part's provides weak damped oscillations which comes from other sources, such as damper windings and the machine's controllers. As power system has only 50Hz frequency with very small amplitude which can hardly any damping by the damper windings, leaving the controllers and the rest of the power system are considered as the main contributors to the damping of the rotor speed oscillations. This review research paper represents small-signal stability analysis of not only isolated but also interconnected autonomous hybrid distributed generation system with sudden variation in load demand, wind speed and solar radiation etc.

Index Terms— Small-Signal, Stability, Distributed Energy, Power System, Oscillations, Wind Source.

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1 INTRODUCTION

IN recent years the demand for hybrid system in power generation is growing in an incredible pace when compared to a standalone system. It is well known that the utilization of conventional energy sources like coal, crude oil and natural gas has several drawbacks including limited availability, increasing cost of these fuels, cost of generation of energy in addition to the higher level of pollution caused to the environment. Organizations and governments around the world have started showing increasing interest in the renewable sources like solar, wind and tidal energy after the oil crisis in the 1970s. It is evident from literature on renewable energy that majority of the studies were focused on areas like cost reduction of generation, efficiency improvement and alternative sources of renewable energy. However, many studies also attempted on solving issues surrounding the enhancement of distribution of renewable energy to meet the increasing demand [1,5]. Despite the fact that the renewable energy shows nonlinear characteristics in comparison with nuclear and thermal energy sources, they do not cause any environmental pollution. Solar energy, wind energy, fuel cell, hydro power and tidal sources are the most extensively used renewable energy resource for electricity generation. Research on renewable energy has been going for a long time in order to identify the energy alternatives and increase the efficiency of the current sources. Hybrid system in renewable energy generation is a new technique that combines the advantage of more than one form renewable energy source. It described the distributed generation as the electric power source that directly connects to either the distribution network or to the consumer end [2]. The distributed power systems are depended on power sources like solar Photovoltaic (PV) cells, wind turbine systems, fuel cells, and micro-turbines. The distributed renewable systems are rapidly developing in order to meet the energy demand globally. The performance of the distributed energy generation systems can be improved by integrating various renewable energy sources to create a hybrid system. The advantage of such hybrid system is that if one of the energy source like wind energy fails to generate and supply to the load, the other source like solar, fuel cell etc. can continue to supply. Thus, the sustainability of the power system can be ensured through continuous supply to the distribute load [3,5].

2 SMALL SIGNAL STABILITY

Small-signal stability analysis is about power system stability when subject to small disturbances. If power system oscillations caused by small disturbances can be suppressed, such that the deviations of system state variables remain small for a long time, the power system is stable. On the contrary, if the magnitude of oscillations continues to increase or sustain indefinitely, the power system is unstable. Power system small-signal stability is affected by many factors, including initial operation conditions, strength of electrical connections among components in the power system, characteristics of various control devices, etc. Since it is inevitable that power system operation is subjected to small disturbances, any power system that is unstable in terms of small-signal stability cannot operate in practice. In other words, a power system that is able to operate normally must first be stable in terms of small-signal stability. Hence, one of the principal tasks in power system analysis is to carry out small-signal stability analysis to assess the power system under the specified operating conditions [4]. In general, both conventional and alternative energy

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generation are faced with the difficult task of maintaining stability when small or large disturbances occur in the power system. Small disturbances, for example fluctuations in mechanical power input to a generator, are constantly perturbing the power system, especially when the influence of wind speed variability is considered in a wind energy conversion system. Our objective is to investigate small-signal stability in power systems that include the integration of renewable energy sources (generation and storage) with conventional generation [5].

This analysis has focused on the particular capacity of power systems to sustain synchronism and keep voltage levels within their limits at all buses under small perturbations, which is called small-signal (small-disturbance) stability. In the analysis of such problems, the system equations can be linearized making the right assumptions e.g., the small magnitude of all signal deviations from the steady-state operating point. This enables the use of linear techniques to calculate relevant sensitivity information, which can be used to determine factors affecting stability [6]. Rotor angle small-signal stability problems can be local or global. Local problems entail a small section of the power system. These are normally related to rotor angle oscillations of one power plant against the rest of the power system, which are called local plant mode oscillations. Global problems entail a group of Single Machines in one area swinging against another group in another area, and have widespread effects. The corresponding oscillations, called inter-area mode oscillations, have complex characteristics, very different from those of local plant mode oscillations [7]. After a full small-signal (linear) state-space model of the power system is established, its eigenvalues (modes) can be calculated. These give the damping and frequency of the oscillatory terms, and the speed of the non-oscillatory ones, in the system (model) dynamic response. This analytical study enables further examination such as establishing the relationship between system parameters and stability. Participation (factors) analysis can then be performed to study interactions between system states and modes [8]. This analysis facilitates the investigation of the sensitivity of the eigenvalues to changes in system states. Moreover, the study of mode sensitivity to changes in system parameters contributes to determine which parameters strongly influence certain modes. In such studies, the influences on slow or poorly damped eigenvalues are of main interest [9].

3 DISTRIBUTED ENERGY SOURCES

Traditional generation units exploiting centralized energy resources are giving way to smaller, more distributed energy resources (DER). DER include distributed storage (DS), demand response (DR) loads and distributed generation (DG), and encompass a wide range of emerging technologies, most of which have power electronics interfaces to the electrical power system. As opposed to traditional generation units, most DER are connected to distribution networks [10,11]. One of the major differences from traditional generation is that DG interfaced with power electronics cannot inherently supply the instantaneous power needs because of the absence of large rotors. Since most DG are inertia-less and respond slowly to control signals, load tracking problems occur when operating without the presence of traditional generation. Thus, a system with groups of such DG designed to operate in that condition needs some sort of (distributed) energy storage to guarantee initial energy balance. The technical challenges are associated with the centralized control of a significant number of units is a fundamental problem for DER. In such a complex control system, the malfunction of a control, communication or software component could potentially cause a system collapse [12].

3.1 Wind Power Generation

The generated power of the wind turbine generator depends upon the wind speed V_W. The wind speed is considered to be the algebraic sum of base wind speed (V_{WB}), gust wind speed (V_{WG}), ramp wind speed (V_{WR}) and noise wind speed (V_{WN}) [13]. Hence speed is given by $V_W = V_{WB} + V_{WG} + V_{WR} + V_{WN}$ The detailed mathematical modeling of these wind speed components are considered from the reference. The mechanical power output of the wind turbine is expressed as

$P_W = 1/2\ \rho\ A_r\ C_p\ V_W^2$

Where, ρ is the air density (kg/m^3), A_r is the swept area of blade (m^2) and C_p is the power co-efficient which is a function of tip speed ratio (λ) and blade pitch angle (β) [14].

3.2 Photovoltaic power generation

A PV system consists of many cells connected in series and parallel to provide the desired voltage and current. The voltage and current relationship is non-linear in nature. The maximum power output of the PV array varies according to solar radiation or load current. Therefore, control strategy is required to use solar radiation effectively in order to obtain maximum power. The output power of the PV system can be expressed as $P_{PVPG} = \eta S\varphi\ [1 - 0.005(T_a + 25)]$. Where, η is the conversion efficiency of the PV array, S is the measured area of PV array (m^2), φ-the Solar radiation (kW/m^2) and T_a – the ambient temperature (Celsius degree) [15].

3.3 Fuel-cell power generation

Fuel cells are static energy conversion device which converts the chemical energy of fuel (hydrogen) directly into electrical energy. They are considered to be an important resource in hybrid distributed power system due to the advantages like high efficiency, low pollution, flexible modular structure etc.

4 WIND TURBINE GENERATOR SYSTEM

There are many different generator types for wind power applications in use today. The main distinction can be made between fixed speed and variable speed wind generator types [16].

4.1 Fixed speed wind turbine generator

In the early stage of wind power development, most wind farms were equipped with fixed speed wind turbines and induction generators. A fixed speed wind generator is usually equipped with a squirrel cage induction generator whose speed variations are limited. Power can only be controlled through pitch angle variations. Because the efficiency of wind turbines depends on the tip-speed ratio, the power of a fixed speed wind generator varies directly with the wind speed. Since induction machines have no reactive power control capabilities, fixed or variable power factor correction systems are usually required for compensating the reactive power demand of the generator. Fig. 1 shows the schematic diagram of the fixed speed induction machine.

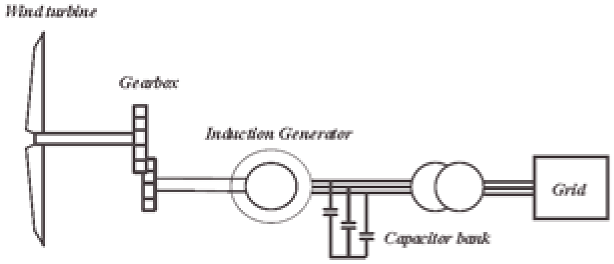

Fig.1. Fixed speed induction generator

4.2 Variable speed wind turbine generator

Variable speed concepts allow operating the wind turbine at the optimum tip-speed ratio and hence at the optimum power coefficient for a wide wind speed range. The two most widely used variable speed wind generator concepts are the DFIG and the converter driven synchronous generator.

4.2.1 Doubly fed induction generator wind turbine

Due to advantages such as high energy efficiency and controllability, the variable speed wind turbine using DFIG is getting more attention. DFIG is basically a standard, wound rotor induction generator with a voltage source converter connected to the slip-rings of the rotor. The stator winding is coupled directly to the grid and the rotor winding is connected to power converter as shown in Fig. 2.

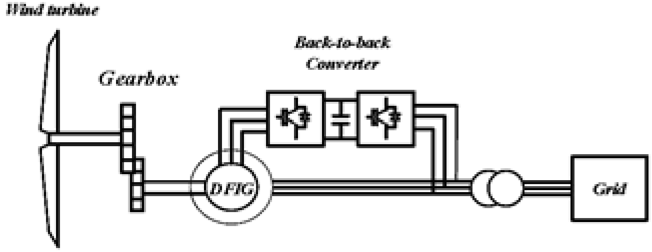

Fig.2. Doubly fed induction generator

The converter system enables two way transfer of power. The grid side converter provides a dc supply to the rotor side converter that produces a variable frequency three phase supply to generator rotor via slip rings. The variable voltage into the rotor at slip frequency enables variable speed operation. Manipulation of the rotor voltage permits the control of the generator operating conditions. In case of low wind speeds, the drop in rotor speed may lead the generator into a sub synchronous operating mode. During this mode, DFIG rotor absorbs power from the grid. On the other hand, during high wind speed, the DFIG wind turbine running at super synchronous speed will deliver power from the rotor through the converters to the network. Hence, the rotational speed of the DFIG determines whether the power is delivered to the grid through the stator only or through the stator and rotor. Power delivered by the rotor and stator is given by, $P_R = sP_S$ and $P_G = (1 \pm s) P_S$. Where, P_G is the mechanical power delivered by the generator, P_S is the power delivered by the stator, and P_R is the power delivered to the rotor. However, under all operating situations, the frequency of rotor supply is controlled so that, under steady conditions, the combined speed of the rotor plus the rotational speed of the rotor flux vector matches that of the synchronously rotating stator flux vector fixed by the network frequency. Hence, the power could be supplied to the grid through the stator in all the three modes of operation, namely, sub synchronous, synchronous and super- synchronous modes. This provides DFIG a unique feature beyond the conventional induction generator as the latter can deliver power to the grid during super synchronous speed only.

4.2.1 Converter driven synchronous generator

This category of wind turbines uses a synchronous generator that can either be an electrically excited synchronous generator or a permanent magnet machine. To enable variable-speed operation, the synchronous generator is connected to the network through a variable frequency converter, which completely decouples the generator from the network. The electrical frequency of the generator may vary as the wind speed changes, while the network frequency remains unchanged. The rating of the power converter in this wind turbine corresponds to the rated power of the generator plus losses.

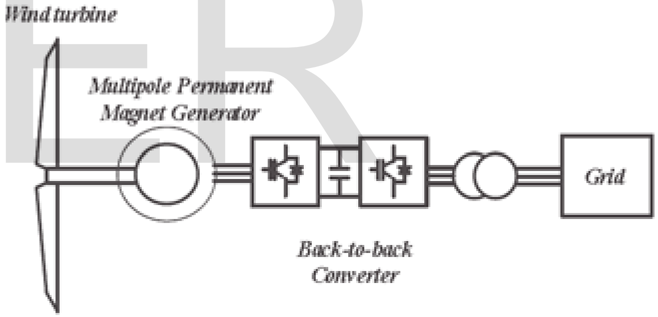

Fig.3. Converter-driven generator

The schematic diagram of the converter driven synchronous generator is as shown in Fig. 3. The comparison between the fixed speed and variable speed wind turbines shows that variable speed operation of wind turbines presents certain advantages over constant speed operation. Variable speed wind turbines feature higher energy yields and lower power fluctuations than fixed speed wind turbines. The last feature is particularly important as flicker may become a limitation to wind generation on power systems. Also variable speed wind turbines produce more reduced loads in the mechanical parts than fixed speed wind turbines. When comparing torque mode control and speed mode control strategies, literature review shows that speed mode control strategy follows wind speed, in order to achieve maximum power coefficient, more accurately, and the higher the speed control loop bandwidth is, the better the tracking is. Nevertheless, as a consequence, it produces more power fluctuations, since speed is rigidly imposed to the turbine. So, from power quality point of view, torque mode control strategy presents better behavior because speed is not directly imposed to the turbine and this control strategy lets the wind turbine to freely change rotational speed during the transient.

5 WIND INTERMITTENT & VARIABILITY

Uncertainty and variability are characteristics that exist in wind power, aggregate electric demand and supply resources and have always posed challenges for power system operators. Future expansion of the loads cannot be predicted accurately, generator outputs and loads fluctuate strongly in different time frames, and it can also lose energy system equipment at any time and without prior warning. Different amounts and types of operating reserves are secured by power system operators to compensate for uncertainty and variability for load reliable service and to keep the system frequency stable. There are many different terms, definitions, and rules concerning what operating reserves entail. The real power capability that can be given or taken in the operating timeframe to assist in generation and load balance and frequency control is defined as the operating reserves. To provide voltage support systems also require reactive power reserve as well, and require certain targets for installed capacity that is often referred to as planning reserve. The type of event the operating reserves respond to, the timescale of the response and the direction (upward or downward) of the response can differentiate the types of operating reserves. Unpredictable imbalances between load and generation caused by sudden outages of generating units, errors in load forecasting or unexpected deviations by generating units from their production schedules can be compensated by spinning reserve (SR). It becomes more difficult to predict accurately the total amount of power injected by all generators into the power system, as the proportion of power produced by wind farms increases. This added uncertainty must be taken into account when setting the requirement for SR. The uncertainty on the wind power generation increases the uncertainty on the net demand that must be met by traditional forms of generation if wind power generation is considered as a negative load. Spinning reserve is intended to protect the system against unforeseen events such as generation outages, sudden load changes or a combination of both by taking the increased uncertainty into account when determining the requirements for SR. It is therefore expected that a large penetration of wind generation might require a significant increase in the requirement for SR. However, this is not always the case. The cost of SR is indeed far from being negligible. A large number of conventional generating units will need to be synchronized when large amounts of SR must be scheduled for a higher wind-power penetration. Therefore, the system operating cost would increase to such an extent that it might be economically desirable to curb this increase in the SR requirement. Determining the optimal amount of SR that must be provided as a function of the system conditions is thus an important and timely issue. The optimal amount of SR is defined as the equality of the cost of generating extra MW of reserve to the benefit that this MW provides, where this benefit is determined as a function of the reduction in the expected cost of interruptions. The ideal case is that the energy and SR amounts and repartitions should be optimized simultaneously. The main difficulties in solving such a problem are: the stochastic nature of the net demand due to the demand and wind forecast errors, and the fact that there are no direct means of incorporating the discrete capacity outage probability distribution in the optimization procedure. The stochastic and highly combinatorial nature of the problem led some researchers to find alternative solutions to the problem [17]. The power system operating cost can be icreased with the SR provision even though the wind generation reduces the overall net demand. It is also suggested that the extra amounts of MW for reserve can be determined using probabilistic methods combining the uncertain load and wind fluctuations and even including the contingency SR requirements.

6 IMPACTS ON POWER SYSTEM

Wind power has impacts on power system operational security, reliability and efficiency. Therefore, it is necessary to know the consequences of dynamic interaction between large scale wind farms and electrical power systems before incorporation of the wind farms into the grid. The electric power supply undergoes a change from a well-known and developed technology of conventional power plants to a partly unknown technology of wind power. High penetration of wind power could be managed through proper wind power plant interconnection, integration of the generation, transmission planning, and system operations. Fig. 4 & 5 show impacts of wind power on power systems, divided in different time scales and width of area relevant for the studies. At the time of developing the standard IEC 61400-21: "Measurement and assessment of power quality characteristics of grid connected wind turbines", the wind turbines were mainly connected to the distribution grid, and the basic concern was their possible impact on the voltage quality and not on power system operation.

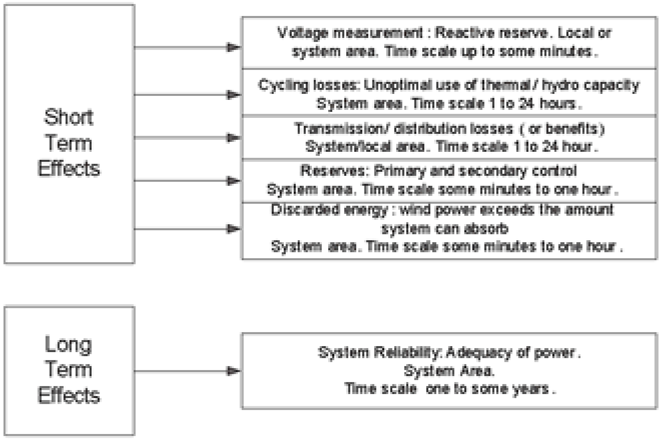

Fig.4. Power system impacts of wind power, causing integration costs

This has changed with the development of large power rated wind farms that may form a significant part of the power system. In consequence, today's wind turbines are able to control the power (active and reactive) delivered both in transient and steady state, they can cope with power ramp requirements and they have low voltage ride through (LVRT) capability.

They may even contribute to the primary frequency control, but then on the cost of dissipating energy [18]. These impacts can be categorized as follows:

- Short-term: impacts on the operational time scale (minutes to hours).
- Long-term: impacts on planning the transmission network and installed generation capacity for adequacy of power.

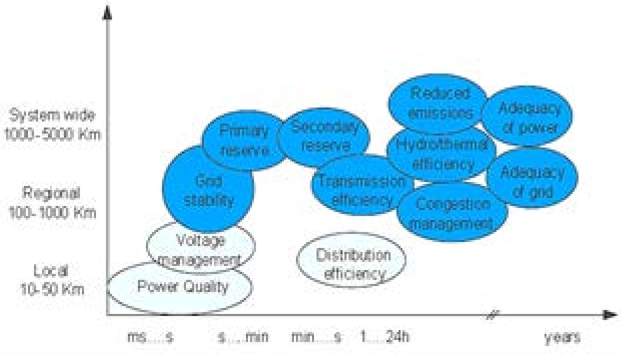

Fig.5. Impacts of wind power on power systems, divided in different time scales

7 GRID INTEGRATED SYSTEM ANALYSIS

Studies show that for an individual wind turbine, the variation in output is small for timescales of less than a few seconds; for an individual wind farm, the variation in output is small for time scales of tens of seconds, due to the averaging of output of individual turbines across the wind farm; and for a number of wind farms spread out across a large area, such as a national grid system, the variation in output of all wind turbines is small for timescales from minutes to tens of minutes. The power produced from a large number of wind turbines will vary relatively less than the power produced from a single wind turbine due to the cancellation effect from the poor spatial correlation of the wind acting on each wind turbine. To enhance the security of supply, new transmission and distribution grid codes specify technical requirements such as fault-ride through capability and frequency control of the electrical conversion systems of wind farms. Fault ride-through capability refers to the generators capabilities to remain connected to electricity networks at voltage levels below nominal. Active power control is closely related to frequency control and the wind farm shall have frequency control capabilities to ramp up and down the wind farm power station's active power output in accordance with the frequency/active power characteristic defined by the grid operator [19-20]. When a power system is subjected to a sudden increase in reactive power demand following a system disturbance, the additional demand must be met by reactive power reserve carried by generators and compensators. If wind farms or other generation units are unable to withstand voltage drops for a limited time, they will disconnect from the system and then the reactive power supplied by these generators is lost that can entail load shedding or even a blackout, in the worst case. To ensure the voltage recovery the wind-turbine generators must remain connected to the system to provide reactive power support after the fault clearance. For many wind turbine manufacturers these are very costly and challenging requirements. In some cases, extensive modifications to the electrical system of the turbines are necessary [21]. Achieving reliable operation at greatly reduced voltage levels is proving problematic. A particular problem regarding power converter-based wind-turbine generators is that conventional controllers for power converters designed for reliable operation around nominal voltage levels will not work as designed during low network voltages that can occur during a fault. A consequence of this is greatly increased converter currents, which may lead to converter failure. New controller design strategies have been proposed for power converter-based wind turbine generators aiming to maintain converter currents within their design limits, even at greatly reduced voltage levels, in order to enhance the wind-turbine generators' fault ride through capability [22]. With the increasing penetration of power converter-based wind turbine generators the rotational speed of the wind turbines is decoupled from the grid leading to a reduction of inertia in the grid. The lower the inertia of a system, the more and faster the frequency will change with variations in generation or load. In order that a variable speed wind turbine to contribute to the system inertia and the frequency control as a result it has been proposed in an additional control loop in the power electronic converter which connects the turbine inertia directly to the grid so that the wind turbine will be able to increase its power supplied to the grid during a drop in the grid frequency. While the wind farms are considered like other generating facilities by some grid operators and as such they are requested to participate in the system frequency and voltage compensation, the wind power sector claims for less strict requirements which imposes unnecessary burden and cost on manufacturers. The wind power sector calls on an overall economically efficient solution where the primary and secondary control should be provided by conventional power plants with the wind farms providing such service only in cases where limits in existing reserves are foreseen, and reactive power compensation provided by Flexible Alternating Current Transmission System (FACTS) devices directly installed in the transmission network [23].

8 CONCLUSION

The complexity of power systems has increased in recent years due to the operation of existing transmission lines closer to their limits due to the increased penetration of new types of generators that have more intermittent characteristics and lower inertial response, such as wind generators. This changing nature of a power system has considerable effect on its dynamic behaviors resulting in power swings, dynamic interactions between different power system devices and less synchronized coupling. Understanding and quantifying the impacts of wind farms on utility systems is a critical first step in identifying and solving problems. The design and operation of the wind plant, the design and operation of the power system, and the market rules under which the system is operating influence the situation. A number of steps can be taken to improve the ability to integrate increasing amounts of wind capacity on power systems such as improvements in wind-turbine and wind- farm models, improvements in wind-farm operating characteristics, improvements in the flexibility of operation of the balance of the system, carefully evaluating wind-integration operating impacts, incorporating wind-plant output forecasting into utility control-room operations, making better use of physically available transmission capacity, upgrading and expanding transmission systems, developing well-functioning hour-ahead and day-ahead markets and expanding access to those markets, adopting market rules and tariff provisions that are more appropriate to weather-driven resources, and consolidating balancing areas into larger entities or accessing a larger resource base through the use of dynamic scheduling or some form of area control error (ACE) sharing. As additional integration studies and analyses are conducted around the world, it is expected that more researches will be valuable as wind penetration increases. And with the large increase in installing wind farms, actual practical experience will also contribute strongly in our understanding of the effects that arise from the increasing installation of wind farms on the system as well as on ways that the impacts of wind's variability and uncertainty can be treated in an inexpensive manner.

REFERENCES

[1] Ersan Kabalci, "Design and analysis of a hybrid renewable energy plant with solar and wind power," Proc Energy Conversion and Management 72, 2013, pp 51–59.

[2] Ackermann T, Andersson G, Soder L, "Electricity market regulations and their impact on distributed generation" Proc Int conf on electric utility deregulation and restructuring and power technologies. London (UK), 2000.

[3] K. Saravanan, A. Senthil Kumar and N. Nandini "Design and simulation of Hybrid Renewable Energy System (HRES) to supply three phase induction motor using fuzzy logic controller" Journal of Chemical and Pharmaceutical Sciences, Volume 9 Issue 4 pp 1922-1929.

[4] Prabha Kundur "Small-Signal Stability Analysis of Power Systems" of Power System Stability and Control book, Ch-8.

[5] Adirak Kanchanaharuthai, Vira Chankong, Kenneth A. Loparo, "Small-Signal Stability Enhancement of Power Systems with Renewable Distributed Energy Resources" Preprints of the 18th International Federation of Automatic Control (IFAC) World Congress Milano (Italy) August 28 - September 2, 2011, pp 513-518.

[6] Prabha Kundur, John Paserba, Venkat Ajjarapu, G□oran Andersson, Anjan Bose, Claudio Canizares, Nikos Hatziargyriou, David Hill, Alex Stankovic, Carson Taylor, Thierry Van Cutsem, and Vijay Vittal. Definition and Classification of Power System Stability. IEEE/CIGRE Joint Task Force on Stability Terms and Definitions. IEEE Transactions on Power Systems, 19(3):1387-1401, August 2004.

[7] Nagaraju Pogaku, Milan Prodanovic, and Timothy C. Green. Modeling, Analysis and Testing of Autonomous Operation of an Inverter-Based Microgrid. IEEE Trans- actions on Power Electronics, 22(2):613-625, March 2007.

[8] Jan Machowski, Janusz W. Bialek, and James R. Bumby. "Power system dynamics: stability and control" John Wiley & Sons, Chichester, United Kingdom, 2nd edition, 2008.

[9] Nathaniel Bottrell, Milan Prodanovic, and Timothy C. Green. Dynamic Stability of a Microgrid with an Active Load. IEEE Transactions on Power Electronics, 28(11):5107-5119, November 2013.

[10] Benjamin Kroposki, Robert Lasseter, Toshifumi Ise, Satoshi Morozumi, Stavros Papathanassiou, and Nikos Hatziargyriou. Making Microgrids Work. IEEE Power and Energy Magazine, 6(3):40-53, May-June 2008.

[11] Tine L. Vandoorn, Brecht Zwaenepoel, Jeroen D. M. De Kooning, Bart Meersman, and Lieven Vandevelde. Smart Microgrids and Virtual Power Plants in a Hierarchical Control Structure" In Proceedings of the IEEE PES 2nd International Conference on Innovative Smart Grid Technologies (ISGT Europe), pages 1{7, Manchester, United Kingdom, 5-7 December 2011.

[12] Robert H. Lasseter. "Microgrids and Distributed Generation" Journal of Energy Engineering, 133(3):144 {149, September 2007.

[13] ANDERSON, P. M.—BOSE, A.: Stability simulation of wind turbine system, IEEE Trans. Power App. Syst. 102 No. 12 (1983), 3791–3795.

[14] LEE, D. J.—WANG, L. "Analysis of a novel autonomous marine hybrid power generation/energy storage system with a high-voltage direct current link" Journal of Power Sources 185 No. 2 (Dec. 2008), 1284–1292.

[15] Prakash K. Ray, Soumya R. Mohanty, Nand Kishor "Small–Signal Analysis of Autonomous Hybrid Distributed Generation Systems in Presence of Ultracapacitor and Tie–Line Operation" Journal of Electrical Engineering, Vol. 61, No. 4, 2010, 205–214.

[16] Ahmed G. Abo-Khalil, "Modeling and Control Aspects of Wind Power Systems", Ch-7, pp 130-150.

[17] T. Ackermann, J. R. Abbad, I. M. Dudurych, I. Erlich, H. Holttinen, J. R. Kristoffersen, and P. E. Sorensen, "European balancing act," IEEE Power Energy Mag., vol. 5, no. 6, pp. 90–103, 2007.

[18] H. Holttinen et al, "Design and operation of power systems with large amounts of wind power" Final report, IEA WIND Task 25, 2006-2008.

[19] R. Leão, T. Degner and F. Antunes, "An overview on the integration of large-scale wind powerinto the electric power system," Dept. of electrical engineering, Federal University of Ceará, Brazil, 2007.

[20] M. Dahlgren, H. Frank, M. Leijon, F. Owman, L. Walfridsson," Windformer TM Wind power goes large-scale", ABB review, no. 3, pp. 31–37, 2000.

[21] S. Repo, "On-line Voltage Stability Assessment of Power System- An Approach of Black-box Modelling," PhD Thesis, Aalborg University, 2001.

[22] A. Mullane et al., "Wind-turbine fault ride-through enhancement," IEEE Trans. Power Systems, vol. 20, no. 4, pp. 1929-1937, 2005.

[23] J. C. Smith, "Winds of change: Issues in utility wind integration," vol. 3, pp. 20–25, Nov. 2005.