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Issues In Wind Electric Distribution System andDifferent Mitigation Methods – A Perspective View

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Abstract: Wind energy is one of the fastest-growing sources of electricity in India and around the world since it is economical, clean and abundant. There are two major types of wind gen-erators, which are commonly used in wind farms. The first one is the squirrel cage induc-tion generator while the second is doubly fed induction generator. In this, squirrel cage induction generator is widely used due to its low cost, low maintenance rate and possible utilization under wind gusting conditions. But wind farms with induction generators while generating real power, consume reactive power. Due to grid faults, the over speed of the induction generator resulted from transient currents drawn by the induction generator from the electrical power system can exceed the stability limit resulting in collapse of the system and islanding operation. Thus operators worldwide have developed new grid codes to integrate this form of generation. One important aspect of the problem is the low-voltage ride-through capability of wind generators. This paper gives a complete re-view of the power quality issues when using wind electric generators and different meth-ods that are being used to mitigate these problems till date.

Keywords: *wind electric generators, power quality issues, low voltage ride through, DVR,Super capacitor.*

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Introduction

Wind energy is one of the fastest-growing sources of electricity in India and around the world. In spite of being cheap, 1. clean and abundant, the continuous fluctuations in the re- *A.* newable energy causes significant power quality issues. People's confidence in wind power can easily be read from the rapidly growing figures. Worldwide installed wind power capacity reached 2, 82,482 MW, out of which 44,711 MW were added in 2012. The annual growth rate reached the highest of 31.7% since 2001 [1]. With the increasing penetration of wind energy and the improvement of technology, the operating characteris-tics of wind farms should be reconsidered carefully, especially during fault conditions. In this context, many countries have issued interconnection requirements for wind farms. Among these grid codes, two main issues are concerned, which of great relevance, are ac-tive and reactive power control in normal conditions and Low Voltage Ride-Through (LVRT) capability during grid fault. In fact, the grid code provides only standard re-quirements at the Point of Common Coupling (PCC). Different types of wind electric generators suffer in different ways due to the voltage dip in the grid.

The fixed speed wind turbines with induction generators are installed in the early age, which are cheap and reliable. But they do not have the ability to control active and reac-tive power flexibly. During grid faults, the wind turbines must be tripped to protect from damages due to over speed. This operation will cause load flow changing violently, even resulting in power system blackout when the wind farm is large and the grid is weak. The variable speed wind turbines are able to control the active and reactive power. But these devices are quite sensitive and need protection from overflow and impulse high voltage. A real problem faced by the wind turbine manufacturers, according to the new grid codes is the wind plant's ability to ride-through a short -term low voltage at PCC [2].

Literature Survey

Modelling of Induction Generator and Power Quality Issues

M.G.Sugirtha and Dr. P.Latha give a technical review of power quality problems associ-ated with grid connected wind power plant. They discuss about the different power qual-ity issues in the grid side and wind electric generator side and also tell about the effects of those issues in the system [3]. K. C. Divya et al have detailed the possibility of using a simple model for grid connected induction generators [4] while studying the dynamic be-haviour of such systems. In this method both the stator and rotor transients of the machines are neglected thus enabling the use of torque-slip characteristics of the induction machines, in the analysis of the dynamic behaviour. A concept of critical clearing slip has also been introduced and its utility has been highlighted.

The squirrel cage induction generators are used with many of the wind turbines, and since these units are incapable of generating reactive power, they cause serious problems in voltage stability of the network. A static voltage stability of the network with wind farm is analyzed by M. Vahedipour Dahraie et al by introducing a new index [5]. Sebastian S. Smater et al have introduced a framework for reliability and dynamic performance analy-sis of Wind Electric Conversion Systems (WECS), which will provide an overall measure of reliability for a particular WECS operating under all possible conditions, and subject to all possible faults in the WECS and the grid [6].

The modelling of Squirrel Cage Induction Generator (SCIG) and Doubly Fed Induction Generator (DFIG) based wind systems, including the turbine, the Field Orientation Con-trol of converters, and connection to the grid are presented by Yu Zou et al [7]. A STA-COM is applied to SCIG system to reduce voltage drop in distribution line. Comparison of SCIG performance with and without STACOM, as well as DFIG system clearly showed different results in the distribution line voltage. A focus on researching and dis-cussing the impact of SCIG in distribution system, and finding the way out to supply higher power quality is studied by Ching-Yin Lee et al [8]. Case study includes choosing different connected location and installed capacity of wind generators and adopting fixed capacitors, SVC and STATCOM for compensation to observe the influence on the mo-ment of the wind generator connected and the period of the wind speed variation.

2. Methods To Satisfy Low Voltage Ride Through (LVRT) Requirements

C. Rahmann et al have proposed an adaptive strategy to obtain technically justified Fault Ride Through (FRT) requirements for Wind Turbine (WT) based on system characteris-tics and on the wind power penetration level [9]. The proposal is specially aimed at coun-tries with still low penetration levels of wind power, where the WT integration is carried out in a competitive environment without any kind of subsidies. Mital G. Kanabar et al have contributed towards the quantification of additional reactive power support neces-sary to satisfy LVRT requirements for the existing constant speed WTGs. To satisfy LVRT requirements of a constant speed WTG, the rotor speed stability margin has to be improved. For this, the formulae for critical slip and critical clearing time have been obtained analytically [10].

Shih-Feng Chou et al suggested a flux compensation method in [11] to mitigate the sag-induced flux offset, and hence reduce the potential post-sag inrush current. The proposed technique commands the converter current to meet the Reactive Current Injection (RCI) specifications of LVRT requirement, and to compensate the transformer flux offset.

Jose Luis Dominguez-Garcia et al have presented a control technique to deal with SCIG connected to the grid through a full power converter [12]. Both stator-side and grid-side are considered, which detail the control scheme to be used in each converter. The pro-posed indirect vector control strategy allows control the stator-side without flux sensor inside the machine, which assures less mechanical problems. Kyoung-Jun Lee et al have put forward a novel Low-Pass Notch filter PLL (LPN-PLL) control strategy to synchro-nize with the true phase angle of the grid instead of using a conventional Synchronous Reference Frame PLL (SRF-PLL), which requires a d−q -axis transformation of three-phase voltage and a proportional–integral controlle r [13].

Chia-Tse Lee et al have put forward an LVRT method to provide the required real power and reactive current without exceeding the ampere limit of grid-connected interface converters [14]. This method consists of a positive and negative sequence current compensa-tion control for the grid-connected converter to support AC grid voltages during the fault and to meet the LVRT requirement.

Ki-Hong Kim et al have come up with a low-voltage ride-through scheme for the Perma-nent Magnet Synchronous Generator (PMSG) wind power system at the grid voltage sag [15]. The dc-link voltage is controlled by the generator-side converter instead of the Grid-Side Converter (GSC). Considering the nonlinear relationship between the generator speed and the dc-link voltage, a dc-link voltage controller is designed using a feedback linearization theory. Po-Hsu Huang et al have introduced a novel shunt and series grid interface topologies of the GSC and transient management scheme to improve FRT capabil ity for DFIG based wind turbines [16]. The system dynamics of the series compensation have been investigated and are represented by a small signal linear model, with which the controller is properly tuned to balance both voltage regulation performance and transient stability margins with consideration of various operating conditions.

Shuai Xiao et al have set forth a new flux-linkage tracking based LVRT control strategy [17] to suppress the short-circuit rotor current. Under the proposed control strategy, the rotor flux linkage is controlled to track a reduced fraction of the changing stator flux link-age by switching the control algorithm of Rotor Side Converter (RSC) during grid faults. Ebrahim Babaei and Mohammad Farhadi Kangarlu have introduced a new voltage sag compensator [18] which is based on the ac/ac direct converter. The converter in each phase is supplied from the other two phases of the grid and hence it does not face problem related to the required compensation power. The phase angle jump can be easily compen-sated by the proposed compensator. S.M. Muyeen et al have considered two-mass drive train model of WTGS [19] for the fault analysis of WTGS. Suitable control strategy of Energy Capacitor System (ECS) is developed to enhance the LVRT capability of WTGS. The performance of ECS during network fault is analysed by using the aggregated single generator model of wind farm.

Alvaro Luna et al have studied some control strategies for improving the FRT capability of a SCIG-WT, by means of controlling its full power processor located in its neighbourhood [20]. In order to analyse the feasibility of this proposal, their performance is tested and compared during fault and post-fault conditions. Jaume Miret et al have proposed a voltage controller to mitigate voltage sags based on the current scheme [21], which re-stores the dropped voltages to its continuous operation limits, thus guaranteeing LVRT and also increasing the stability of the power system. A detailed mathematical analysis of the injected currents during the voltage sag is also carried out in order to develop the proposed control.

Mohsen Rahimi and Mostafa Parniani have put forward two coordinated ride-through approaches to fulfil the ride-through requirement in DFIG based wind turbines [22]. One approach is realized through the RSC control and by using additional equipment, called SDR. Second approach is realized through efficient control of GSC that effectively re duces the dc-link voltage fluctuation when the DFIG is subjected to a voltage drop. Manuel Reyes et al have analysed the double synchronous reference frame controller [23] and its structure is improved by adding a decoupling network for estimating and compen-sating the undesirable current oscillations. Jose Luis Domınguez-Garcıa et al have se-lected an indirect field-orientation method [24]. This method is generally more dependant of the machine parameters, but it allows to work without necessity of Hall-Effect sensors which increment the cost of the system and reduce its robustness. The control applied is less dependent of the knowledge of machine behaviour.

3. Use of Dynamic Voltage Restorer

Jovica V. Milanovic and Yan Zhang have proposed a new methodology to financially analyze the investment in Flexible AC Transmission System (FACTS) devices to mitigate voltage sags by incorporating financial aspects of the problem [25]. Scenarios are evalu-ated with and without optimally placed FACTS devices. The capital investment cost and annual maintenance of devices over their life time is also considered. Jovica V. Milanovic and Yan Zhang presents have modeled three widely used FACTS devices (STATCOM, SVC and DVR) developed for large system fault analysis and static fault calculation stud-ies [26]. Mathematical models of FACTS devices for symmetrical and asymmetrical fault studies are presented and incorporated in custom made system impedance matrix. H. M. Huang et al have proposed a study of applying STATCOMs to provide voltage support for offshore wind power plants to meet the LVRT requirement when connecting to the onshore power grid [27]. The required STATCOM capacity to meet voltage sag regula-tions imposed by grid codes for the investigated offshore wind power plant is also presented.

Hailian Xie et al have discussed the cost of a proposed interface system between an En-ergy Storage (ES) and a Voltage Source Converter (VSC) [28]. Mojtaba Nemati et al have described the role of the different parts of the Dynamic Voltage Restorer [29] and, the ap-plication of it has been evaluated. Theoretical concepts with practical results have also been compared. Naohiro Hasegawa and Teruhisa Kumano have studied LVRT capability enhancement of FSIG using DVR device [30] and it also proposes the method for de-creasing the energy storage and inverter capacity of DVR. Bhim Singh et al have devel oped a new control algorithm [31] based on unit templates for the control of capacitor supported DVR for sag, swell, harmonics and unbalance in supply voltage. Hyunsik Jo et al have proposed a fast and robust sag detection algorithm for the line-interactive DVR [32], which calculates the fundamental and harmonic components by using the discrete Fourier transform and has a constant detection response time regardless of phase angle at which sag occurs. During the sag compensation, a new selective harmonic mitigating method for voltage controller is proposed.

H. Gaztafnaga et al have set forth the contribution of a DVR compensator to the transient behaviour improvement of fixed-speed wind farms [33]. This analysis is carried out in real time reduced-scale test conditions in order to get as close as possible to real imple-mentation conditions but minimizing costs and shortening the test process. N. Amutha et al have suggested a method based on the system equivalent circuit [34] to calculate the critical speed and Critical Clearing Time (CCT) of a SCIG based wind generator con-nected to grid. DVR has been used in this paper to improve CCT of the SCIG based wind generation system. O. Viktorin et al have discussed the topologies for the DVR with high frequency transformers [35]. This variant requires additional AC-AC converters in series with line voltages, making them less energy efficient. The proposed DVR topologies are designed in order to enable the elimination of zero sequence voltage components.

Tanonsak Keawsakunee and Paisan Boonchiam have discussed a detailed analysis of con-trol strategies for medium voltage DVR for enhancing power quality [36]. A method of determining the exact amount of voltage injection required to correct a specific voltage reduction with minimum power injection is also described. Christoph Meyer et al have analysed different control strategies for a medium-voltage DVR [37]. First, a short de-scription of the requirements on the DVR control has been given then three different con-trol strategies has been described and compared.

Yan Li et al have developed control principles of the dual coupled inverters with super capacitor based energy storage, to achieve precise and fast response [38]. The control principles of each inverter of DVR are presented and the control principles of the DC/DC converter of the super capacitors are also explained. Long Hee Han et al have described the development of on-line type DVR whose reliability is superior [39]. EDLC (Electrical Double Layer Capacitor) that is profitable in capacitance, life cycle, stability, environ-mental side is used instead of electrolytic capacitor to store energy. R. Omar and N.A. Rahim have proposed a system which comprises of a super capacitor as energy storage, DC–DC converter, and the component of DVR [40]. The DVR components consist of a three phase inverter, filtering scheme and its controller. Digital signal processing (DSP) was used in order to produce the required control to DC–DC boost converter and Voltage Source Inverter (VSI). This system is capable to mitigate voltage disturbances at low voltage distribution system.

II. Conclusion

A Dynamic Voltage Restorer with supercapacitor as an energy storage can be used to sat-isfy the low voltage ride

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through capability of wind electric generators and in mitigating other disturbances in the network. Thus a squirrel cage asynchronous wind generator will be able to remain connected to the grid during voltage sag with the aid of a DVR.

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