Low Voltage Ride through Capability Improvement of Fixed-Speed Induction Generator: A Review

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Abstract— Environmental and political impact for a sustainable development have encouraged the growth of electrical generation from renewable energies. A pressing demand for more electric power coupled with depleting natural resources has led to an increased need for energy production from renewable energy sources such as wind and solar. The latest technological advancements in wind energy conversion and an increased support from governmental and private institutions have led to increased wind power generation in recent years. Wind power is the fastest growing renewable source of electrical energy Wind power generation of electricity is seen as one of the most practical options and with better relation cost-benefit inside the energetic matrix now a days. This study provides the results of a study conducted to assess the "Low Voltage Ride through Capability improvement of Fixed-speed induction generator using STATCOM" in a power system.

Keywords: Squirrel cage induction generator, Low Voltage Ride through, Wind Turbine Model, Reactive power, STATCOM

I. INTRODUCTION

Modern power system networks consist of various types of generators, and loads interconnected to significantly complex and large transmission and distribution systems .The size of wind turbines and wind farms are increasing quickly; a large amount of wind power is integrated into the power system. To assist the power system in serving the peak load, the wind turbines for example, can be used as small power generators that are connected to the distribution system or directly at the customer's site. Since the primary fuel of wind turbines is air, which is free, they are considered cheap and clean energy resources.

However, they may require fairly high initial costs compared to generator using fossil fuels. The output power of a wind turbine generally depends on its size and where it is located. Recently, manufacturers produce wind turbines that provide rated output power ranging between hundreds of Watts to few Mega Watts (MW) Due to the intermittent behavior of wind, known as "wind variability", it would be difficult to have an accurate prediction of the output power from wind turbines. Therefore, such a phenomenon could result in challenging impact on the reliability of the power network and on the steadiness of the voltage magnitude For instance, if the wind generation drops rapidly, then it would produce an immediate voltage drop effect at the end of a feeder. The main focus of this paper is to provide an understanding of the low voltage ride through capability improvement of fixed-speed induction generator using STATCOM.

The rapid increase in wind power contribution to the total generation mix over the last decade has led power systems engineers, operators and designers to study and investigate the impact of wind power on network stability and reliability. In some countries the wind power share has increased to more than 15% of the total generated power. This necessitates the introduction of strict requirements for wind farms (such as the provision of active and reactive power support to the grid during ac faults), to ensure system stability during major transient events.

Grid Codes differ from country to country, but most of them include the following.

- Ability of wind farms to provide voltage and reactive power control at the point of common coupling (PCC).
- Contribution to active power and frequency control.
- Fault Ride-Through capability.

Wind farms must remain transiently stable and connected to the network for a close-up solid three-phase short circuit fault for a total fault clearance time of up to 140 ms (7 cycles). After fault clearance the wind farm has to provide active power of at least 90% of its pre-fault value within 0.5 seconds.

A significant number of the wind farms in operation are based on fixed-speed induction generator wind turbines (FSIGs) with squirrel cage induction generators and capacitor banks providing the generator reactive power requirements. FSIGs have a simple construction and require minimum maintenance. However, they consume considerable amounts of reactive power for its excitation, and are unable to regulate its terminal voltage as the load on the generator varies. This complicates Grid Code compliance for FSGI wind farms. In [3] the authors presented a FSIG wind farm connected to a simple network and investigated wind farm transient stability by studying the effect of electrical, mechanical, and operational parameters on critical fault clearing time

A. Squirrel cage induction Generator(SCIG)

Squirrel cage induction generator (SCIG) is fixed speed machine which is directly connected to the grid. The slip and rotor speed of SCIG vary with the generated power. These variations in rotor speed are too small so it is considered as fixed speed machine. Although they are widely used now days, their inability to generate reactive power is limiting factor.

B. Reactive power Compensation

A majority of the wind turbines installed in the past were induction generators that absorb reactive power from the system even during normal operating conditions. As WTs are a sink for reactive power, an effective dynamic reactive power management system is required to avoid low-voltage issues in the wind power system. Mechanically switched capacitors are used in wind farms containing asynchronous generators to provide reactive power support during system disturbances. However, limited support provided by these small wind generators is required to meet the interconnection standards such as to ride through a fault. Hence, additional compensating equipment is needed by the system in order to restore quickly after the fault has been cleared so as to maintain system stability and to avoid generator tripping. In some instances, the collector bus of the wind farm may have some reactive power compensation, which is typically lower than that required for critical contingencies in the system

II. LOW VOLTAGE RIDE THROUGH ON FSIG

Between the two types of trend (Fixed and Variable speed) of Wind Turbine Generator Systems, constant speed wind generator has weaker fault ride through capabilities. Induction Generators have brushless and rugged construction, low cost, maintenance and operational simplicity and is therefore preferred as wind generators. Statistics shows that the total installation of Fixed Speed WTGS is around 40%. Therefore it is still needed to analyze the Fault Ride Through characteristics in Fixed Speed WTGS. In the past, wind generators were allowed to be shut down from the network when the voltage of the wind farm is greatly dropped because of a network disturbance in power system. Shut down operations of large wind farms is no longer considered to be suitable as it can have serious effect on the power system operation. Thus, a new set of grid codes has been defined to suit the wind farm grid interfacing. As a result, specifications are now being revised to reflect new requirements for wind turbine integration into the network. Some measures are proposed about the low voltage ride through capability of the wind turbine with Fixed Speed Induction Generator. Flexible AC Transmission Systems (FACTS) have recently emerged as more promising devices for power system applications as FACTS have the ability to improve both voltage and power quality of wind generator.

III. REVIEW OF PAPERS OF LVRT CAPABILITY IMPROVEMENT OF FSIG

In ref (1), the design and implementation of a new control scheme for reactive power compensation, voltage regulation and transient stability enhancement for wind turbines equipped with fixed-speed induction generators (IGs) in large interconnected power systems has been studied. The low-voltage-ride-through (LVRT) capability is provided by extending the range of the operation of the controlled system to include typical post-fault conditions. It is shown that a static synchronous compensator (STATCOM) with energy storage system (ESS), controlled via robust control technique, is an effective device for improving the LVRT capability of fixed-speed wind turbines. A ten-machine power system has been used to evaluate the performance of the designed controller. Simulation results show that despite the non-linear interconnections between different types of generators and significant operating condition variations following fault, the proposed controller can greatly enhance the transient and voltage stability as well as LVRT capability of wind turbines.

In Ref (2), a voltage control structure for a STATCOM at an FSIG-based wind farm under unbalanced grid voltage condition has been analyzed. The proposed structure controls the positive and the negative sequence of the voltage independently with priority on the positive-sequence voltage. The novel contribution of this paper lies in the coordination of the positive- and the negative sequence voltage control by the STATCOM and the related effect on the wind turbine behavior. While the positive-sequence voltage compensation leads to an increased voltage stability of the wind farm, the negative-sequence voltage compensation leads to a reduction of torque ripple, increasing the lifetime of the generator drive train. The coordination is realized by prioritizing the positive-sequence voltage control. If there is remaining STATCOM current capability, the STATCOM is controlled to compensate the negative-sequence voltage additionally, in order to reduce the torque ripple during the grid fault

In ref (3), the energy capacitor system (ECS), composed of power electronic devices and electric double layer capacitor to enhance the low voltage ride through (LVRT) capability of fixed speed wind turbine generator system (WTGS) during network disturbance, is discussed. Control scheme of ECS is based on a sinusoidal pulse width modulation voltage source converter and DC–DC buck/boost converter composed of insulated gate bipolar transistors. Two-mass drive train model of WTGS is adopted because the drive train system modeling has great influence on the characteristics of wind generator system during network fault. Extensive analysis of symmetrical fault is performed with different voltage dip magnitudes and different time durations. Permanent fault because of unsuccessful reclosing is also analyzed, which is one of the salient features of this study. A real grid code defined in the power system is considered and LVRT characteristic of WTGS is analyzed. Moreover, it is reported that ECS can also enhance the stability of SG.

In ref (4), an algorithm to design a robust output feedback simultaneous STATCOM and pitch angle controller for a wind farm composed of fixed-speed turbines is proposed, with the objective of enhancing the LVRT capability of the farm. The designed controller guarantees stability if the system post fault operating point is in the region for which the controller is designed. The results from the simulations show that the combination of the control of the dynamic reactive compensation and fast-acting pitch angle can improve the robustness of the overall solution applied to stabilize operation of the large wind farm and improve the fault-ride-through capability. The controller order is the same as the order of the model so we need to do either model aggregation before controller design or controller order reduction after the design.

In ref (5), the transient stability of a directly connected FSIG is analyzed using an approach based on torque-slip characteristics, the STATCOM and pitch control model used in the simulated system are introduced. The transient performance of wind farm based FSIG equipped with pitch only, STATCOM only or STATCOM in combination with pitch have been studied. The STATCOM helps the voltage at generator terminal recover its nominal value and pitch control can maintain the rotor speed stability as well, thus using pitch control and STATCOM can realize the LVRT of the wind farm based FSIG. wind farms are becoming larger in size and constructed away from the point of connection, increasing problems are issued, such as issues related to frequency operating ranges, reactive power capability, and voltage operating ranges under steady state and transient conditions. In this paper, the method using STATCOM and pitch control can efficiently realize LVRT (it is considered as the most difficult to be realized one of the problems) capability of wind farm based FSIG.

In ref (6), authors proposes a new topology based on TSC to realize the LVRT capability of fixed speed wind generators, and analyses the wind generators transient characteristics equipped with and without the LVRT topology under the grid unbalanced fault. Since impacts on wind generators under different faults are different, the compensation modes are different either; thus asymmetrical compensation mode is needed for unbalanced fault as each phase need different compensation capacity. With the help of the LVRT topology, the transient characteristics and the corresponding LVRT ability are improved. In the proposed LVRT topology, the series reactor L could increase the wind turbine terminal voltage, while the parallel R could absorb instead of consuming the excess active power so as to improve the wind turbine LVRT capability; and this new topology could support the reactive voltage for the wind turbines and reduce the reactive compensation capacity together with dynamic reactive power compensator TSC.

In ref (7), it is evidences that a proper operation of a full power converter of a SG-WT is able to enhance the FRT capability of a SCIG that belongs to another WT. The influence on the SCIG performance depends on the different power strategies, as it varies in function of the active/reactive power injection, while the three presented current patterns affect mainly the power processor's behavior. This paper shows also that the Dual Second Order Generalized Integrator Phase Locked Loop (DSOGIPLL) plays a crucial role in the response of the current control strategies during and after the fault, thanks to its accurate and fast detection of the symmetrical components of the voltage. The results of this work open the door for new applications oriented to take advantage of the increasing number of power processors that are connected to the grid. This new functionalities permit to reinforce the FRT performance of the already existing generation facilities, something that finally benefits the robustness of the electricity network.

In ref (8), authors discussed the application of STATCOM for fulfillment of LVRT requirements of single induction generators. Moreover, the impact of STATCOM modeling has been also addressed. Modeling of STATCOM as an ideal current source may be deceiving and might lead to premature tripping of the induction machines if the trip settings are adjusted to the CCT calculated for this ideal model. Therefore, a more exact and realistic modeling using a shunt reactance, that accounts for the coupling transformer, should be applied in order to practically calculate the CCT and hence determine the protection device settings

In ref (9), authors propose a new method of pitch angle control for induction-generator-type of wind turbine. If the turbine rotor speed can be reduced quickly during voltage dip so as not to rise over the maximum speed, then the sudden disconnection of wind turbine generator can be avoided. The proposed pitch control system can modify the pitch angle in the short response time by the coordination of protective relay for wind turbine. The simulation study shows that the proposed pitch control system is effective to enhance LVRT capability of induction-generator type of wind turbine. The effectiveness of the proposed pitch controller is confirmed for the improvement of the wind farm LVRT capability. By the coordination with the protective relay system for wind turbine, the pitch controller can be enhanced to design the wind turbine to react rapidly to the voltage dip. So the reduction in the cost for wind farm integration can be expected.

In ref (10), the performance of the DSTATCOM based external FRT solutions used in wind farms equipped with FSIG is evaluated. The DSTATCOM provides voltage support following voltage dips that arise from external short-circuits occurrence, reducing voltage drops and increasing the stability margin of the power system. Therefore, the DSTATCOM can be considered as an effective mean to improve FRT capability of these existing wind farms. However, special care should be put regarding over voltages experimented by the non-faulted phases when single phase defaults arrive in the grid, due to current injection in the three phases, since over voltage protections can trip out the wind generators. In order to avoid such situations, complementary control procedures to define the volume of reactive power injection from the DSTATCOM should be derived. For this purpose the negative sequence of the wind farm terminal bus voltage should be also taken into account

In ref (11), authors discussed that with increased penetration of wind energy and moving toward active networks, grid codes are being revised to reflect new requirements. Among which, fault ride-through capability of induction wind generator is a problem of major concern. As DFIGs are being largely deployed and hence influencing system dynamics more than FSIGs, it becomes more necessary to model DFlG and the associated control and protection circuits adequately, specifically in the event of fault. Currently –developed models are being discussed for both FSIG and DFIG in terms of induction machine models, aero dynamical and mechanical models, Power Electronics converters models and dedicated power system studies, where their drawbacks have been highlighted.

In ref (12), the application of the bridge-type FCL, which has a control scheme based on dc reactor current measurement, has been proposed for improving the FRT capability of FSWT and limiting the fault current. Based on simulation results of a system with an FSWT and the bridge-type FCL, the following points can be drawn:

1) During the fault condition, the increment of the fault current is limited by dc reactor without any delay and smoothing the surge current waveform and prevention from instantaneously deep voltage drop during fault. This characteristic of bridge-type FCL improves transient behavior of FSWT system in fault instant before inserting discharging resistor in series with dc reactor.

2) Then, by controlling the duration of ON and OFF periods of semiconductor switch generates a controllable resistor in order to control the terminal voltage of IG at threshold value during fault, which causes reducing the rotor acceleration

and stabilizing the system by consuming the dc reactor energy over limiting fault current in acceptable level.

3) The comparison with SDBR shows that the bridge-type FCL is more effective for enhancement of FRT capability than SDBR.

In ref (13), the use of dynamic reactive power compensation devices such as the STATCOM to improve power quality and Fault Ride-Through capabilities of FSIG wind farms is investigated. Also, the use of VSC-HVDC transmission to isolate the wind farm from impacts of potential faults in the grid side is investigated. Dynamic performance of the FSIG wind farm is explored under several operating conditions, such as a three phase short circuit at the point of common coupling (PCC) and wind speed fluctuations. The paper also compares the outcomes of the approaches presented to connect the FSIG wind farm and summarizes the merits and demerits of each of them. This paper investigated the possible approaches for integration of FSIG wind farms to the power network. The investigation focused on the ability of each arrangement to improve Fault Ride-Through capability and voltage control. The paper also investigated the potential use of FACTS devices, such as the STATCOM, and VSC-HVDC transmission to reduce flicker, improve dynamic voltage control and Fault Ride-Through capability.

In ref (14), authors discussed that among the renewable energy technologies being vigorously developed, Wind turbine technology has been undergoing a dramatic development and now is the world's fastest growing energy. The continuous increase in wind power penetration level is likely to influence the operation of existing utility networks, especially the power system stability. Because of clean and economical characteristics, Wind energy is considered as one of the prospective energy sources of the future world. The present target is to achieve 12% generation of the world's electricity from, wind power by 2020. The new European Wind Energy Association scenario shows that by 2030, wind power could be satisfying 22% of Europe's total electricity supply. From these predictions, it can be easily comprehended that a huge number of wind farms will be connected to the power system in the near future. Therefore it is essential to analyze the characteristics of wind generators during the network disturbances. The STATCOM helps the voltage at the generator terminal to recover its nominal value and also can achieve rotor speed stability. Fixed Speed Induction Generators have strong construction and is therefore preferred for Low cost, simplicity in maintenance and operation. FSIG based WECS can effectively realize LVRT at low cost through STATCOM.

In ref (15), an attempt has been made to compare the response of SVC and D-STATCOM during faults to control the voltage violation of fixed speed wind turbine generators. A sample 33 bus distribution system has been considered for analysis and the dynamic response of the system with SVC and D-STATCOM has been studied separately for different faults. It is observed from the results that the response time of DSTATCOM is better than that of SVC for the considered cases. The case in which the combination of SVC and D-STATCOM is considered fared well for all the fault cases and showed better performance than a single SVC placed in the system. It is also observed that the response of D-STATCOM is similar to that of the combination of SVC and D-STATCOM for the severe fault and for the fault applied nearer to the source.

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