Low Voltage Ride Through Capability Improvement of Fixed Speed Squirrel Cage Induction Generator based Wind Farm

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***Abstract*—With increased penetration of wind power the ability of the wind power plant to stay connected during grid disturbances is important to avoid a cascading effect. Making it necessary to introduce new code of practice, the grid operators require that wind turbines stay connected to the grid during voltage dips. Low voltage ride through has emerged as a new requirement that system operators demand to wind farms. This paper investigates the need of improving low voltage ride through capability and analysis the effectiveness of alternative ways to improve the low voltage ride through capability of fixed-speed squirrel cage induction generator based wind farms.**

Keywords—Low Voltage Ride Through (LVRT), Squirrel Cage Induction Generator (SCIG), Permanent Magnet Synchronous Generator (PMSG), Static Synchronous Compensator(STATCOM).

I. INTRODUCTION

Due to its environment-friendly and economical benefits, wind power is getting vast deliberation throughout the world. According to the report of EWEA, 12% of the world's electricity is expected to be generated from wind power by 2020 [1].

There are two types of Wind Energy Conversion Systems (WECSs), fixed speed WECS and variable speed WECS. The fixed speed WECS has weaker fault ride through capability. SCIGs are used, in general, as fixed speed wind generator due to their superior characteristics such as brushless and rugged construction, low cost, maintenance free, and operational simplicity. However, it requires large reactive power to recover the air gap flux when a short circuit fault occurs in the power system, unless otherwise SCIG becomes unstable and it requires to be disconnected from the power system [2]. Earlier, at the time of low wind penetration; SCIG based wind turbines were accepted to disconnect from the power system in the event of a grid disturbance. Now in these days, wind farms are being installed in larger numbers and the penetration level increases; so their impact on the grid can no longer be ignored. The disconnection of large amount of wind power will result in serious consequence to the grid. Their nuisance tripping can cause long restart delays and production losses. Many utilities now require the wind generators to operate in the same way as the conventional generators. Hence new grid connection codes for wind generators are established, covering topic such as issues related to frequency operating ranges, reactive power capability and voltage operating ranges under steady state and transient conditions. One requirement is LVRT capability, which implies that wind generators should stay connected to the network and keep operation under common coupling voltage dips caused by grid faults and could provide reactive power for the system in order to support the terminal voltage [1].

Voltage or current source inverter based flexible AC transmission system (FACTS) devices such as static var compensator (SVC), static synchronous compensator (STATCOM), dynamic voltage restorer (DVR), solid state transfer switch (SSTS) and unified power flow controller (UPFC) can be used for flexible power flow control. FACTS with energy storage system (ESS) have recently emerged as more promising devices for power system applications. Some of them are even applicable to wind farm stabilization. STATCOM, superconducting magnetic energy storage system (SMES), and energy capacitor system (ECS) composed of electric double layer capacitor and power electronic devices have already been proposed to enhance the LVRT capability of fixed speed wind farm. However, the installation of FACTS devices at a wind farm composed of fixed speed wind generators increases the overall cost.

On the other hand, variable speed WECS equipped with full or partial rating power electronic converter has comparatively strong fault ride through capability. Additionally, it can extract the maximum power from the wind due to its variable speed operation. Therefore, the use of variable speed WECS has been becoming very popular these days [2]. A PMSG based WECS located closely to the SCIG based wind farm can be used to improve LVRT capability of SCIG based wind farm by compensating the reactive power which is absorbed by the SCIG based wind farm [3]. Therefore combined installation of PMSG based WECS with SCIG based WECS in a wind farm can have required LVRT capability with reduced system investment cost.

II. NEED OF LVRT CAPABILITY

General fixed speed WECSs use SCIGs, in which the stator side is directly connected to the network through the transformer as showed in Fig.1.

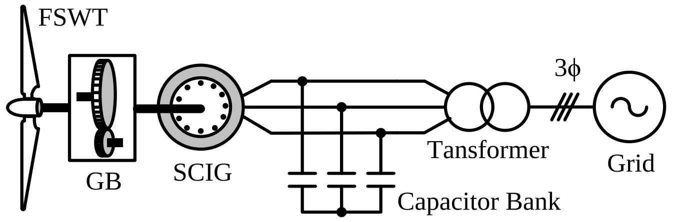

Fig. 1. Configuration of fixed-speed SCIG based WECS.

This direct coupling will result that the grid voltage drop directly reflects on the stator voltage of the generator. The induction generator adopted in fixed speed wind generators operate at a super-synchronous speed and consume reactive power from the system or other installed reactive power compensation equipments to support its operation in steady state. The installed equipments include fixed capacitor banks or other electronic equipments and the former is adopted. The fixed capacitor banks will provide the reactive power and ensure the power factor. When a grid fault occurs, the system voltage together with the wind turbine terminal voltage will drop in a very short time. The electromagnetic torque also drops instantaneously since it is proportional to the square of the terminal voltage, while the mechanical torque is remain unchanged at the moment. So the unbalance of electromagnetic torque and mechanical torque will result in rotor speed acceleration. At the same time, it will also reduce the output electrical power from the wind turbines, if there is no sufficient electrical power to balance the mechanical power, the power surplus then leads to rotor acceleration, which also lead to reactive power consumption. The generator is thus not able to recover after the fault; it has to be tripped out by protection systems [4]. But when the wind power penetration level is high, the protective disconnection of a large amount of wind power will be an unacceptable consequence that may threaten the power system transient stability. Therefore, a new set of grid codes have been defined recently, which includes the LVRT requirement for WECS during the network disturbances.

III. LVRT Standard

Different utilities have defined LVRT requirement as a part of their grid code. According to LVRT requirement of the U.S. grid code, set by Federal Energy Regulatory Commission (FERC); if the voltage does not fall below the minimum voltage indicated by the solid line in Fig. 2 and returns to 90% of the nominal voltage within 3 s after the beginning of voltage drop, the plant must stay online [5].

IV. Alternative Ways to Improve LVRT Capability of Fixed Speed SCIG based Wind Farm

Voltage-source or current-source inverter based flexible AC transmission systems devices such as static var compensator, static synchronous compensator, dynamic voltage restorer, solid state transfer switch and unified power flow controller have been used for flexible power flow control, secure loading and damping of power system oscillation. However, the installation of FACTS devices at a FSWT-SCIG based wind farm increases the system overall cost.

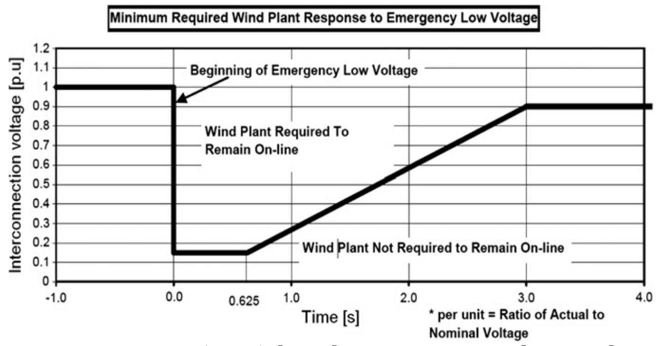

Fig. 2. Low voltage ride-through standard [5].

In [6], SVC is reported with SCIG for reactive power compensation. But STATCOM has relatively better performance compared to SVC for reactive power compensation, as reported in [7]. In [8, 9], a two level Voltage Source Converter (VSC) based STATCOM is discussed. But for high voltage application, at least a three-level inverter is the right choice for a VSC based STATCOM [10]. It is also possible to improve LVRT capability up to a certain range by pitch angle control [11]. However, the reported pitch controller needs complex computation resulting in an increase in the cost of the controller.

A STATCOM has only the reactive power controllability. But when an energy storage system (ESS) is integrated with a STATCOM, it gives batter controllability of both real and reactive power. In [12], a flywheel energy system is proposed for smoothing the wind power fluctuations. A flywheel system has high standby loss within the range of 5% of its power rating. Moreover, the control strategy is complicated. Some authors have proposed [13] a Superconducting Magnetic Energy Storage (SMES) system for minimizing wind power fluctuation. Though SMES is a very good system for wind power smoothing due to its high response speed and high efficiency, its practical implementation in large megawatt range applications is still doubtful for its large installation and continuous maintenance cost. In some reports, a Battery Energy Storage System (BESS) integrated with a STATCOM is proposed to obtain real and reactive power support [14]. Fig. 3 shows the schematic diagram of STATCOM/BESS topology. A two-level voltage source converter based STATCOM shown inside the dotted lines in Fig. 3, controls only the reactive power output. Therefore, BESS is incorporated with a STATCOM, resulting in control of both real and reactive power. But the application of STATCOM with BESS in wind power application may not be a good choice because it is based on a chemical process and it has low response speed and a short service life. Another recently developed technology is an Energy Capacitor System (ECS), which combines power electronic devices and an Electric Double Layer Capacitor (EDLC). It has both real and reactive power controllability [15].

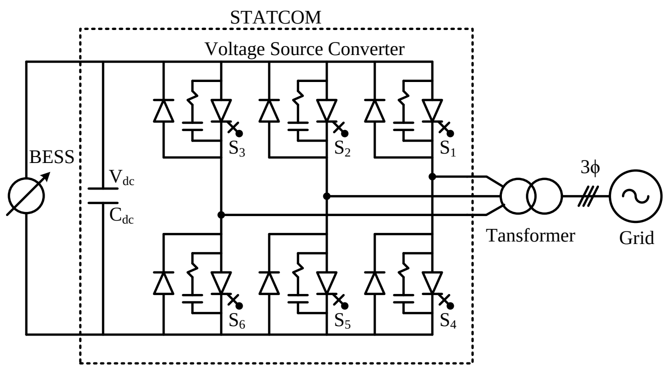

Fig. 3. Schematic diagram of STATCOM/BESS topology.

Variable Speed Wind Turbine with Permanent Magnet Synchronous Generator (VSWT-PMSG) has become the dominant type among installed WECSs. VSWT-PMSG is designed to achieve maximum aerodynamic efficiency over the wide range of wind speed, increase energy capture, improve power quality and reduce mechanical stress on the wind turbine. The VSWT-PMSG system is equipped with back to back power electronic converters, and it has strong LVRT capability during and after fault condition on grid system. Therefore, as shown in Fig. 4; combined installation of VSWT-PMSG and FSWT-SCIG in a wind farm can have required LVRT capability with reduced system investment cost. In Fig.4, the back to back converter of VSWT-PMSG consists of stator-side converter (SSC) and grid-side converter (GSC) linked by DC circuit. The role of SSC is to control the active power output of generator with maximum power point tracking (MPPT) while the GSC controls the DC-link voltage and reactive power delivered to the network effectively. In the normal condition, the converter control method guarantees the efficient and reliable operation of the PMSG-based wind energy system. During grid faults, the control priority to the GSC automatically changes, that is, controlling reactive power at the PCC is prior to controlling the DC-link voltage. By this approach, converter capacity can be efficiently utilized for LVRT capability enhancement of a wind farm having combined installation of VSWT-PMSG and FSWT-SCIG [3].

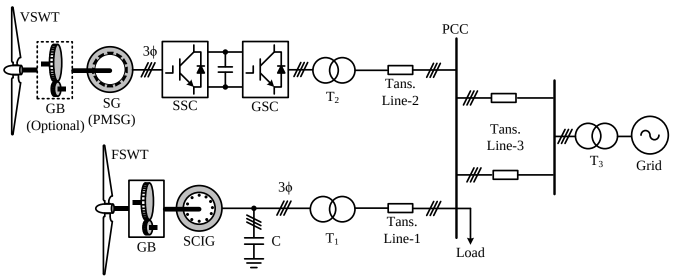

Fig. 4. Combined installation of VSWT-PMSG and FSWT-SCIG in a wind farm.

In [16] Fuzzy-PI controller is proposed for the GSC controllers of VSWT-PMSG to improve its LVRT capability as well as the performance of the neighbouring wind farm composed of FSWT-SCIG. The results show that the proposed Fuzzy-PI controller is very effective in improving the fault ride through capability of overall wind farm system during fault conditions. In [3] a control strategy for a PMSG-based wind turbine system located closely to the SCIG-based wind farm is proposed in order to improve LVRT characteristics of SCIG-based wind farm by compensating the reactive power which is absorbed by the SCIG-based wind farm. Their simulation results have shown that the PMSG-based wind farm equipped with the proposed controller has provided the precise reactive power and voltage responses, which supports the SCIG-based wind farm to improve LVRT capability without any additional measures.

V. Conclusion

In this paper it is investigated that it is very important to improve LVRT capability of FSWT-CSIG based wind farms to have superior power system transient stability. Also, the effectiveness of different methods for improving the LVRT capability of FSWT-SCIG based wind farm has been analyzed. Use of FACTS devices, pitch angle controllers and energy storage systems at the FSWT-SCIG based wind farm gives improved LVRT capability, but it also increases the system overall cost. Another way is to have combined installation of VSWT-PMSG and FSWT-SCIG in a wind farm, which can improve LVRT capability with reduced system investment cost.

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