Effect of STATCOM on the Low-Voltage-Ride-Through Capability of Type-D Wind Turbine Generator

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Abstract—**Variable speed wind turbine with full scale converter or so-called Type-D wind turbine generator worldwide installation has been significantly increased in the last few years. Voltage sag in the grid side may cause the wind turbine to be disconnected from the grid. In this paper, effect of STATCOM on the low voltage ride through capability of Type-D wind turbine during voltage sag in the grid side is studied. Simulation is carried out using MATLAB/Simulink software. Results show that STATCOM can significantly improve the voltage profile at the Point of Common Coupling (PCC) and improve the capability of Type-D wind turbine and prevents it from being disconnected from the grid during certain level of voltage sag in the grid side.**

***Index Terms*—LVRT, STATCOM, Type-D WTG.**

I. Introduction

Wind energy is one of the most promising renewable energy resources in the world. The global wind energy installed capacity has been increased from 2 GW at the end of year 1990 to 94 GW by the end of year 2007. In 2008, electricity generation using wind power has reached to 1% of global electricity generation and by year 2020, it is expected that wind power to supply about 10% of the global electricity [1]. About 21.3% of the total installed wind turbine generators (WTGs) worldwide in the year 2002 were based on Type-D WTG or so-called full converter wind turbine technology [2]. In the early stages of using WTG, it was allowable to disconnect the WTG from the grid during the event of grid disturbance to avoid wind turbine damages. Due to the significant increase in WTGs and the global trend to establish smart grids, the transmission system operators (TSOs) require the connection of WTGs with the grid to be maintained during certain level of faults to provide support to the grid during fault conditions [3]. There are many of international codes related to the LVRT capability of WTGs such as the ones defined by Denmark [4] and Sweden [5] which are shown in Fig. 1. In this figure, all voltage levels below the solid line of LVRT of Denmark will require WTGs to be disconnected from the grid. The minimum voltage sag at the point of common coupling (PCC) at the instant of fault occurrence is 0.25 pu and lasts for 100 ms, after that the voltage profile of the LVRT increases linearly till 0.55 s after which it will be maintained at 0.75 pu. After 10 s, the voltage at the PCC has to be within a safety margin of ± 10% (0.9-1.1 pu) of the nominal value. The lowest allowed voltage sag at the PCC for Sweden grid code (dashed line in Fig. 1) is 0.25 pu for a duration of 250 ms. After 250 ms from fault occurrence, the LVRT profile increases linearly to a value of 0.9 pu and remains constant at this level. All voltage sag levels below the dashed line will lead to the disconnection of the WTGs from the system.

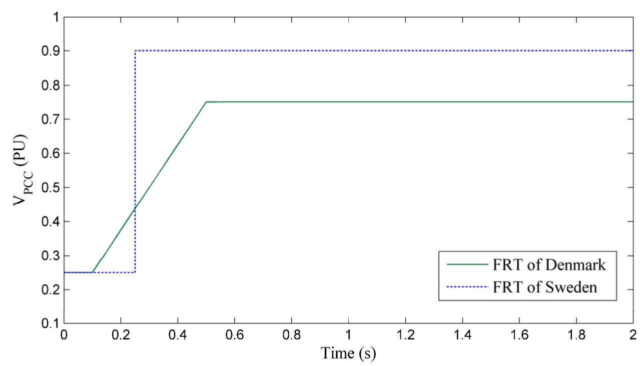

Fig. 1. LVRT grid codes of Denmark (<100 KV) [4] and Swedish (<100 MW) [5]

One strategy to meet the grid requirements with the existing installed WTGs is the application of flexible AC transmission systems (FACTS) [6-11]. In this paper, the performance of Type-D WTG during voltage sag at the grid side is investigated. A STATCOM is proposed to be connected to the system to maintain the WTGs connection to the grid during fault conditions. In this context, simulation results are presented without and with STATCOM to investigate its impact on wind energy conversion system to comply with the international LVRT codes and hence maintaining the connection of WTGs during certain levels of fault conditions.

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II. System Under Study

The system under study is shown in Fig. 2. It consists of five 2 MW Type-D WTG connected to the grid through 25 KV transmission line and two transformers. The STATCOM is connected to the PCC bus.

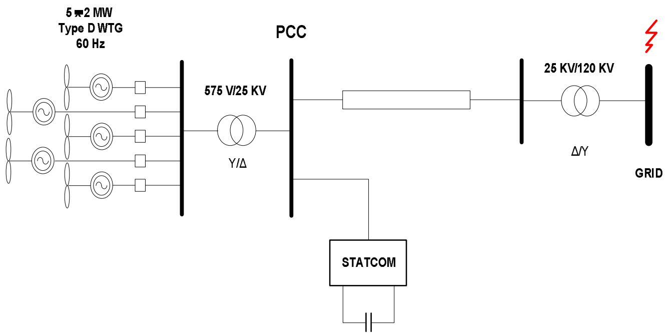

Fig. 2. System under study

The Type-D WTG under investigation consists of synchronous generator connected to a diode rectifier, DC-DC IGBT-based PWM boost converter and DC/AC IGBT-based PWM converter as shown in Fig. 3. This configuration enables the turbine to take part in the power control [12]. The reactive power produced by the wind turbine is regulated at 0 Mvar during normal operating conditions. For an average wind speed of 15 m/s which is used in this paper, the turbine output power is 1 pu, the pitch angle is 8.9° and the generator speed is 1 pu which is maintained by the control system of the DC-DC converter.

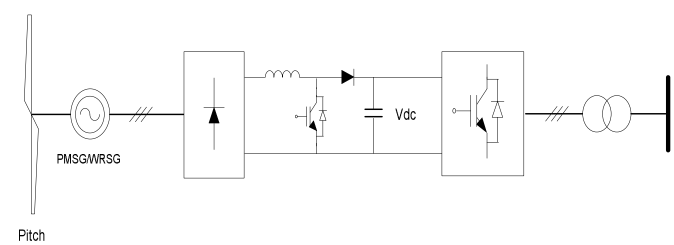

Fig. 3. Typical generic Type-D WTG

III. STATCOM Configuration

STATCOM is one of the promising technologies applied to improve power system performance. The advantages of STATCOM include fast response time, better voltage support capability and reactive power support at low voltage levels. Moreover, it does not require thyristor-controlled reactors (TCR) or thyristor-switched capacitors (TCS) and does not produce low harmonic order distortions [13, 14]. STATCOM mainly consists of a pulse width modulation (PWM) voltage source converter (VSC) with a capacitor in the DC side, coupling transformer and control system as shown in Fig. 4. The interaction between the grid voltage and the voltage at the STATCOM ac side provides the control of reactive power flow. The control system enables adapted regulation of bus voltage and the DC voltage levels and hence controlling the reactive power flow according to the system requirements. The VSC consists of 12 pulse IGBT converter station to minimize the harmonics generated from switching operation.

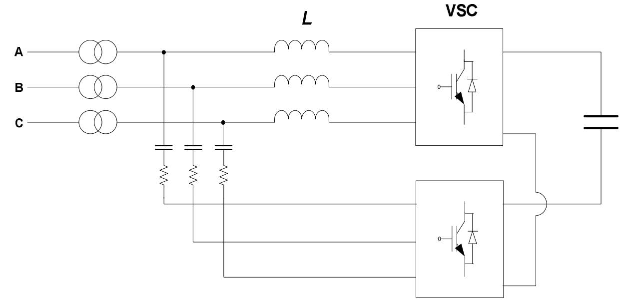

Fig. 4. STATCOM configuration

The basic principle of STATCOM operation is illustrated in Fig. 5. If the voltage at the STATCOM terminals is higher than the grid voltage (Fig. 5 (a)), reactive power will be injected from STATCOM to the grid and STATCOM will behave as a capacitor. When the voltage at the STATCOM is less than the grid voltage (Fig. 5 (b)), STATCOM will behave as an inductor and reactive power flow will be reversed. Under normal operating conditions, both voltages will be equal and there will be no power exchange between the STATCOM and the grid.

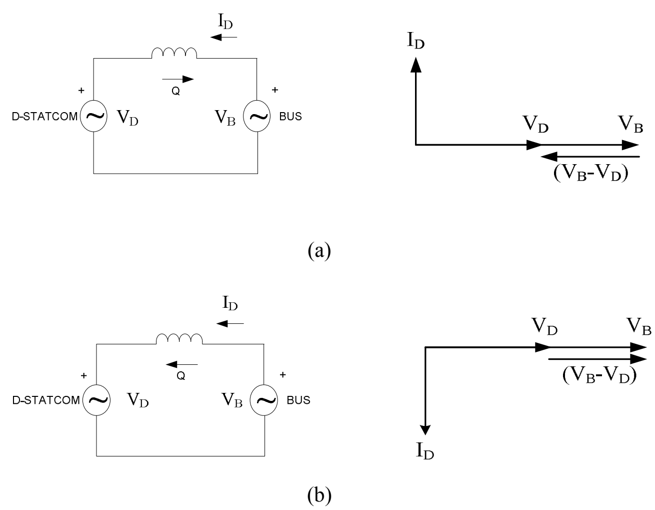

Fig. 5. STATCOM principle of operation [14]

The detailed control system of the STATCOM is shown in Fig. 6 [14]. In this system, the DC Voltage across the capacitor, the grid three-phase currents and three-phase voltages at the PCC are sensed and converted to the *d-q* reference frame to create I_d, I_q, V_d and V_q. These parameters in *d-q* reference frame are then compared with the corresponding nominal values to create error signals (ΔI_d, ΔI_q and ΔV_{AC}) which are fed to PID/PI controller to create Modulation Index (MI) and phase angle (Phi) required for the voltage source converter (VSC) switching operation.

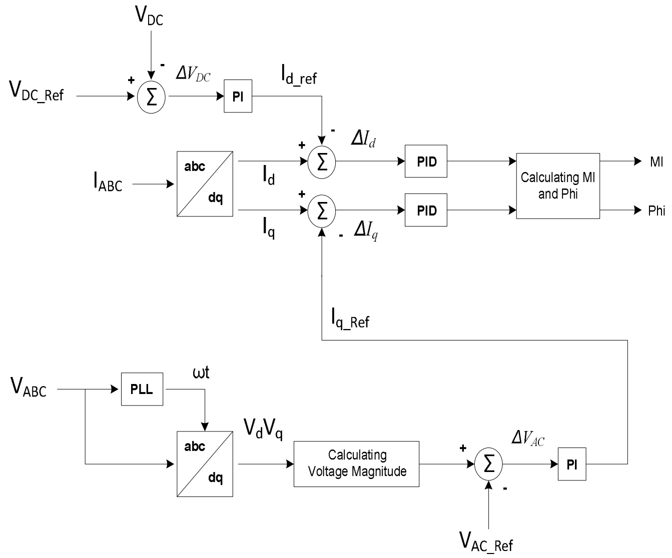

Fig. 6. Control system of STATCOM

IV. Simulation Results

Simulation is carried out with 3 phase short circuit grid fault that causes a voltage drop at the PCC bus to be about 0.15 pu for a duration of 100 ms. This fault is complied with the low voltage ride through of Denmark and Sweden grid codes. A three-phase short circuit fault at the grid side is applied at 0.5 s and cleared out at 0.6 s. The voltage behavior at the PCC is investigated during the fault and results with and without a 6 MVAr STATCOM connected to the PCC bus is compared. As can be seen in Fig. 7 and 8, the grid fault causes the voltage at the PCC to be 0.16 pu (black solid line in Fig. 7). In this case, referring to the Denmark LVRT grid code for system under 100 KV (shown in green marked line) which states that when the voltage at the PCC drops below 0.25 pu, the WTGs are to be disconnected from the grid, the TSO should disconnect the WTGs from the grid. However, by connecting the STATCOM to the grid at the PCC bus, the amount of voltage drop at the PCC bus is reduced to reach the safety margin of the grid requirement and hence avoiding the disconnection of WTG as can be shown in Fig. 7 and Fig. 8.

Another LVRT code applied in this study is the LVRT of Sweden grid code for systems under 100 MW. If this grid code is applied for the system under study, without STATCOM, voltage drop at the PCC reaches 0.16 pu as stated above, therefore the WTGs has to be disconnected from the system, however as shown in Fig. 9 and Fig. 10, voltage drop can be maintained at a safe level and the WTGs connection to the grid can be maintained during the fault.

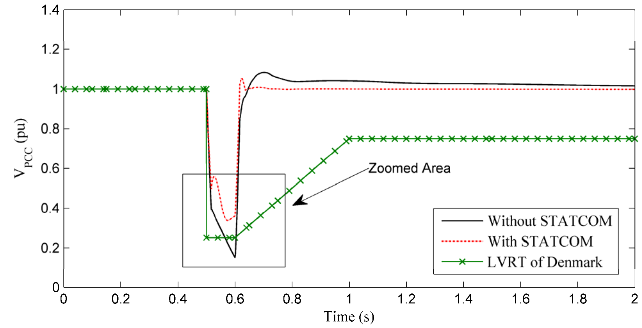

Fig. 7. Complying with LVRT of Denmark (<100 KV) [4]

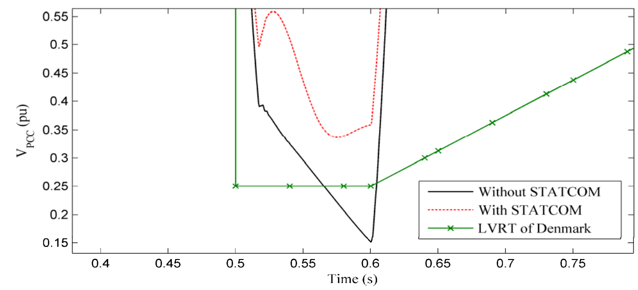

Fig. 8. Zoomed area of Fig. 7

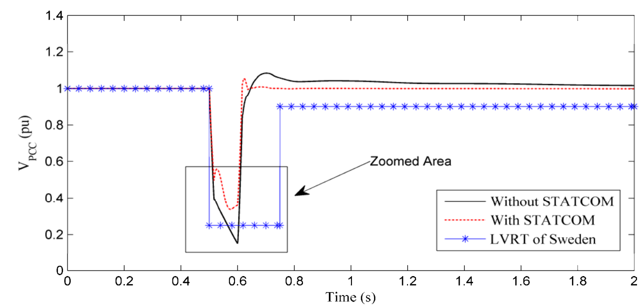

Fig. 9. Complying with LVRT of Sweden (<100 MW)

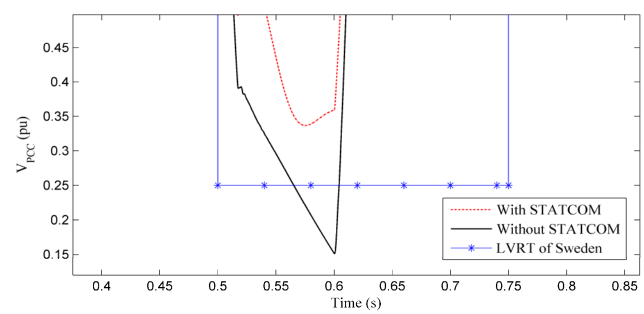

Fig. 10. Zoomed area of Fig. 9

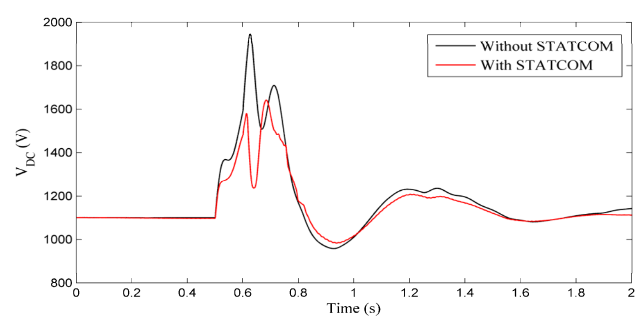

Fig. 11. V_{DC} waveform of Type-D WTG

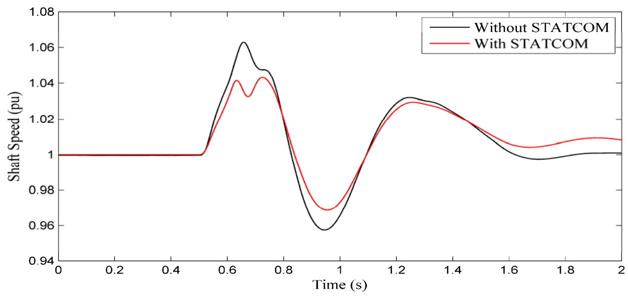

Fig. 12. Shaft speed of Type-D WTG

The voltage across the WTG capacitor (V_{DC}) is an important parameter for FRT study. This voltage is shown in Fig. 11, with and without the connection of the STATCOM connected to the system, the maximum overshoot of the wind turbine V_{DC} is reduced by about 32% compared with the system without the connection of the STATCOM to the system. On the other hand, the effect of the STATCOM on the shaft speed is insignificant as shown in Fig. 12.

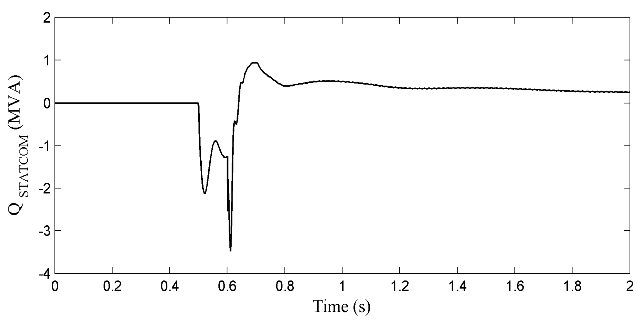

Fig. 13. Q response of the STATCOM during fault

The performance of the STATCOM during fault can be examined in Fig. 13. When the fault is applied at 0.5 s, the reactive power is supplied by the STATCOM to the system and when the fault is cleared at 0.6 s, the STATCOM returns to the idle condition as shown in Fig. 13.

V. Conclusion

STATCOM is applied to a wind energy conversion system equipped with Type-D WTG. Results show that, without STATCOM, the WTG has to be disconnected from the system under study according to the LVRT codes for Denmark and Sweden. However, with the application of STATCOM, Type-D WTG connection to the grid can be maintained. STATCOM instantly modulate the reactive power of the grid when a fault occurs and hence it can maintain the voltage at the PCC at a safe margin according to the different LVRT grid codes studied in this paper.

VI. Acknowledgment

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