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 swell in the grid side may cause the wind turbine to be disconnected from the grid. In this paper, STATCOM is applied to improve the high voltage ride through capability of type-D wind turbine during voltage swell in the grid side. Simulation is carried out using MATLAB/Simulink software. Results show that STATCOM can significantly improve the high voltage ride through (HVRT) capability of type-D wind turbine and prevents it from being disconnected from the grid during certain level of voltage swell in the grid side.

Index Terms—HVRT, STATCOM, Type-D WTG

I. INTRODUCTION

RENEWABLE energy sources have been recently given a significant concern worldwide as they generate electricity from infinite and clean natural resources [1, 2]. Wind energy is one of the most efficient and promising renewable energy resources in the world which is continuously growing with the increase of electrical power demand and the decrease in conventional electricity generation resources [3]. In the year 2010, the growth rate in wind power generation worldwide was 23.6% and by the year 2015 the global wind power capacity is expected to be 600,000 MW which is expected to increase to 150,000 megawatts by the year 2020[4]. In the early stages of using wind turbine generators (WTG), it was allowed 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 reliable 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. Therefore, grid codes have been established in many countries to comply with the new requirements. Since voltage sag is a common power quality problem in power systems, most of studies are focused on the performance of WTGs during voltage sag. Although it is a less power quality problem, voltage swell may also lead to the disconnection of WTGs from the grid. Voltage swell is defined as an increase in voltage level in the range of 1.1 pu to 1.8 pu for a duration of 0.5 cycle to 1 minute. Voltage swell is mainly caused by switching off a large load, energizing a capacitor bank and voltage increase in un-faulted phases during a single line-to-ground fault. There are many of international codes related to the high voltage ride through (HVRT) and low voltage ride through (LVRT) capability of WTGs. Among these codes, this paper focuses on the HVRT grid codes for Spain and the US shown in Fig. 1.

Fig. 1 shows Spain and US grid codes for HVRT capability of wind turbine generators. The allowed voltage swell at the point of common coupling (PCC) of US grid code is 1.2 pu that lasts for a duration of 1 s from the occurrence of the fault. After that the HVRT profile decreases by 0.5 pu every 1 s during the following 3 s and after the 4th s the voltage at the PCC has to be within the safety margin of 0.05 pu from the nominal value [5]. On the other hand, the maximum voltage swell at the PCC for Spain grid codes at the instant of fault existence is 1.3 pu which remains for 0.25 s after which it will decrease to 0.1 pu that lasts for 1 s. Then the voltage level at the PCC has to be maintained within the safety margin of 0.1 pu from the nominal value [5].

Y. M. Alharbi is with king Abdullah scholarship program (e-mail: y.alharbi1@postgrad.curtin.edu.au).
A. M. Shiddiq Yunus is with the Departement of Mechanical Engineering, Energy Conversion Study Program, State Polytechnic of Ujungpandang, Perintis Kemerdekaan KM. 10 Makassar 90215, Indonesia (e-mail:a.yunas@postgrad.curtin.edu.au).
A. Abu-Siada is with the Department of Electrical and Computer Engineering, Curtin University, Perth, WA 6845 Australia (e-mail: a.abusiada@curtin.edu.au).
WTGs will require to be disconnected from the grid in case of voltage levels at the PCC higher than the HVRT of US and Spain limits.

Flexible AC transmission system (FACTS) devices have been used to maintain the WTGs penetration with the electricity grid during fault conditions [6-8]. This paper investigates the application of STATCOM to improve the wind turbine HVRT capability in compliance with Spain and US grid codes. To examine the improvement in system performance using STATCOM, simulation results of the studied system with and without the connection of STATCOM are presented.

II. SYSTEM UNDER STUDY

Fig. 2 shows the system under study which consists of five-2 MW WTGs connected to the grid which is simulated as an ideal 3-phase voltage source of constant voltage and frequency through 25 KV transmission line and two transformers. The STATCOM is connected to the PCC bus to increase the damping of the system and to provide reactive power support to the system during fault conditions.

Fig. 2. System under study

Fig. 3 shows the wind turbine under investigation which consists of synchronous generator connected to diode rectifier, DC-DC and DC-AC converters. During normal operation, the reactive power produced by the wind turbines is regulated at 0 Mvar. For an average wind speed of 15 m/s which is used in this study, the turbine output power is 1 pu and the generator speed which is controlled by the control system of DC-DC converter is 1 pu [9].

Fig. 3. Typical generic type-D WTG

III. STATCOM CONFIGURATION

With the enormous global growth in electrical power demand, there has been a challenge to deliver the required electrical power considering the quality, sustainability and reliability of the delivered power. To achieve this goal, it is essential to control of the existing transmission systems for efficient utilization and to avoid new constructions[10]. FACTS technology play an important role in improving the utilization of the existing power system as it can provide technical solutions to improve the power system performance [11]. STATCOM is a shunt connected reactive power compensation controller, capable to control electrical power system parameters by generating or absorbing reactive power. The emergence of FACTS devices and in particular GTO thyristor-based STATCOM has enabled such technology to be proposed as serious competitive alternatives to conventional static var compensator (SVC) [12].

Fig. 4. STATCOM Configuration

The interaction between the AC system voltage and the voltage at the STATCOM AC side terminals as shown in Fig. 4 provides the control of reactive power flow. If the voltage at the STATCOM terminals is higher than the system voltage, reactive power will be injected from STATCOM to the system and STATCOM will behave as a capacitor. When the voltage at the STATCOM is less than the AC voltage, STATCOM will behave as an inductor and reactive power flow will be reversed. Under normal operating condition, both voltages will be equal and there will be no power exchange between the STATCOM and the system [13]. Fig. 5 shows the STATCOM control system. At the point of common coupling the DC voltage across the capacitor, the grid 3 phase currents and voltages are sensed and converted into d-q reference frame to create \( I_d \), \( I_q \), \( V_d \) and \( V_q \) (\( \Delta I_d \), \( \Delta I_q \) and \( \Delta V_{dc} \)) signals errors are created by comparing the parameters in d-q reference frame with the corresponding nominal values. Theses error signals are fed to PID/PI controllers to create modulation index (MI) and phase angle (Phi) that are required for the voltage source converter (VSC) switching operation [14].
IV. SIMULATION RESULTS

Simulation is carried out with voltage swell at the grid side that causes a voltage swell at the PCC bus to be about 1.35 and 1.25 pu for a duration of 250 ms. This fault is complied with the high voltage ride through grid codes of Spain and US. At the grid side a fault is applied at 2 s and is assumed to last for duration for 0.25 s. The voltage performance at the point of common coupling is investigated during the fault without and with the connection of the STATCOM to the PCC bus and results are compared. Fig. 6 shows that the grid fault causes the voltage at the PCC to increase to level higher than 1.3 pu as can be seen in the zoomed faulty duration shown in Fig. 7. Referring to the Spain HVRT grid code for systems less than 100 KV which shows that when the voltage at the PCC jumps over 1.3 pu, the WTGs are to be disconnected from the grid to save it from being damaged. However, by connecting the STATCOM to the grid at the PCC bus, the amount of voltage swell at the PCC bus is reduced to reach a safety margin of the Spain grid requirement as can be shown in Fig. 8 and Fig. 9 and therefore avoiding the disconnection of WTG.

Another HVRT grid code applied in this study is the HVRT of US grid code for systems less than 100 MW. If this grid code is applied for the system under study, without STATCOM, voltage swell at the PCC violate the safety margin of HVRT grid code of the US which is 1.2 pu as shown in Fig. 10 and Fig. 11 and therefore the WTGs has to be disconnected from the system. However, when the STATCOM is connected to the system, voltage swell can be maintained at a safe level and the WTGs connection to the grid can be maintained during the fault as can be shown in Fig. 12 and Fig. 13.

Fig. 5. Control system of STATCOM

Fig. 6. HVRT of Spain without STATCOM

Fig. 7. Zoomed area of Fig. 7

Fig. 8. HVRT of Spain with STATCOM

Fig. 9. Zoomed area of Fig. 9
Fig. 10 shows the voltage across the WTG capacitor ($V_{dc}$) with and without the connection of the STATCOM, with the STATCOM connected to the system the over shooting and settling time are significantly reduced compared to the system without the connection of the STATCOM.

The performance of the STATCOM during fault can be examined in Fig. 15. When a voltage swell at the PCC is applied at 2 s, the reactive power is instantly absorbed by the STATCOM from the system to maintain the voltage at the PCC at a safety level as shown in Fig. 16 and Fig. 17 of both Spain and US grid code. When the fault is cleared, the STATCOM returns to the idle condition and there will be no reactive power exchange between the system and the STATCOM as shown in Fig. 15.
V. Conclusion

This paper investigates the use of STATCOM to enhance the HVRT of wind energy conversion system to comply with the grid codes of Spain and the US. Results show that, without the use of the STATCOM, WTGs must be disconnected from the grid to avoid the turbines from being damaged. However, the proposed controller of the STATCOM can significantly improve the HVRT capability of the WTGs and their connection to the grid can be maintained to support the grid during fault conditions and to guarantee the continuity of power delivery.

VI. Acknowledgment

The first author would like to thank the Higher Education Ministry of Saudi Arabia and King Abdullah scholarship program for providing him with a PhD scholarship at Curtin University, Australia.

VII. References


VIII. Biographies

Yasser Mohammed R Alharbi Received his B.Eng. from Riyadh collage of technology, Riyadh, Saudi Arabia, in 2007. He also received his M.Sc. from Curtin University of Technology, Perth, Australia, in 2010. He is currently pursuing his PhD study at Curtin University of Technology. His research interest includes Power quality, Renewable energy and power system stability.

A. M. Shiddiq Yunus (S’11) was born in Makassar, Indonesia. He received his B.Sc from Hasanuddin University in 2000 and his M.Eng.Sc from Queensland University of Technology, Australia in 2006 both in Electrical Engineering. He recently towards his PhD study in Curtin University, WA, Australia. His employment experience included lecturer in the Department of Mechanical Engineering, Energy Conversion Study Program, State Polytechnic of Ujungpandang since 2001. He is also member of assessor institution of Indonesia in electrical engineering since 2007. His special fields of interest included superconducting magnetic energy storage (SMES) and renewable energy.

A. Abu-Siada (M’07) received his B.Sc. and M.Sc. degrees from Ain Shamis University, Egypt and the PhD degree from Curtin University of Technology, Australia, All in Electrical Engineering. Currently, he is a lecturer in the Department of Electrical and Computer Engineering at Curtin University. His research interests include power system stability, Condition monitoring, Power Electronics, Power Quality, Energy Technology and System Simulation. He is a regular reviewer for the IEEE Transaction on Power Electronics, IEEE Transaction on Dielectrics and Electrical Insulations, and the Qatar National Research Fund (QNRF).