Increase in fault ride through capability of direct drive 
permanent magnet based wind farm using VSC-HVDC

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Abstract. Burning of fossil fuels and green house gasses causes global warming. This has led to 
governments to explore the use of green energies instead of fossil fuels. The availability of 
winds has made wind technology a viable alternative for generating electrical power. Hence, 
many parts of the world, especially Europe are experiencing a growth in wind farms. However, by 
increasing the number of wind farms connected to the grid, power quality and 
voltage stability of grid becomes a matter of concern. In this paper, VSC-HVDC control 
strategy which enables the wind farm to ride-through faults and regulate voltage for fault types 
is proposed. The results show that the wind turbine output voltage fulfills the E.ON grid code 
requirements, when subjected to three phase to ground fault. Hence, continues operation of the 
wind farm is achieved.

1. Introduction

Direct Drive Permanent Magnet wind Turbine (DDPMT) has been introduced to the world since 
1991. Many researches have presented the control strategies for this type of wind turbine. In [1], 
the control system using A Neutral-Point Clamped Converter (NPC) System for Direct-Drive Variable-
Speed (DDVS) Wind power unit is presented. The machine-side NPC converter provides torque-
speed control of the synchronous generator via vector-control strategy. In [2] and [3], the control of a 
standalone variable speed wind turbine with a permanent magnet synchronous generator is presented. 
The results show that the maximum power is tracked via the generator-side converter. On the other 
hand, the absence of the grid makes the results less reliable. In this paper, continues operation of the 
wind farm PMSG-based wind turbine connected to the grid is investigated.

1.1. VSC-HVDC for offshore wind farm 

Long distance between generation units such as offshore wind farms and load makes HVDC systems 
more preferable than HVAC systems to transmit bulk power over long distances.

1.2. E.ON grid code fault ride through requirements

The aim of fault ride through (FRT) capability for the wind farms is to increase the reliability of the 
wind turbines connected to the grid and to make sure that the wind turbines have no diverse effect on 
the grid operation [4]. There are different FRT curves and their specifications vary from country to 
country. Likewise Germany’s standard, E.ON grid code [5], which is used in this paper to clarify the 
accuracy of system response.

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2. Power system modelling
In this paper, FLT for the wind farm is done via VSC-HVDC system. By implementing two stages 6-pulse Insulated-Gate Bipolar Tyristors (IGBT) at the generator and grid side of the power system, two Voltage Source Converter (VSC) stations are simulated in PSCAD/EMTDC software. Control strategy is shared between stations in order to improve the fault ride through and voltage regulation for the wind farm. Figure 1 shows the power system presented in this paper. Using 20 sets of 2 MW 11kV wind turbines, a 40 MW offshore wind farm is simulated in PSCAD/EMTDC. The power is then transferred via HVDC lines and connected to the grid.

![Figure 1. Configuration of the system simulated in PSCAD/EMTDC](image)

Where, $\text{Ph1}$ is the desired phase angle and $M_1$ is the desired voltage magnitude for generator side converter, $\text{PH2}$ is the phase angle and $M_2$ is the voltage magnitude for grid side converter

2.1. Generator side VSC control strategy
Equations 6 and 7 show the principle of this control strategy.

\[
P = \frac{U_1 U_2 \sin \theta}{X}
\]

\[
Q = \frac{U_2^2 - U_1 U_2 \cos \theta}{X}
\]

Where, $P$ and $Q$ are the active and reactive powers between two electrical nodes in AC systems with voltage magnitudes, $U_1$ and $U_2$. $\theta$ is the phase-angle difference and $X$ is the line reactance between the two nodes [6]. Equations (1) and (2) show that the active power is mainly controlled by controlling the phase angle difference while, the reactive power is more affected by the magnitude of the voltage. Equation (3) shows the mathematical equations for reactive power control strategy used in this paper.

\[
M = \left(K_p^Q + \frac{K_i^Q}{s}\right) [Q_{ref} - Q]
\]

Where, $M$ is the changes in the voltage magnitude, $K_p^Q$ is the proportional gain and $K_i^Q$ is the integral gain of the PI controller. $Q$ represents the actual reactive power and $Q_{ref}$ presents the reference
reactive power. The reactive power is controlled by changing the magnitude of the voltage. A proportional-integral (PI) controller is used to generate the desired magnitude of the voltage \((M1)\). Moreover, equation (4) shows the mathematical equations used to control the real power generated by the wind turbine.

\[
Ph = \left( K_p^P + \frac{K_i^P}{s} \right) [P_{ref} - P]
\]  

(4)

Where, \(Ph\) presents the desired phase shift, \(K_p^P\) is the proportional gain and \(K_i^P\) is the integral gain of the PI controller. \(P_{ref}\) is the reference power and \(P\) is the actual power of the wind farm [6]. The control strategy is shown in figure 2.

2.2. Grid side converter control system

Control strategy for grid side converter is presented in figure 3. Grid side converter control system is responsible for controlling the phase and the magnitude of the voltage in the grid side. Voltage magnitude is controlled by controlling the DC voltage. The desired voltage phase is achieved by controlling the phase of the voltage in the grid side. The error signal is fed to the PI controller to determine the magnitude of the control signal \((M2)\). Moreover, the per unit voltage in the grid side is compared with the reference value to determine the voltage phase angle \((Ph2)\) at the grid side.

![Figure 2. The generator side control strategy](image)

![Figure 3. The grid side control strategy](image)

3. Simulation results

A three phase to ground fault is initiated at the grid side to investigate the performance of the VSC-HVDC. At 5s, the fault is applied and is cleared after 150ms. During the fault, the voltage in grid side drops to 0 kV and remains at 0 kV for 150 ms. The DC voltage, which can be controlled to 150kV during the fault, has some oscillation at the beginning of the fault and at the fault clearance. Figure 4 shows the VSC-HVDC response to the three phase fault. The E.ON grid code voltage requirement is also presented in figure 4.d. From the simulation results, it can be seen that the active power is reduced during the fault time and the reactive power is increased and injected to the Point of Common Coupling (PCC) to reduce the voltage sag at the wind farm side.

(a)  

(b)
4. Conclusion
In this paper, the proposed control strategy for VSC-HVDC system shows the capacity to increase the FRT of the offshore wind farm DDPM generator based. The results are validated with E.ON standard grid code. Proposed VSC-HVDC control system ensures that the wind farm stays connected during the fault, thus keeping the system stable.

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