

# GRID INTEGRATION OF OFFSHORE WIND FARMS USING MULTI-TERMINAL DC TRANSMISSION SYSTEMS (MTDC)

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## Abstract

This paper discusses the control flexibility and fault ride-through capability of the bi-polar multi-terminal DC transmission system based on voltage source converters used for integration of large-scale offshore wind farms. Issues such as voltage support and short-term frequency stabilization of the AC network utilizing the stored energy in the wind turbine inertia and DC link capacitors are discussed. Regarding control flexibility, two aspects are presented: power sharing between the grid-side converters by any ratio, and provision of an alternative path for the power flow in case of a permanent DC fault or loss of one grid-side converter. In this investigation, the wind farms are based on fixed-speed wind generators, while the converters are modelled as a neutral-point clamped converter using the universal bridge. The investigation was conducted in Matlab/Simulink.

## 1 Introduction

Today, wind power plays a major role in meeting the greenhouse emission targets in various countries worldwide. However, the variable nature of the wind resource introduces some difficulties concerning the quality, reliability and availability of the power generated from wind.

Power electronic converters now play a leading role in facilitating the integration of wind power into the grid. The introduction of voltage source converters (VSC) in high-voltage high-power applications such as DC transmission, reactive power compensation devices and active power filtering devices, offer several features such as [5]:

1. Ability to provide voltage/reactive power support to the network.
2. Decoupling of the AC systems which results in improved fault ride-through capability.

3. Since power electronic converters are current control devices, they do not change significantly the fault level at the point of connection.
4. Facilitates connection of weak systems such as wind farm, independently of the effective short circuit ratio (ESCR).
5. Black start capability, this eliminates the need for the start-up generator.

There are however, some disadvantages such as, inability to operate under unbalanced conditions and survive asymmetrical faults, vulnerability to DC faults, and the risk of system collapse in case of an open circuit at the terminal of the grid-side converter.

Features of VSC-HVDC transmission such as low space requirement, less visual impact, voltage support and independent control of active and reactive power have made the use of multi-terminal VSC-HVDC transmission more attractive for new expansions. Additionally, the VSC-HVDC multi-terminal increases the control flexibility and improves reliability and stability of the AC power system as each AC system maintains its autonomy while exchanging the active power.

In reference [6], the authors have developed a control strategy that enables the use of multi-terminal VSC-HVDC for offshore wind farms integration. In this reference, the wind farm is represented by a coherent model of a variable speed wind turbine based on doubly fed induction generators (DFIG). To guarantee the power balance between the AC and DC sides, the AC voltage at the wind farm side is controlled such as to transfer to the grid all the power generated by the wind farm, without the need for an active power command. However, the authors assume constant frequency at the offshore network to facilitate the integration of DFIG-based wind turbines. In practice, this will require a start-up generator with significant power rating compared to the wind farm to set the reference frequency for the DFIGs. In [4] the authors presented a multi-terminal VSC-HVDC system based on modular multilevel converters connecting two AC grids to improve the reliability

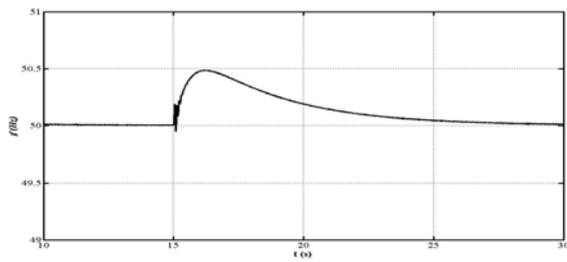




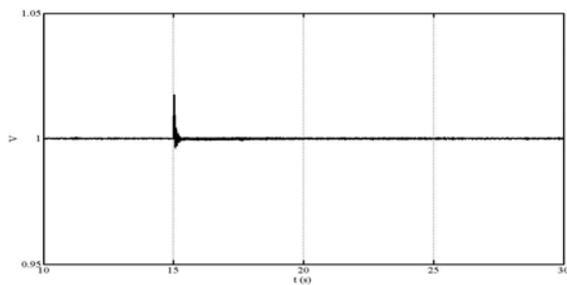
- Power management.
- Power sharing between the grid-side converters.
- Loss of the one grid side converter VSC<sub>4</sub>.

*Case I: Frequency support and voltage regulation*

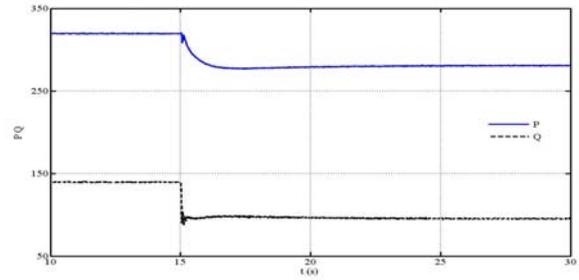
As the active power balance in the power network is strongly coupled to the frequency, any mismatch between the generation and demand may cause the system frequency to rise or decrease, depending on the net difference between generation and demand. Similarly, voltage relates to the reactive power balance. The network sees any disturbance and fault as the increase or decrease in the active and reactive power demand and this must be addressed as fast as possible in order to maintain virtually constant voltage and frequency. Therefore, the faster response of the converter station of the VSC-HVDC, compared to conventional synchronous machines with relative large mechanical inertias, can be utilized to provide short-term frequency stabilization and continuous voltage support at the point of common coupling. To demonstrate the capability of the multi-terminal VSC-HVDC transmission system presented in Fig. 1 to provide the necessary voltage support and frequency stabilization to the grid, the load connected at bus B<sub>9</sub> is reduced by (80+j60)MVA at time t=15s. The results obtained from this case are shown in Fig. 6. It can be observed in Fig. 6a that the frequency has increased slightly and then it is stabilized at 50Hz (nominal frequency) as the converters VSC<sub>3</sub> and VSC<sub>4</sub> reduce their output powers to match the new load demand (Fig. 6c) Also, the converters VSC<sub>3</sub> and VSC<sub>4</sub> adjust their reactive power exchange with the grid to maintain the reactive power balanced in order to maintain the voltage at the points of common coupling B<sub>3</sub> and B<sub>4</sub> at 1.0pu (nominal voltage) (Fig. 6c).



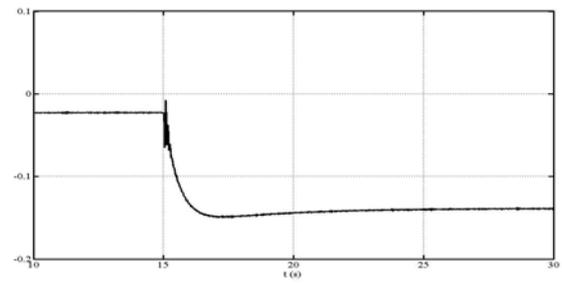
(a) AC network frequency



(b) Grid-side Voltage



(c) Grid-side active and reactive power

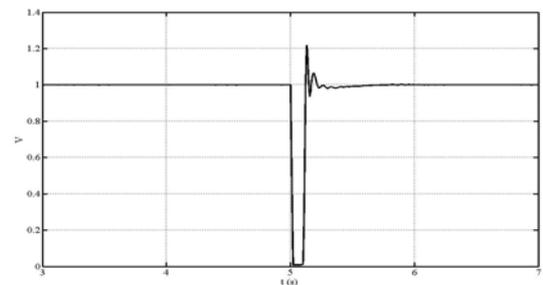


(d) Frequency controller correction signal

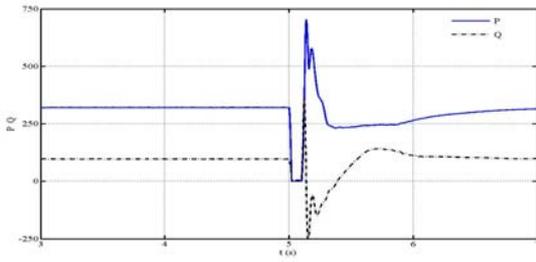
Fig. 6 Case I key simulation results (Frequency support and voltage regulation)

*Case II: Fault ride-through capability (3-phase fault at B<sub>3</sub>)*

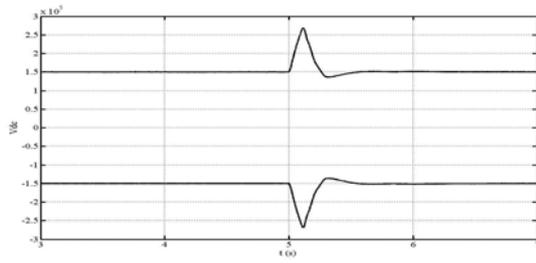
To demonstrate the improved fault ride-through capability of the multi-terminal DC transmission system based on voltage source converters, the system in Fig. 1 is subjected to a three-phase fault at bus B<sub>3</sub>, with duration of 100ms (5 cycles for 50Hz) at t=5s. Fig. 7 shows the key waveforms obtained. As expected the voltage at the wind farm side (busses B<sub>1</sub> and B<sub>2</sub>) remains less sensitive to the AC fault in the grid (Fig. 7e). However, the DC link voltage of converter VSC<sub>3</sub> increases during the fault period as a result of the trapped energy in the DC link (Fig. 7c). It can be observed that the voltage magnitude at bus B<sub>3</sub> collapses during the fault period as the reactive power capability of the converter decreases (Fig. 7a). Despite the voltage collapse at B<sub>3</sub>, the converter VSC<sub>3</sub> contributes limited current to the fault.



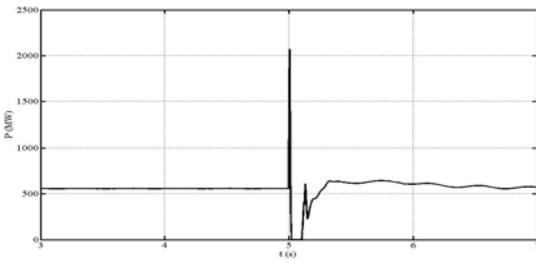
(a) Grid-side voltage



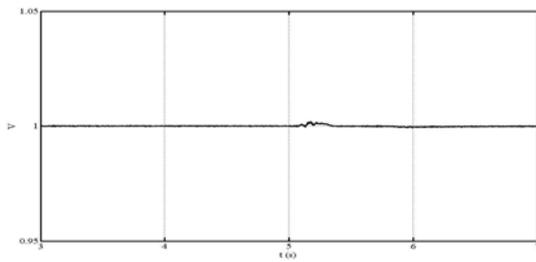
(b) Grid-side active power



(c) DC link voltage



(d) Synchronous machine power



(e) Wind farm side voltage

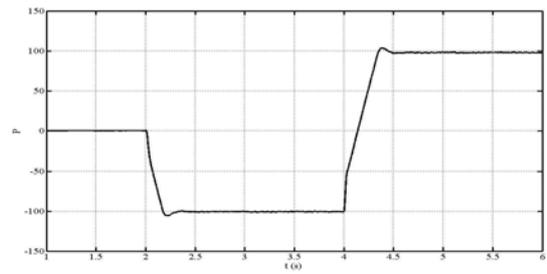
Fig. 7 Case II key simulation results (Fault ride-through capability (3-phase fault at B<sub>3</sub>))

*Case III: power management and loss of grid side converter*

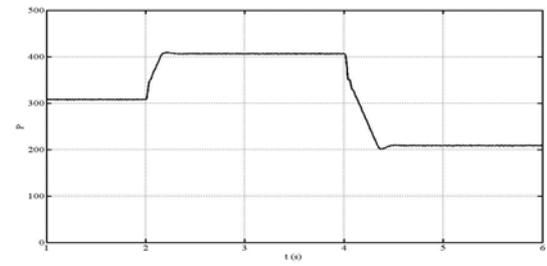
Fig. 8 shows the active power sharing between the grid-side converters VSC<sub>3</sub> and VSC<sub>4</sub>. At the start each converter injects 330MW of active power into the AC network at B<sub>3</sub> and B<sub>4</sub>. It can be seen that that no power flows in the DC line connecting converters VSC<sub>3</sub> and VSC<sub>4</sub> in Fig. 1. At time t=2s, the droop control is activated to enable converter VSC<sub>3</sub> to deliver 430MW into B<sub>3</sub> and converter VSC<sub>4</sub> delivers the remaining 230MW

into B<sub>4</sub>. It can be observed that 100MW are flowing in the DC line between VSC<sub>3</sub> and VSC<sub>4</sub>. At t=4sec the power command has been changed to inject 430MW through VSC<sub>4</sub>, and 230MW through converter VSC<sub>3</sub>. In this case, the power flow in the DC line between converters VSC<sub>3</sub> and VSC<sub>4</sub> is reversed. Fig. (8) shows that the power injected by converters VSC<sub>1</sub> and VSC<sub>2</sub> into the DC network remains constant at 340MW during the entire simulation period.

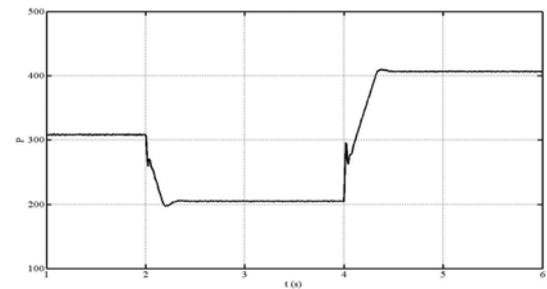
To show the potential benefits of using multi-terminal VSC-HVDC transmission systems in terms of reliability and security of supply, the loss of one grid-side converter is investigated. Fig. 9 shows the results obtained during temporary loss of converter VSC<sub>4</sub>. In this case, converter VSC<sub>4</sub> is deliberately disconnected at t=2s and reconnected at t=4s. It can be observed that during the loss of converter VSC<sub>4</sub>, all the power is delivered to the grid through the converter VSC<sub>3</sub>. To make this case possible, the rating of the converters VSC<sub>3</sub> and VSC<sub>4</sub> are increased to twice that of VSC<sub>1</sub> and VSC<sub>2</sub> in order to be able to carry the full power from the wind farm in case of loss of one of the grid converter.



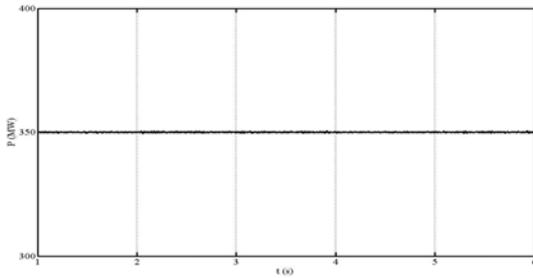
(a) Active power at auxiliary cable



(b) Active power at grid-side converter (VSC<sub>3</sub>)

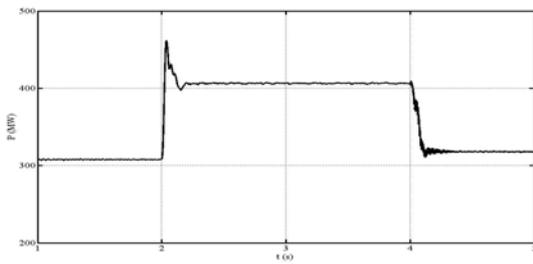


(c) Wind farm side converter control (VSC<sub>4</sub>)

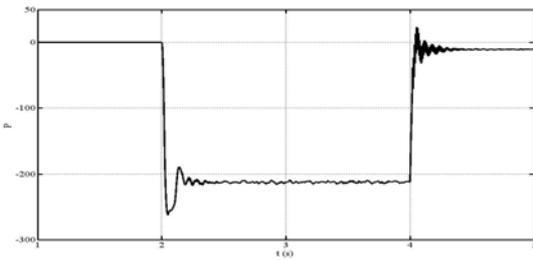


(d) Wind farm side converter Control

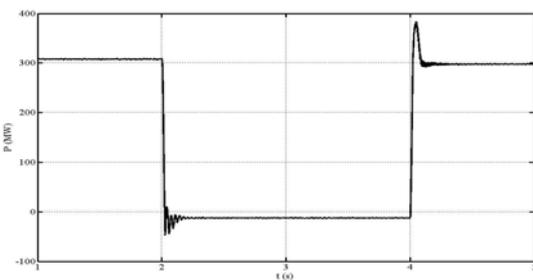
Fig. 8 Case III simulation result (power management)



(a) Active power at grid-side converter (VSC3)



(b) Active power at grid-side converter (VSC4)



(c) Active power at auxiliary cable

Fig. 9 Case III simulation result (loss of grid side converter)

## 6 Conclusions

This paper discussed the application of a multi-terminal DC network to transfer power from two offshore wind farms to the grid. It was found that the use of multi-terminal DC transmission system may improve system reliability against loss

of a converter, it may also allow the improvement of transient stability as the converter stations are able to remain connected to the grid during the entire fault period in the grid side as long as it takes, providing reactive power support without increasing the risk of converters failure if proper current control is in place.

## 6 References

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