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DYNAMIC MODELLING OF VSC-HVDC FOR CONNECTION OF OFFSHORE WIND FARMS

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Abstract

A VSC-HVDC (Voltage Source Converter – High Voltage Direct Current) dynamic model with a set of control strategies is developed in DIgSILENT Power-Factory with the objective of analyzing the converter's operating capability for grid support during grid faults.

The investigation is carried out based on a 165 MW offshore wind farm with induction generators and a Low Voltage Ride-Through solution of the offshore wind turbines and Static Voltage Compensator units in the point of connection with a grid represented by a reduced four-generator power grid model.

VSC-HVDC promises to be a reliable alternative solution for interconnection with off-shore wind farms as they become larger, with a higher installed power capacity, increased number of wind turbines, and geographically situated at larger distances from suitable connection points in the transmission grids.

1 Introduction

Environmental constraints play an important role in the power system and specific problems are expected when renewable energies, such as large wind farms, have to be integrated into the system, particularly when connecting AC links (Alternating Current) are weak and when sufficient reserve capacity in the neighbouring systems is not available. In the future, an increasing part of the installed capacity will be connected to the distribution levels, which poses additional challenges to the planning and safe operation of the systems [1].

As offshore wind farms become larger, with a higher installed power capacity and number of wind turbines, and get located at larger distances from suitable connection points in the transmission grids, VSC-HVDC systems become relevant for grid-connection of large offshore wind farms. This at the same time means that using VSC-HVDC systems grid-code compliance from the transmission system operator must be achieved, such as grid support capability, which specifies that

transmission connected power parks are to assist the power system by supplying ancillary services, such as voltage control, to secure a safe and reliable grid operation [2].

The objective within this work is to demonstrate the grid support capability of a VSC-HVDC system by means of voltage control during a grid fault in the connected AC network.

In order to accomplish the objective, a simple VSC-HVDC model with respective controls is built for interconnection between an off-shore wind farm and a grid as a part of a reduced four-generator power grid model. The dynamic model with a set of control strategies is developed in DIgSILENT Power-Factory (PF). The work for achieving the objective encompasses the following aspects:

- System model
- VSC control
- VSC grid support capability

2 System model

The approach for modelling and simulation of the VSC-HVDC is to build a HVDC grid in Power Factory as an addition to the existing AC grid model represented by a reduced four-generator power grid model. The main task is to implement and control the VSC as part of the HVDC system, whose control capability is with regard to short-term voltage stability and grid support.

The model is based on self-commutating VSC based HVDC technology with a PWM technique, which in comparison with the alternative line-commutating CSC (current source converter), do not requires an AC voltage source for the commutations, and that these are practically instantaneous, whereas the duration of the commutations in LCC depends on the voltage source level and the commutation reactance. Thus, even when the firing angle is 0, LCC consumes reactive power, the amount of which can be as much as 60% of the active power in an HVDC converter. Moreover, the reactive power requirement in LCC varies with the amount of active power conversion and, therefore, the converter filters and VAR compensation structures need to be adjusted as the load

varies. VSC, on the other hand, can provide any reactive power (sink or source) independently of the active power transfer.

In LCC, as the active power transfer varies, the corresponding changes in the reactive power produce AC system voltage fluctuations. The AC voltage drops cause additional reactive power consumption and further voltage reduction, which may lead to voltage instability. To prevent the instability a minimum short-circuit ratio (SCR), defined as the ratio between the short-circuit power and converter power ratings, is required, which can be typically 2. The VSC has no minimum SCR requirement, but the active power transfer is limited by the impedance of the AC system viewed from the converter AC terminal.

Since each arm of the converter bridge switches only once per cycle, LCC needs filters for the 12-pulse related harmonics, the filter capacity being typically 20 to 30% of the converter rating. With the use of intercycle PWM switching, or multi-level configurations in the VSC schemes, the filter requirements are drastically reduced or even eliminated altogether.

A short circuit on the inverter AC system side will cause commutation failures in the case of LCC, with temporary interruptions in the power transfer. VSC does not suffer from commutation failures and can continue to transfer active power under such condition, the amount of power being limited only by the reduction of the AC voltage during the fault [9].

2.1 AC grid model

The investigation is carried out based on a 165 MW offshore wind farm with induction generators and a LVFRT (Low Voltage Fault Ride Through) solution of the offshore wind turbines and SVC (Static VAR Compensator) units at the point of connection with a grid represented by a reduced four-generator power grid model [4].

The off-shore wind farm and its components when connected to the grid by means of a HVDC system may be seen as a power source [5]. Because of the nature of a DC transmission system, faults and changes of power at the AC side do not considerably affect neither performance nor stability of the offshore system [6]. Therefore, it may be represented as a DC current source for modelling simplification. One has to keep in mind that is not the intention in this study to investigate the wind-farm side of the DC-link, but the grid side inverter.

The transmission network showed in Figure 2-1 will be used as platform for the investigation. This is based on a reduced model of the transmission power grid with a large offshore wind farm provided by Energinet.dk and Risø, the Danish TSO and the National Laboratory for Sustainable Energy, respectively. The reason for choosing this model as a basis for the project rather than other available, or even a simple external grid, is because it represents a more realistic case for stability studies since it was developed by the parties mentioned as a result of intensive research and development

[4]. Besides, the model includes a large off-shore wind farm representation, which serves very well as basis for comparison for this project since it uses an AC-link for interconnection with the grid and includes a solution for grid support during a grid fault. This is similar to the Danish offshore wind farm commissioned in the year 2003 at Nysted/Rødsand.

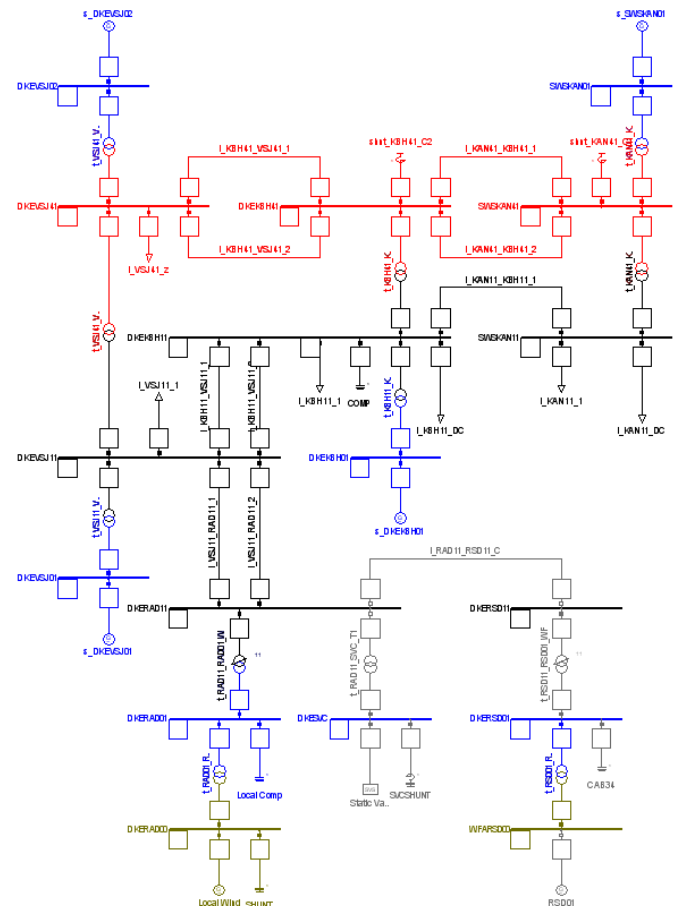


Figure 2-1: Reduced four-generator power grid model

2.2 VSC grid model

The VSC grid model as a replacement of the existing HVAC-link (VSC-HVDC system) consists in general of three buses, a power transformer, a power converter (VSC), a DC-cable, and a DC-current source.

The offshore wind farm and AC-cable from the original model is replaced by a VSC- HVDC system. As mentioned earlier, the 165MW wind farm is substituted by a DC current-source, which simplifies the model by injecting DC-current same as an off-shore wind farm will do as a complete leg system if connected to a DC-link, so it basically represents the off-shore rectifier and wind farm together.

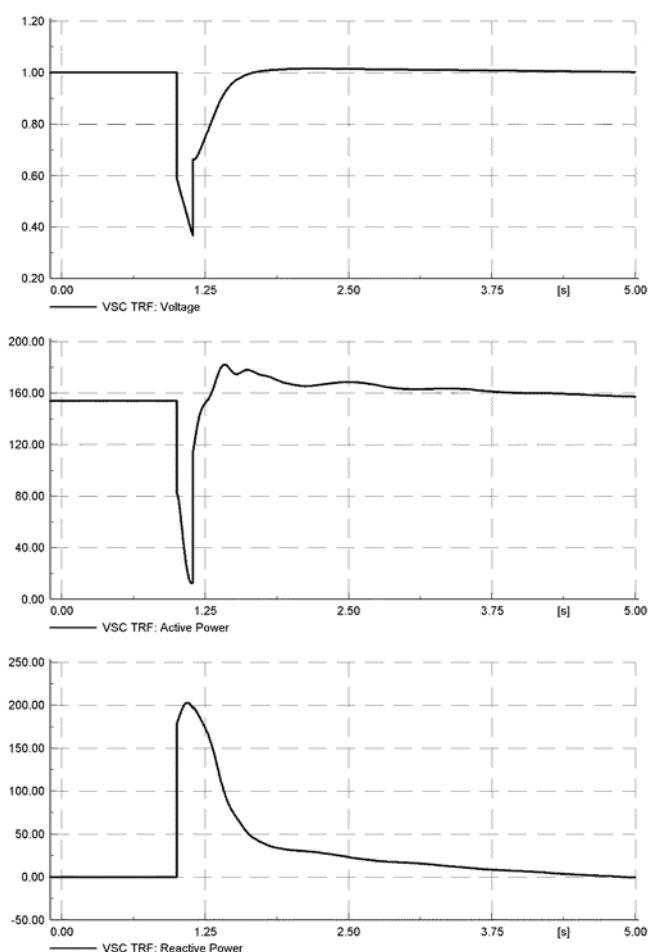


Figure 4-1: Voltage (a), active power (b), and reactive power (c) during the short circuit event.

VSC-HVDC manages to control the reactive power efficiently, helping the voltage to re-establish quickly by injecting reactive power during the duration of the fault to then diminishing smoothly without oscillating. The same way, the DFIG wind farm equipped with voltage control manages to re-establish the voltage rapidly by controlling the reactive power supply injected to the grid during the fault [4], but fluctuating down to negative reactive power for finally reaching stability over 10 sec.

In the plots, the influence of grid support capability can be seen during the fault by supplying reactive power, and after the fault, by controlling the voltage.

5 Conclusions

VSC-HVDC proves to be a suitable alternative for interconnection with offshore wind farms as they become larger, with a higher installed power capacity, increased number of wind turbines, geographically situated at larger distances from suitable connection points in the transmission grids.

The simulation results demonstrate the grid support capability of the VSC-HVDC by means of contributing with reactive

power and helping therefore to re-establish the grid's voltage during the fault.

VSC-HVDC systems become relevant for grid-connection of large offshore wind farms since its control capability and flexibility enables grid-code compliance required from the transmission system operators.

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Biographies

Bardo Rios received his Engineering degree from Chihuahua Institute of Technology ITCH Mexico and obtained a MSc in Electrical Engineering with specialisation in wind-energy from Technical University of Denmark DTU in 2009.

He has worked on a project basis as research assistant with Siemens Germany within HVDC-plus technology, and has several years of experience working with electrical power marine systems and telecommunications.

Rodrigo Garcia-Valle received the electrical engineering degree from the National Polytechnic Institute of Mexico, in 2001, the MSc degree from CINVESTAV, Guadalajara, Mexico, in 2003 and obtained his PhD degree from the University of Glasgow, U.K., in 2007. In 2008, he was granted with the Hans Christened Ørsted Award at the Centre for Electric Technology (CET) by the Technical University of Denmark to carry out postdoctoral research activities. Since 2009 he holds the position as Assistant Professor. His research interests are dynamics, stability and control of electric power systems; artificial intelligence techniques; renewable energy integration; and modelling and simulation of FACTS and custom power controllers. He is an IEEE, IET and CIGRE member.