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IFAC PapersOnLine 50-1 (2017) 85–89

Damping Control of HVDC Links to Mitigate Controller Interaction with Resonances of the Offshore Wind Farm

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Abstract: This paper deals with the harmonic instability problem in offshore wind farms caused by the interaction of HVDC controller with the resonance frequencies of the grid. Due to the HVDC filters, transformers and long submarine cables wind farms have natural resonances, which are close to the operating frequency of the HVDC converter. Even through the grid resonances exhibit inherent damping, the converter control may amplify the oscillations resulting in harmonic instability. Therefore, the converter control has to be designed properly taking into account all possible operating conditions and grid topologies. In this paper a new damping control approach is presented that is using the dq components of the current for modulating the converter output voltage. The parameters of the damping controller are estimated by the heuristic optimization algorithm MVMO simultaneously for three different disturbance scenarios. Simulation results in the time domain demonstrate the effectiveness of the proposed method.

Keywords: HVDC, offshore WF, Controller design, MVMO, Harmonic stability

1. INTRODUCTION

The ratio of the renewable energy resources has been increasing in recent years especially the installation of the offshore windfarms. The only technologically viable option at present to connect distant offshore wind farms with the main grid is the voltage source based high voltage direct current (VSC-HVDC) transmission (Erlich et al., 2014). Since, the VSC-HVDC based transmission system are new and the experience to operate them at high power levels is nearly nonexistent. It should come as no surprise if during the testing or operation phase, certain phenomena are to be observed which were not observed or were part of the design of the system (Erlich et al., 2016). One example is the overvoltages caused by the wind turbine controllers during the opening of the HVDC circuit breaker Erlich, I. et al., (2016), which is of great concern for the system operators. Another phenomenon, which is relatively new and is based on the excitation of the grid resonances. Such phenomena could occur, if the grid resonances lie near the operating range of the (bandwidth) of the controller and no proper attention is paid while selecting the controller parameters. The grid natural resonances usually decay due to the resistance or damping naturally present in the grid but if a source of excitation of the resonance exists in the grid, these resonances could be repeatedly excited which could or would drive the system to the instability.

In this paper, the work is extended which was presented in (Korai, A. Erlich, I., 2016). The working of the HVDC converter control and its interaction with the network is discussed and the design of damping control as well as the tuning of the parameters using a heuristic optimization method are elaborated.

The paper is structured is as follows. First, the HVDC control structure will be presented and discussed. Then, the new damping control which extends the existing HVDC controller to eliminate resonance excitation caused by the HVDC controller in the grid will be presented. Finally, the proposed damping controller parameters are tuned using the optimization method and tested in time domain. The controller is tested with different grid configurations at the end.

2. PROBLEM STATEMENT

Typical offshore VSC based HVDC transmission network connecting the offshore wind farms with the onshore gird is shown in Fig. 1. The wind turbines are connected to the offshore platform using a 33-kV collector network. At the platform this voltage is then stepped up to the transmission voltage level of 155 kV (usually using three winding transformers). The combined power is then exported to the mainland grid using an HVDC transmission line fed by a converter. The offshore Wind farm grid has multiple resonance frequencies ranging from hundreds to some thousand Hz (Lukasz, 2012). As the lower end resonance frequencies may interact with the HVDC and wind turbine converter controls, they are of special interest (Erlich et al., 2016). The focus of this paper is on the HVDC converter control and its effect on the excitation of the resonance frequencies which already exist in such networks. Without the excitation, the grid will naturally damp out the resonances but a HVDC controller may amplify the resonances, thus making the system unstable. It is also to be noted that such actions of the controller are very critical in marginally stable systems if the natural damping is small.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.08.015

The proposed damping controller has to cover all operating conditions and possible changes in the grid structure. The damping must also work if the grid topology changes i.e. one transformer or one cable out of service, or the parallel connection of another HVDC line as part of extension of the wind farm. The other important aspect is the changes in the operation point of the wind farm. The operating point such as changes in the filter compensation for the cables, power generation changes or the changes in the set point of the ac voltage of the HVDC converter must also be considered in the damping control design.

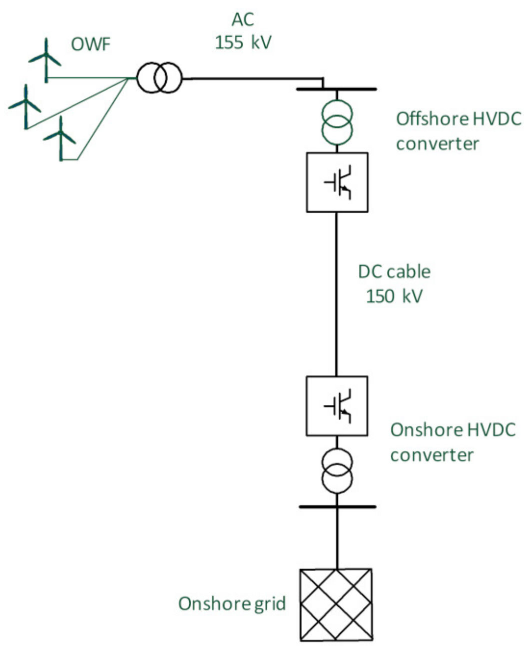

Fig. 1.HVDC transmission system

3. SYSTEM CONFIGURATION

Fig. 2 shows the diagram of the offshore grid to be studied in this paper. The switching frequency of the HVDC converter used in this study is assumed to be 2 kHz. As a result, the HVDC filter is tuned at 2 kHz. The wind turbines are connected to the offshore collector bus (33 kV) using a 0.69/33kV wind turbine transformer. The offshore wind farm platform is then connected with the HVDC platform with two parallel 155 kV cables of 30 km length each. The rated power of the offshore installation is 400 MW but in this study, the windfarm supplies only 300MW, while the rated DC voltage of the offshore converter is 300 kV.

The control of the wind turbines is also implemented in the simulation model where Type 4 WT models are used for the simulation. As the time frame of the study is some hundred milliseconds and the fact that the grid sees only the grid side converter, the model of the WT doesn't include the machine side converter as well as model of the machine and mechanical part of the WT. It should, however, be noted that the DC circuit dynamics are properly represented in the model along with the model of the chopper.

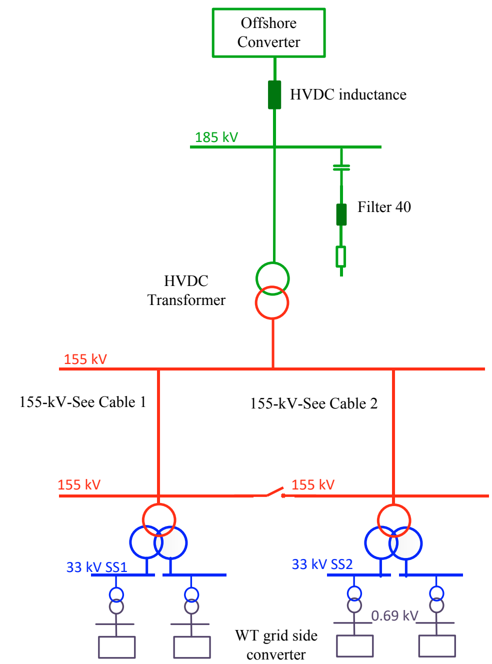

Fig. 2. System under investigation

3.1 Control of the wind turbine

The decoupled control of active and reactive power is achieved by the current control of the converter, which is working in a terminal voltage oriented reference frame. The reference values for d- and q-axis components of the converter currents are calculated according to the structure shown in Fig. 3. The DC voltage controller as shown in Fig. 3 (a) generates the d-axis reference current while the AC voltage controller as shown in Fig. 3 (b), generates the q-axis reference current of the converter. Additionally, a fast voltage controller is attached for voltage support through reactive currents during grid faults. The converter current control is performed using a feed-forward decoupled control structure similar to that shown in Fig. 4. The current controller generates the reference voltages for the converter. The reference voltages are limited before being sent to converter (Erlich, I. et al., 2017).

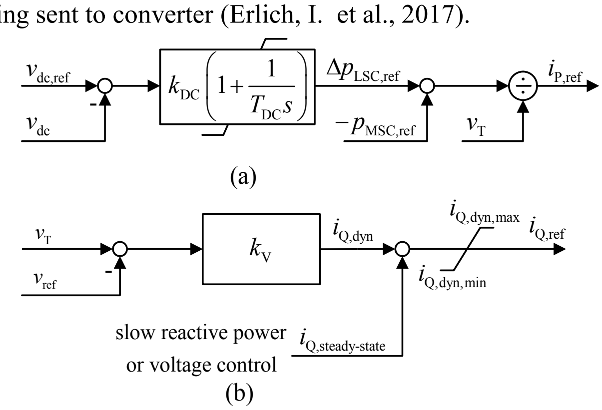

Fig. 3. Structure of reference value calculation for active (a) and reactive (b) converter currents