Control Design Strategy to Enhance the Fault-Ride-Through Capability of VSC-HVDC Transmission System Interconnecting Offshore Wind Power Plant

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Introduction:

Most of the wind power plants currently installed at North Sea are near to shore connected with the onshore grid through AC cable. AC transmission technology is proven and reliable, but there will be a need to switch from AC to DC transmission since large number of offshore power plants at longer distance to shore are expected to be installed by the end of 2020. Furthermore, to enhance the integration of European energy market, offshore power plants are proposed to be interconnected with each other through HVDC transmission system. This has developed a new concept of establishing the mesh DC network [1]. High voltage direct current (HVDC) transmission system based on voltage source converter (VSC) become imperative to cater the offshore wind power plant integration challenges. IGBT based converter offer distinguish feature compare to thyristor based converter such as ease of power reversal, and black start operation; that are crucial for the integration of offshore power plants. One of the important aspect in realizing the integrated DC offshore network is to establish it in fragments and must be able to operate in isolation, in case of fault. Thus in first phase, point-to-point connection from offshore substation to onshore station is expected to be developed using HVDC transmission system. In [2] dynamic model of VSC and its operational behavior has been analyzed for point-to-point configuration. The fundamental operation of the offshore converter is to provide the reference frequency to the network and maintain the voltage level at the reference bus. LCL-filters are preferable over L-filters as reference bus would not remain floating and same switching harmonics damping can be achieved using smaller inductance [3], [4]. One of the problem with the LCL-filters is the resonance effect that causes instability in the network which is usually overcome through active damping method [5], [6].

Transmission system operator has requirement for the offshore wind power plant to fulfill the grid integration codes in order to maintain the system stability. In [7] fault-ride-through (FRT) capability of the offshore wind power plant connected through HVAC system has been investigated using coordinated control method. Fault-ride-through capability in wind power plant having doubly-feed-induction generators (DFIG) is usually achieved by controlled demagnetization method to limit the generator short circuit currents [8]. Further during faults, it is also required by the transmission system operator to inject maximum reactive current into the gird by the wind turbine to support the voltage at the point of common coupling (PCC) [9], [10].

This research envisage the designing of voltage source converter (VSC) control system for integrating offshore wind power plant with the grid. This article proposed a method of selecting control scheme according to ITAE (Integral of Time weighted Absolute Error) criteria. Linearized system equations are developed and with the application of classical control theory, optimum value of controller gains are determined. Furthermore, control system for fault at onshore is also developed. Fault-ride-through capability of VSC control system is evaluated according to grid code compliances.

Methodology:

The research has been carried out on the system shown in Figure 1. Onshore and offshore side network have same substation configuration which allow having identical control architecture in both side of converters and the derivation of the network dynamics equation would be similar.

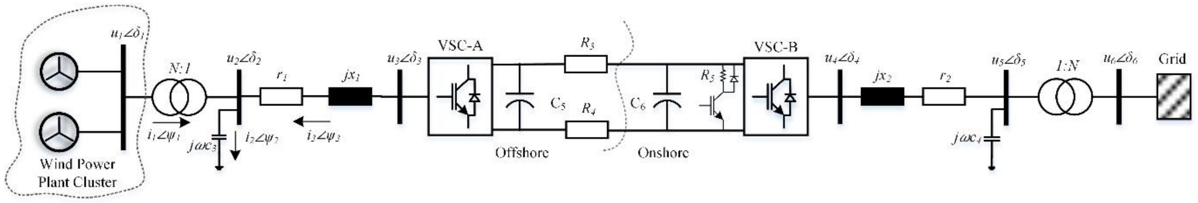

Figure 1: Single line diagram of VSC-HVDC transmission system interconnecting offshore wind power plant with the grid

At first, linearize system equations are developed. Linearization of the system enable the application of linear control theory to design the control scheme. Converter control is based on vector control scheme and designed in voltage synchronous rotating frame. Onshore network dynamic equation are derived using equivalent diagram shown in Figure 2. It can be stated from control theory prospective that the input signal for the model is a converter voltage ($\underline{u}_4$) and grid voltage ($\underline{u}_6$) act as a disturbance signal. The main output signal is the current ($\underline{i}_4$) through reactor which is control by inner current control loop. The outer control loop is designed to operate converter in different operational mode such as DC voltage ($\underline{u}_{dc}$) control, AC voltage ($\underline{u}_{ac}$) control, active power (p) control and reactive power (q) control. ITAE [11] criteria is applied to determine the gains for inner current and outer loop controllers to achieved system stability. The performance of a feedback system is described in term of the characteristic equation root location in s-plane. In the proposed control method, desire closed loop response of the system is achieved by selecting the controller gains using root-locus method.

Similarly, equivalent diagram of offshore network is shown in Figure 3. The output signal of the model is reactor current ($\underline{i}_3$) and voltage ($\underline{u}_2$) at the reference bus. The current ($\underline{i}_1$) injected by the offshore wind power plant is the disturbance signal of the model. It is addressed in the research that the onshore converter inner and outer feedback control system can be designed sequentially, as the reference bus voltage ($\underline{u}_5$) to the network is providing by the grid. However, reference voltage for the offshore network is provided by the converter, therefore, closed loop feedback system incorporating inner and outer controller, is required to formulate the system characteristic equation as shown in Figure 4.

DC chopper is installed to dissipate energy in the DC network during onshore fault. In case of fault, method of power reduction based on reference AC bus voltage is proposed in order to reduce the large transient in DC voltage as well as to avoid the loss of synchronism [12]. According to the grid codes, reactive current must be injected during fault to support bus voltage. Traditionally, it is achieved by injecting constant reactive current at the rated value, however, during fault due to high voltage error, integral of the PI controller get saturated without anti-winding scheme. Further, there are two main methods for anti-winding, firstly by back-calculation in which integral input reduces according to the output limit of the PI controller, and secondly by clamping in which integral input forces to zero. During fault recovery period in either method, the difference between the voltage error signal and reactive current reference is large, and in extreme case opposite in direction which could lead to transient instability. To resolve this issue, AC voltage control scheme has been proposed based on reactive current feedback signal. System response of the fault at onshore network is shown in Figure 5. It can be seen from the voltage angle (δ_5) plot that voltage dependent active power reduction scheme keep the angle during fault near to steady-state operating angle which improves the system transient response.

Conclusion:

In this article, method of selecting controller gains of voltage source converters connecting offshore wind power plant with the grid is proposed. Using classical control theory, stability of the system is analyzed and controller is

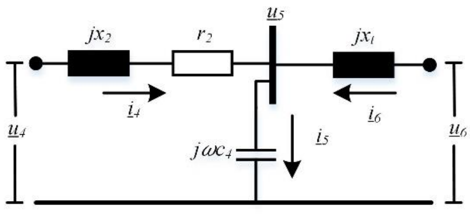

Figure 2: Equivalent diagram of onshore network

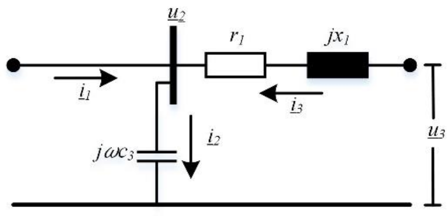

Figure 3: Equivalent diagram of offshore network

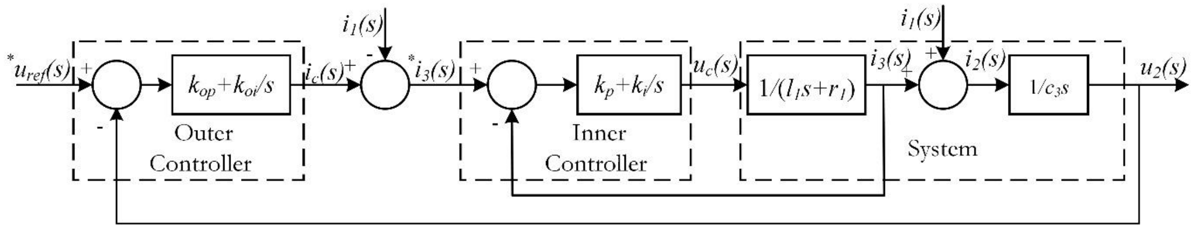

Figure 4: Closed loop feedback control system for voltage control of offshore side converter

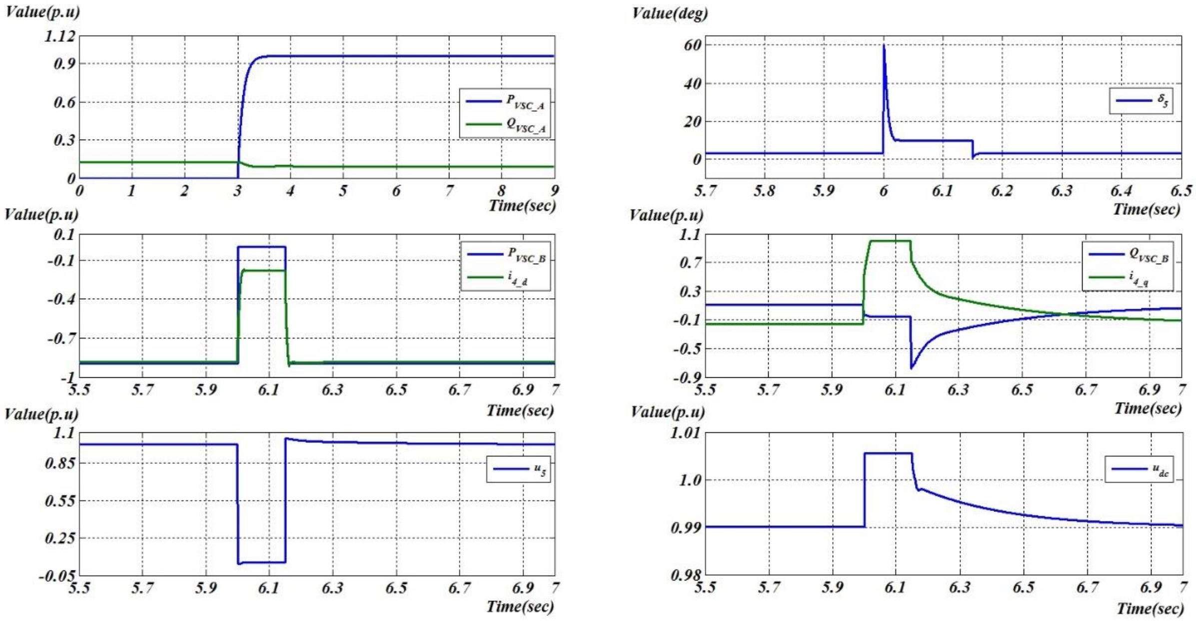

Figure 5: Short-circuit analysis of the fault at onshore network

designed to achieve the require performance of the system. Control system design in *dq0* frame gives benefit to approximate the system linearly, and linear control theory can be applied to determine the controller gain.

Further, short circuit analysis has been performed and the coordination between DC chopper control and outer voltage control of grid side converter is demonstrated.

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