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Frequency Regulation of offshore Wind Power Generation using VSC-HVDC Converter

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Abstract : *This paper deals with the development of a Mat lab-simulink model of a new proposed scheme for grid connected off shore wind farm (OWF) and marine current farm (MCF) on a VSC-HVDC. The purpose of this simulation Model to getting better damping enhancement and voltage control. An equivalent Doubly fed Induction Generator is used here to operate the Off shore wind farm while an equivalent Permanent magnet Synchronous Generator is used to operate the marine current farm. The PMSG is used to guide for an equivalent marine current turbine and the DFIG is The VSC-HVDC controller plays an important role here. A frequency-domain approach based on a linearized system model using Eigen value techniques and a time-domain scheme based on a nonlinear system model subject to various disturbances are both employed to simulate the effectiveness of the proposed control scheme. In this paper we also implement the concept of artificial neural network, applied to the control strategy of VSC-HVDC controller.*

I. INTRODUCTION

During the last decades, Wind Energy Conversion System (WECS) has grown dramatically. Variable-speed wind Turbines (VSWTs) attract considerable interest around the world, which is one of the solutions with the highest potential to reduce wind energy cost. The VSWT systems are usually based on doubly fed induction generators (DFIGs) or permanent magnet synchronous generators (PMSGs). Basically wind farm consists of many wind turbines that are connected with each other to produce small amount of electrical power that becomes powerful after connecting with the transformer. Areas that consists of the number of wind turbines for the sake of power generation from wind and are connected with each other in the different way is called wind farm. Basically wind farm consists of many wind turbines that are connected with each other to produce small amount of electric power. Different strategies are used to build the wind farms in different locations or area. Since oceans cover more than 70% surface of the earth, a hybrid power generation system containing both offshore wind farm (OWF) can be extensively developed at the specific locations of the world in the future. One of the simple methods of running an OWF is to connect the output terminals of several DFIGs together and then connect to a power grid through an offshore step-up transformer and undersea cables. To run an OWF may use several Permanent Magnets synchronous generators (PMSGs) connected directly to the power grid through an offshore step-up transformer and undersea cables. This paper is organized as below. The configuration and the employed models for the studied integrated OWF with VSC-HVDC are introduced first [1]. Then, the design procedure and design results for the PID damping controller of the proposed VSC-HVDC using pole-placement technique are depicted. Both steady-state operation points under various wind speeds and marine-current speeds and the comparative dynamic responses of the studied system with the designed PID damping controller under different operating conditions can be elaborately done here.

1. OFF SHORE WIND TURBINE:

1.1 Wind Energy System:

The generation of electrical power is obtained mainly in two ways i.e one is conventional source and other is non- conventional energy sources. The generation of electricity using non-renewable resources such as coal, natural gas, oil and so on, shows great impact on the environment by production of pollution from their general gases. Hence, by considering all these conditions the generation of electricity is obtained from the renewable energy sources.

Basically, out of all renewable energy sources the wind turbine plays an important role for generating electricity. And also from economical point of view the wind turbine has low maintainece cost because it needs no fuel so that it is pollution free. Mostly, in present world 50-60 percent of energy is generated from wind turbine as compared with all other renewable energy sources.

The typical layout of wind power generation as shown below.

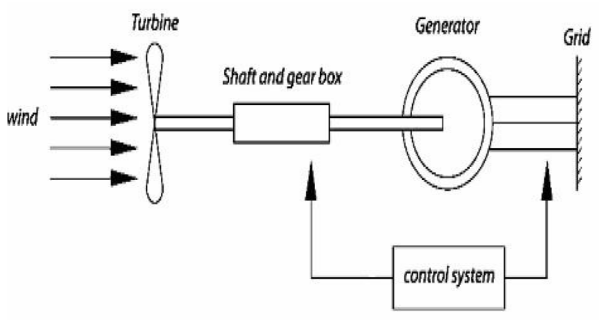

Fig.2 basic schematic diagram of wind turbine

The mechanical power (in W) produced by a WT can be expressed by

$$P_{\mathrm{mw}} = \frac{1}{2}\rho_w \cdot A_{\mathrm{rw}} \cdot V_W^3 \cdot C_{\mathrm{pw}}(\lambda_w, \beta_w)$$

Where ρ is the air density in kg/m, Arw is the blade impact area in m2, Vw is the wind speed in m/s, and Cp is the power coefficient of the WT.

2. DOUBLY FED INDUCTION GENERATOR:

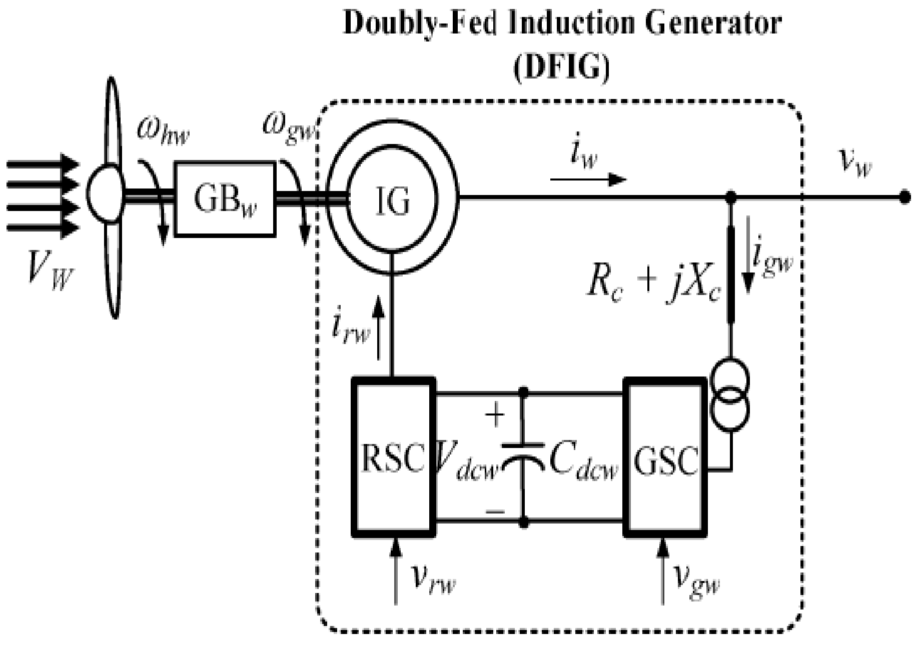

Fig 3: Schematic Diagram for DFIG

Fig. 4 shows the one-line diagram of the studied wind DFIG. DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly, but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine. Figure 4 indicates the doubly fed induction generator model. DFIG is of great advantage, and is widely used in large capacity wind turbines in recent years.

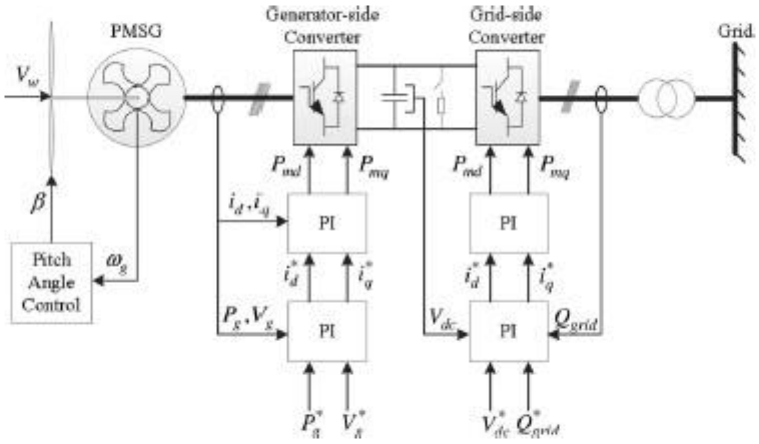

Fig 4: Modelling of DFIG based MCF

Because the rotor speed is proportional to the frequency of excitation, synchronous motors can be used in situations where constant speed drive is required. Since the reactive power generated by a synchronous machine can be adjusted by controlling the magnitude of the rotor field current, unloaded synchronous machines are also often installed in power systems solely for power factor correction. The armature winding of a conventional synchronous machine is almost invariably on the stator and is usually a three phase winding.

Detailed modelling of PM motor drive system is required for proper simulation of the system. The d-q model has been developed on rotor reference frame shown in Figure 5. At any time t, the rotating rotor d-axis makes and angle with the fixed stator phase axis and rotating stator mmf makes an angle ± with the rotor d-axis [13]. Stator mmf rotates at the same speed as that of the rotor.

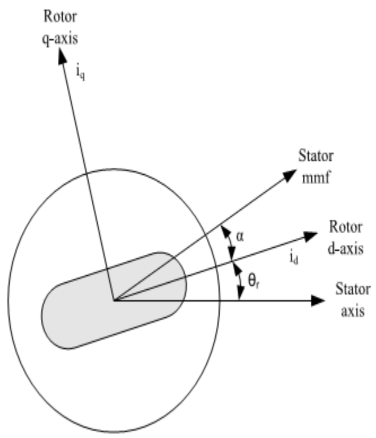

Fig 5: d-q model for the rotor reference frame

The mathematical modelling is obtained by considering the KVL equations for figure 2.

$$V_a = i_a r_a + L\frac{di_a}{dt} + e_a$$

$$V_b = i_b r_b + L\frac{di_b}{dt} + e_b$$

$$V_c = i_c r_c + L\frac{di_c}{dt} + e_c$$

For solving these equations, in this paper we used a concept of line to line parks transformation technique.

These parks transformation converts the three phase voltages to two phase coordinators and is expressed as,

$$\begin{bmatrix} Vab \\ Vca \end{bmatrix} = \begin{bmatrix} \frac{1}{3} & -\frac{1}{3} \\ \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

The matrix coordinators obtained from the above line to line parks transformation are transformed to orthogonal matrix coordinators (α, β).

Similarly, same like as voltage, the three phase currents also transformed to two phase orthogonal matrix. These two phase currents (I_α, I_β) and voltage (V_α, V_β) are used for calculating the flux linkages (ψ_α, ψ_β) from the expression described as,

$$\psi_\alpha = \frac{1}{L_\alpha}(V_\alpha - i_\alpha r_a)$$

$$\psi_\beta = \frac{1}{L_\beta}(V_\beta - i_\beta r_a)$$

And from this equation the phase angle is calculated as,

$$\psi = \psi_\alpha + j\psi_\beta$$

$$\theta = \tan^{-1}(\psi_\beta / \psi_\alpha)$$

The measured values of direct axis and quadrature axis currents are obtained by the following matrix,

$$\begin{bmatrix} i_d \\ i \end{bmatrix} = \frac{2}{3} \begin{bmatrix} -\sin(\theta - 30) & \sin(\theta + 30) \\ \cos(\theta + 30) & -\cos(\theta - 30) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

These obtained measured are compared with reference direct and quadrature axis currents for obtaining error tolerance. The reference current signals are obtained by the electromagnetic torque. From the definition of newton's law of motion, the total applied torque is equal to sum of all individual torques across each element.

$$T_e = T_m + J\frac{dw_m}{dt} + Bw_m$$

The electromagnetic torque produced by a brushless dc motor can be expressed as

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{w_m}$$

Assuming the windings of the three phases are symmetrical, the magnitudes of back emfs and currents should be equal for three phases. From the above two equations, the electromagnetic torque can be developed by a BLDC motor at any instant is

$$T_e = \frac{2e_p i_p}{w_m}$$

Where e_p is called phase back emf and i_p is a non-zero phase current.

3. VSC-HVDC CONTROLLER:

The VSC-HVDC is connected to the power system at a PCC (point of common coupling), through a step-up coupling transformer, where the voltage-quality problem is a concern. The PCC is also known as the terminal for which the terminal voltage is UT. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals (firing angle) to drive the main semiconductor switches of the power converter accordingly to either increase the voltage or to decrease it accordingly.

A VSC-HVDC is a controlled reactive-power source. It provides voltage support by generating or absorbing reactive power at the point of common coupling without the need of large external reactors or capacitor banks. Using the controller, the VSC and the coupling transformer, the VSC-HVDC operation is illustrated in Figure 6:

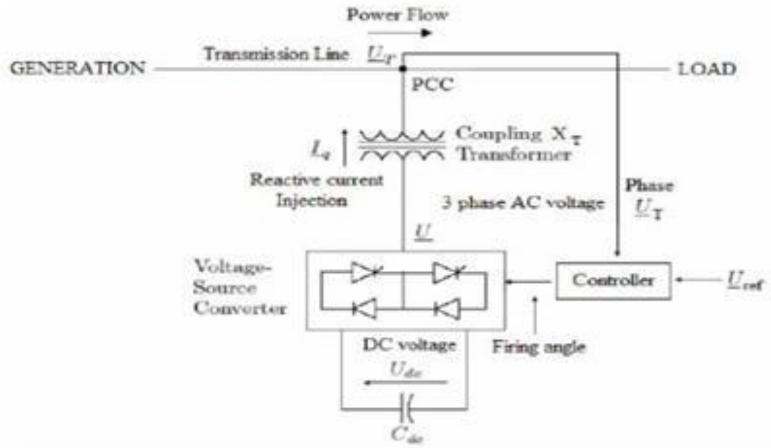

Fig 6: VSC-HVDC Controller

II. SIMULATION DIAGRAM

The power system presented in Figure 1 has been used for this study. It consists of three conventional power plants: one medium fast hydropower plant, one fast gas turbine, and one coal-fired power plant. The three plants are connected on the 230-kV level via a closed ring with overhead lines. Load A, B, and C are aggregated static loads and Load D is composed of induction motors.

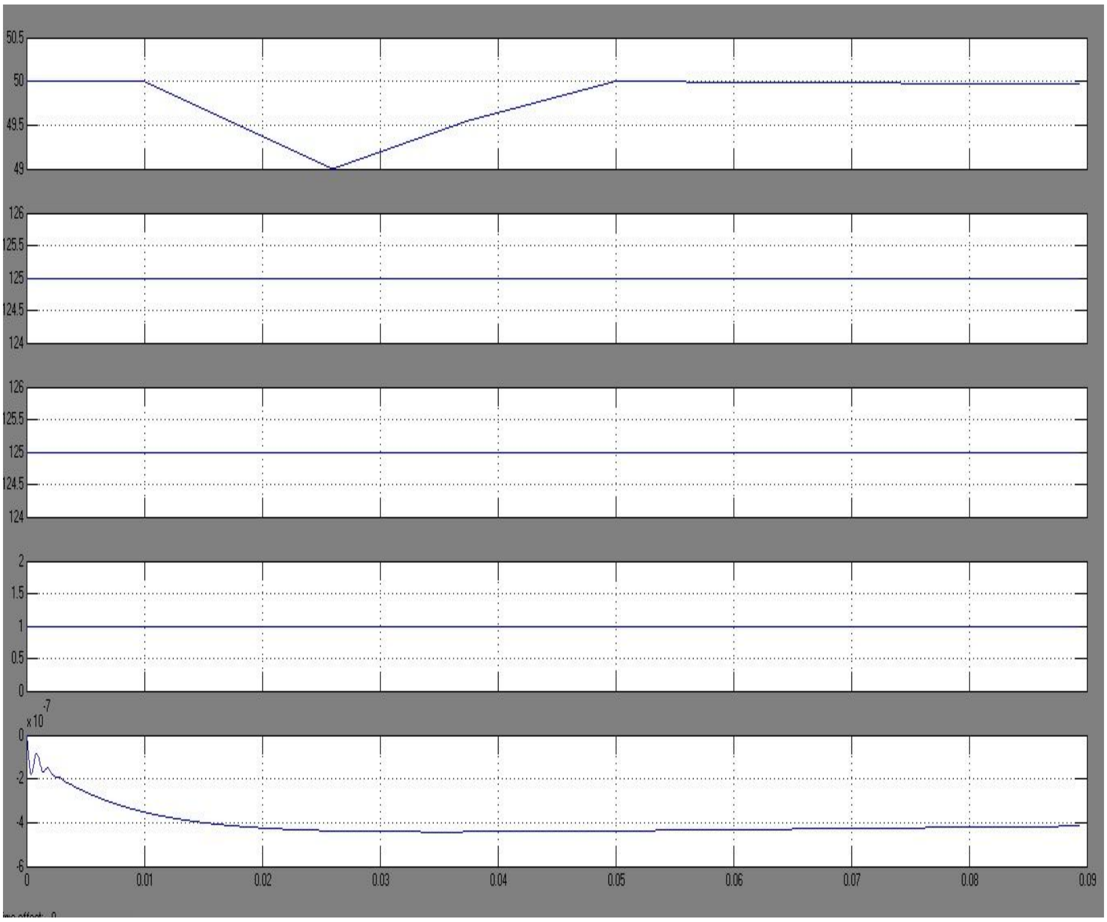

Figure 7: Simulation Result for (a) System Frequency, (b) Active Power, (c) Dc-link Voltage, (d) VSC active Power under normal frequency.

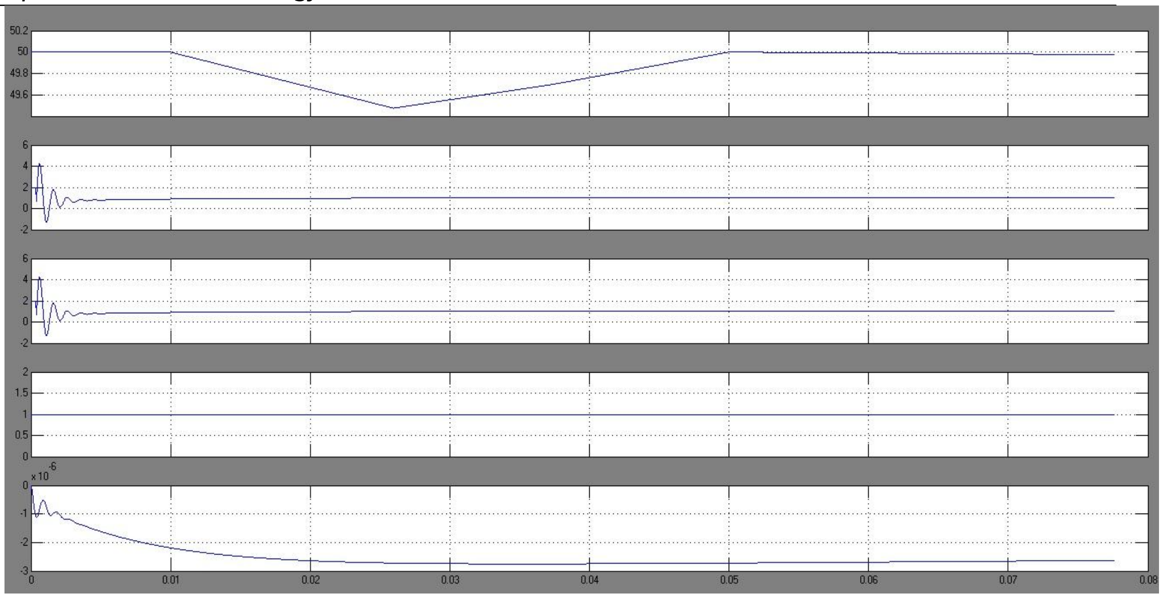

Figure 8: Simulation Result for (a) System Frequency, (b) Active Power, (c) Dc-link Voltage, (d) VSC active Power under sudden decreasing of frequency.

III. CONCLUSION

The implementation of the proposed control strategy is deliberately coupled with the frequency control of the FCWTs of the offshore wind farm, which is integrated into the onshore power grid by the VSC-HVdc. Through simulations and analysis, it is shown that the proposed control strategy allows the VSC-HVdc to provide effective inertial response without any extra investment. The coordination of the frequency control of the VSC-HVdc and wind turbines obtains a significantly enhanced frequency response for the studied power system. The collective frequency support capability is comparable to that of conventional power plants.

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