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Improved Transient Management Scheme in UHVDC Based Offshore Wind Power Plant

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Abstract: In this paper PI controller based improved transient management between offshore wind power plant and onshore high voltage direct current transient system has been discussed. The proposed configuration has both series and shunt compensation named as unified VSC-HVDC simply called as UHVDC. This configuration utilizes variable frequency extraction for SRF control scheme to enhance the transient management and fault clearance capability. The entire system is designed in such a way to minimize transient and serious grid fault. The test system is modelled using MATLAB/SIMULINK platform.
***Keywords*: Transient management, PI controller, HVDC, wind power plant, and DC link voltage.**

I. INTRODUCTION

In recent era, energy demand is the crucial problem in worldwide. To compensate the increased energy demand, integration of renewable energy sources with grid system is one of the contemporary solution. Wind energy conversion (WEC) system is the promising renewable energy source which has the capability to satisfy energy demand [1]. Wind energy conversion system comprises of wind power plant (WPP) and power converter units to generate and transfer electrical power. The configuration of WPP contains permanent magnet synchronous generator (PMSG) [2]. Wind power plant is configured with grid using voltage source converter connected back to back.

The configured wind power plant is integrated with grid through high voltage direct current (HVDC) transmission system. HVDC system ensures cost efficient and increases system reliability [3]. Hence the generated electrical power is transmitted over long distance through HVDC transmission system. Some of the merits of HVDC transmission such as, bulk power transmission, asynchronous interconnection, independent control of active and reactive power flow and hence increased system efficiency [4].

The important constraint to be considered during bulk power transmission is grid fault and other grid related disturbances. It is a challenging task to maintain the system stability under fault/disturbance conditions. To enable system stability by performing fast fault clearance voltage source converter based HVDC (VSC-HVDC) is incorporated in recent power transmission system [5]. It is noted that, large WPP and VSC-HVDC system should contain the capacity to handle fault ride through capability. The modern transmission system utilizes unified VSC-HVDC (UHVDC) to provide compensation against series and shunt distortions, line communication interference problem. The unified VSC station contains IGBT switches which provides higher efficiency and force commutation [6].

The enhanced fault clearance is achieved by implementing appropriate control technique and hence fast response is attained without any deviation in power transfer of entire system [7]. This paper comprises of synchronous reference frame (SRF) technique for series and shunt compensators separately. The proposed configuration delivers better transient management, symmetrical and asymmetrical fault clearance, optimal dc link voltage control, smooth power transfer and improved system reliability. The whole system is modelled and simulation analysis has been done using MATLAB/SIMULINK environment.

II. SYSTEM CONFIGURATION

The PMSG based several wind turbines are configured in series and shunt to form wind power plant (WPP) [3]. To transfer the produced electric power from WPP to grid HVDC with power converters is employed. The modern power electronic utilizes voltage source converter (VSC) for interconnection of network [8]. The VSC-HVDC system overcomes limitation identified in traditional transmission system like large size, requires thyristor valves. It contains a compact IGBT/GTO semiconductor switches and it is based on self- commutation PWM technology. Mostly IGBT is used because it can operate under higher frequency. The conventional CSC-HVDC system employs reactive power support but the proposed IGBT based VSC-HVDC operates without any requirement of reactive power supply [9]. Hence it provides independent control of active and reactive power flow. This makes the proposed system suitable for changing power flow direction under dc link voltage is maintained in the network. VSC-HVDC system can be configured as monopole, bipole, back to back, asymmetric and multi-terminal [5], [10]. Here multi terminal VSC-HVDC system has been presented.

In this paper, unified VSC-HVDC (UHVDC) configuration of both series and shunt compensation has been presented. The Fig.1 shows the power circuit of proposed UHVDC for wind energy conversion system. WPP contains onshore and offshore

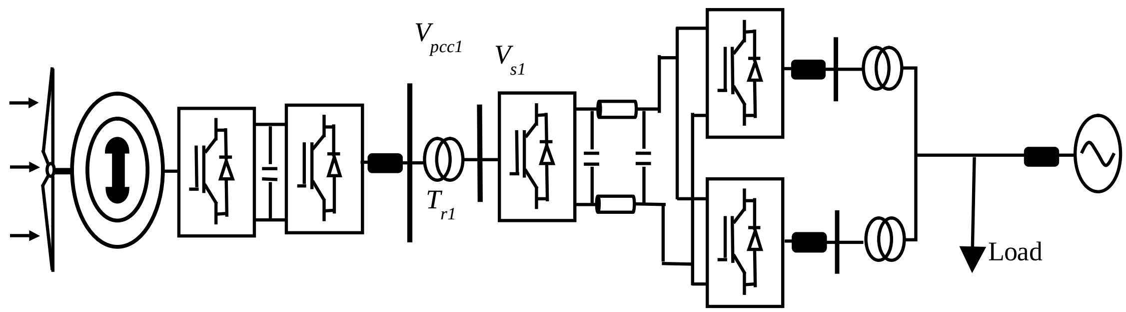

Fig.1. Configuration of UHVDC connected to offshore WPP and onshore grid

VSC station. Each station has independent converter units. Offshore station has one converter unit and onshore station has two converter units. The onshore converter station is named as series and shunt converters. Two shunt connected transformer is placed between onshore station and electrical grid referred as T_{r3} and T_{rn} [11]. This shunt connected step-up transformer enables power flow from WPP to the utility grid system through HVDC transmission system. Hence this transformer and converter units should have the capability to handle the bulk power generated by WPP. The central point where HVDC and utility grid is interconnected is termed as point of common coupling (PCC). The ultimate merits of proposed configuration is, no need of additional compensation devices and thus UHVDC system can perform compensation against series and shunt disturbances and other grid fault. Hence the proposed structure is more affordable than conventional configuration.

When severe grid fault occurs in one of the voltage source, series transformer injects series voltage to prevent entire system [12]. That is if fault occurs in V_{s2}, the transformer delivers series voltage (V_{ser}) at V_{s3} side to inhibit UHVDC from any kind of grid disturbances. If fault occurs in V_{s3} side, V_{ser} is injected at V_{s2} side. The proper control of converter circuit ensures successful switch over from one operation to another under steady state and transient conditions [13]. The next section discusses about mathematical modelling of converter stations.

III. CONTROL SCHEME OF ONSHORE AND OFFSHORE WIND POWER PLANT SYSTEM

The enhanced compensation capability is achieved by implementing appropriate control technique. Separate control scheme is adopted for each converter units of onshore and offshore UHVDC system. It is important to identify suitable control strategy by conducting more literature reviews. Among the variety of control strategy synchronous reference frame control technique has been covered in this paper because of its undesirable characteristics such as suitable for distorted/unbalanced grid conditions, no requirement of complicated algorithms [14]. The control technique is divided into two major category as control strategy for series compensator and shunt compensator. The offshore VSC station delivers power generated from WPP to the electrical grid and thereby regulates the grid voltage. Onshore VSC station performs DC link voltage regulation at PCC.

A. Control Scheme for Shunt Compensator

Both onshore and offshore system has shunt compensation and the control scheme for shunt compensator is shown in Fig.2. Here the control scheme has four stage of operation that is, negative sequence component extraction, positive sequence component extraction, transient detection and management scheme and final part is pulse generation for inverter.

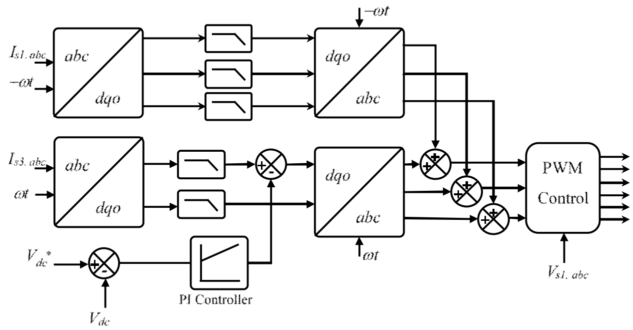

Fig.2. Control Scheme for onshore and offshore shunt UHVDC system

PI controller with SRF technique produces better accurate result by tuning PI parameters such as Kp and Ki. PI controller delivers fundamental current by make a comparison of actual and reference dc link voltage [15]. The resultant error signal is given as,

$$e(t) = V_{dc,ref} - V_{dc} \qquad (1)$$

Where, e(t) be the error, Vdc and Vdc ref be the actual and reference dc link voltage respectively. This error signal is given to control technique part to produce reference source current.

The transformation from three phase distorted source current to two phase rotating dq frame is given as,

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{s0} \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \qquad (2)$$

This is given to low pass filter to block higher harmonics contents. The fundamental current from PI controller output is subtracted with this d-axis current and the resultant signal is again transformed to three phase reference source current signal as,

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta & \frac{1}{2} \\ \sin(\theta - \frac{2\pi}{3}) & \cos(\theta - \frac{2\pi}{3}) & \frac{1}{2} \\ \sin(\theta + \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{s0} \end{bmatrix} \qquad (3)$$

B. Control Scheme for Series Compensator

The onshore WPP has series converter to compensate series grid voltage fault and transient management scheme. Fig 3 shows block diagram for control scheme of series converter. If any fault occurs at any one of the voltage source, this series converter acts very fast and supply series voltage V_{ser} at the other side to protect the system from severe damage.

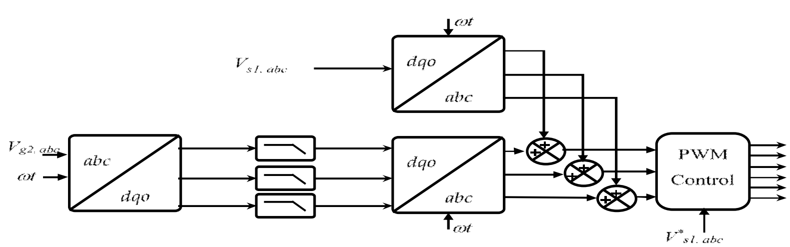

Fig.3. Control Scheme for series VSC of offshore WPP based UHVDC system

The injected series voltage is given by,

$$V_{ser}\angle\rho = V_{s3}\angle\delta - V_{s2,F}\angle\delta' \tag{4}$$

The total power delivered at series UHVDC system is given by the equation (9).

$$P_{tot,ser} = P_{ser} + P_{\cos}\cos(2\omega t) + P_{\sin}\sin(2\omega t) \tag{5}$$

The total power includes sine, cosine and series average power. The final part is, obtained series voltage is delivered to firing pulse generation scheme to produce switching pulses for inverters. The next section discusses about frequency estimation using PI control scheme.

C. Frequency Estimation by PI Control

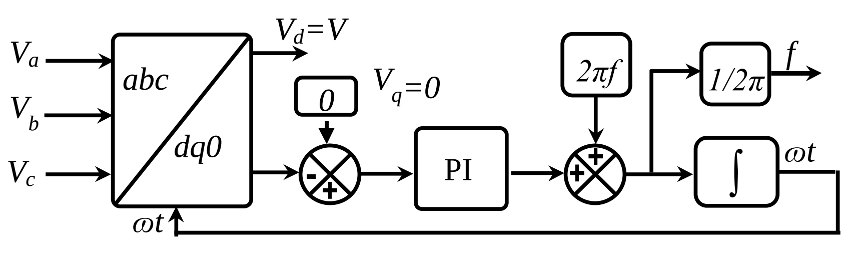

Fig.4. Block diagram of variable frequency technique using PI controller

This section discusses estimation of frequency using PI control for SRF control scheme. The SRF control scheme requires supply frequency for its operation. This frequency has been estimated using PI control block and the diagram for this process is shown in Fig4. Here the three phase grid voltage is converted into two phase d-q component to estimate quadrature component grid voltage. The actual q-axis voltage is compared with its reference value and the resultant error signal is given to PI control unit. The obtained output is summed with constant frequency value and then given to integrator part to deliver required frequency for SRF control technique [16].

IV. SIMULATION RESULTS AND DISCUSSION

In this section, the enhancement of compensation capability of proposed SRF control scheme has been elaborately discussed. The proposed test system is designed to compensate high transient, series grid fault and analysis has been made under normal and faulted condition. The proposed system is designed in such a way to give fast response and enhanced compensation to reduce overshoot. The voltage rating of the network is 230KV and the rating of HVDC is 250KVA which is equivalent to the offshore WPP. Parameter taken for simulation is given in table 2.

The compensation capacity of UHVDC system has been determined by the optimal control of dc link voltage at its rated voltage. Here dc link voltage is controlled at 400KV using PI controller. The tracking of estimated frequency using PI control with supply frequency is shown in Fig. 5 and 6 respectively. In this case study, the different operating conditions are conventional frequency and variable frequency estimated by PI control under low and high frequency transient conditions. The performance of PI controllers under low and higher frequency transient are analyzed and compared in table 1. This demonstration confirmed that the better minimization transients and better control of DC link voltage is achieved by the proposed PI controller.

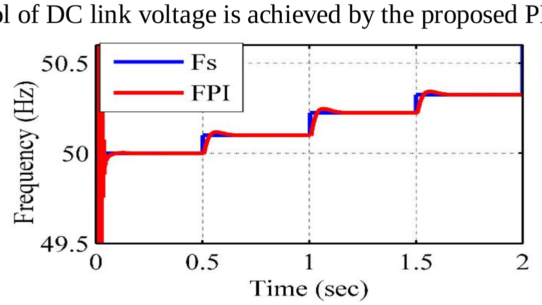

Fig.5. High frequency transient estimation using conventional and PI control

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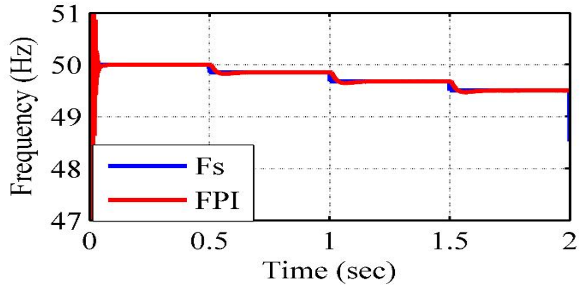

Fig. 6. Low frequency transient detection using PI controller

Simulation analyses on d-axis positive sequence voltage for low and high frequency transient using conventional SRF and proposed variable frequency SRF technique is shown in Fig 7. In Fig 7, simulation result of pu value of positive sequence grid 1 and grid 2 voltage and injected series voltage under low and high transient condition has been plotted. From the plot, it is observed that, peak overshoot present in conventional system has been reduced by proposed PI control technique. Under conventional system more peak overshoot and higher oscillation is identified. While using PI controller grid voltage and series injected voltage are successfully controlled with minimum oscillation and hence achieved optimally.

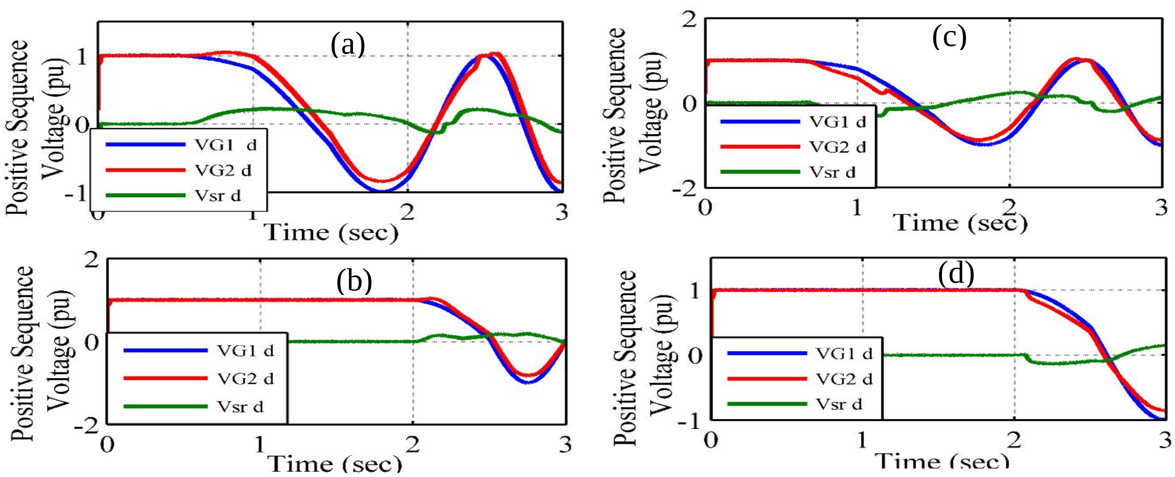

Fig. 7.d-axis Positive sequence voltage for low frequency transient - (a) Conventional, (b) Variable frequency, for high frequency transient - (c) Conventional, (d) Variable frequency

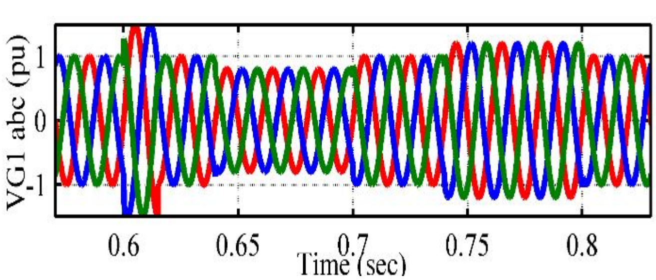

Fig. 8.a Three phase grid 1 voltage

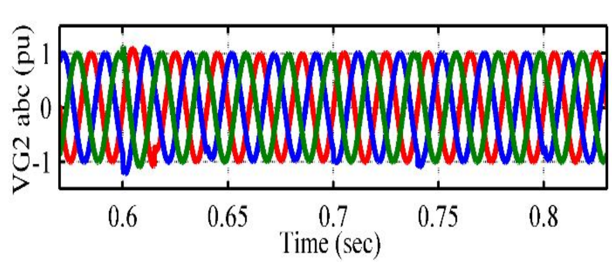

Fig. 8.b Three phase grid 2 voltage

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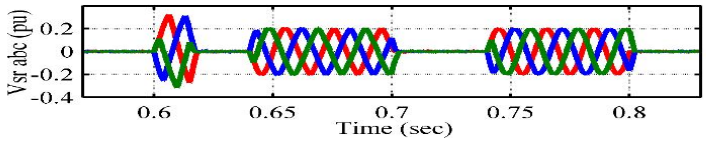

Fig. 8.c Three phase compensation voltage

The simulation results of regulation of positive sequence voltage V_{G1}, V_{G2} and V_{sr} in d axis using PI controller has been successfully achieved. The main objective of the proposed configuration is to maintain rate voltage 230KV at PCC. Under normal operating conditions, V_{G1} and V_{G2} are in equal and Vsr is found to be zero. For under voltage condition, required voltage is injected by series VSI and thereby rated voltage is maintained at point of common coupling. For over voltage condition, required voltage is absorbed by series VSI and thereby rated voltage is maintained. While using conventional system, transient detection is found to be poor and it requires more time to compensate whereas using PI controller, transient detection is found to be optimum and it has fast compensation time. The simulation results for three phase voltage of grid 1, grid 2 and series voltage or compensation voltage are shown in Fig. 8.a, Fig. 8.b and Fig. 8.c. Under normal condition, rated voltage is maintained whereas under faulted condition the require voltage is injected by series VSI so that it maintains rated voltage at grid 2.

TABLE I

ANALYSIS ON COMPENSATION FOR LOW AND HIGH FREQUENCY TRANSIENT

Power Frequency (Hz)		Estimated Frequency (Hz)		DC Link Voltage (pu)	
Low	High	Low	High	Low	High
50	50	50.15	50.15	0.995	0.997
49.85	50.1	49.74	50.08	1.01	1.02
49.68	50.23	49.61	50.21	1	1.02
49.5	50.33	49.45	50.35	1.03	1.03
48.53	51.3	49.1	50.9	1.05	1.04
47.98	51.65	49.3	50.98	1.06	1.05

TABLE III

SYSTEM PARAMETERS

Electric Grids		Offshore Station	
Frequency	50Hz	Rated Power	250MVA
Grid voltage	230KV	WPP Voltage	33KV
X/R	20	Transformer Ratio	33KV/230KV
Short circuit ratio	30	Leakage Reactance	0.11pu
Leakage Reactance	0.11pu	AC Filter L1	40mf
Transmission Line Impedance	0.2pu	AC Filter C1	100uf
Onshore Station			
Series Compensator		Shunt Compensator	
Rated Power	125MVa	Rated Power	125MVa
Transformer rating	200MVA	Transformer rating	200MVA
Transformer Leakage reactance	0.06pu	Transformer Leakage reactance	0.11pu
AC Filter 2 Series L2s	20mh	AC Filter 2 Series L2s	45mh
AC Filter 2 Series C2s	100uF	AC Filter 2 Series C2s	150uF
DC Link			
DC Link Voltage		400KV	
DC Capacitance		1600uF	
DC cable resistance		0.004ohms/km	
DC cable capacitances		11.3uF/km	

V. CONCLUSIONS

The transient management and smooth power transfer between offshore WPP and onshore grid through UHVDC system using PI-SRF control technique has been proposed in this paper. The variable frequency for SRF control technique is extracted using PI control variable frequency method. The proposed system ensures reduction in peak overshoot and higher transient under grid fault and distorted conditions. The entire system is investigated under low frequency and high frequency transient conditions and the simulation analysis has been done elaborately. From the investigations, it is observed that proposed configuration has better compensation capability to reduce transients and ensures better power transfer between WPP and onshore grid.

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