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Advanced Control of Unified HVDC for Onshore and Offshore Wind Power Plant

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ABSTRACT

This paper proposes control of unified high voltage direct current transmission (HVDC) system for offshore wind power plant to improve transient management scheme. The modern HVDC transmission system overcome drawbacks of conventional AC transmission network and thus HVDC is preferred in between offshore WPP and onshore grid. The configuration of this HVDC system comprises of both series and shunt compensator named as unified HVDC (UHVDC). This ensures smooth power transfer, DC link voltage regulation and fast fault clearance during transient conditions. Optimal control of Unified HVDC is realized by synchronous reference frame technique (SRF). Entire system is designed and simulated using Matlab/Simulink platform and the obtained results are analyzed.

Keywords : Wind Power Plant, Unified HVDC, Synchronous Reference Frame Technique, Transient Compensation

I. INTRODUCTION

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). Wind power plant is configured with grid using voltage source converter connected back to back.

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. 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 [2].

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 [3]. 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.

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 [4]. The whole system is modelled and simulation analysis has been done using MATLAB/SIMULINK environment. 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.

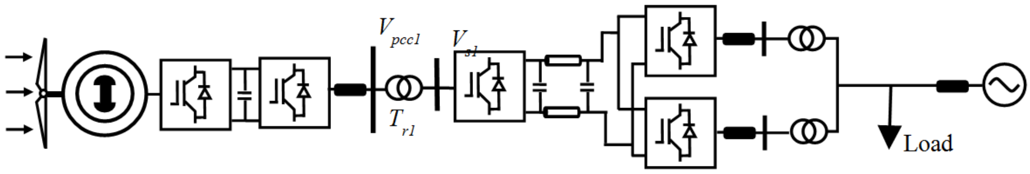

Fig 1. Configuration of UHVDC connected to offshore WPP and onshore grid

II. SYSTEM UNDER STUDY

The generated electrical power from WPP is transmitted to grid through existing HVDC transmission system. It requires modern semiconductor switches to assure fast fault clearance and hence attains enhancement in compensation. The modern power converter switches maybe either IGBT/GTO. Generally, IGBT is chosen to overcome the drawbacks of conventional thyristor valve based converters. IGBT has the ability to turn ON/OFF with higher frequency than GTO and it can operate under self-commutation based PWM technology [5]. Fig.1. shows proposed configuration of offshore and onshore WPP using UHVDC. The 'n' number of wind turbines are configured together to form wind power plant. The connection maybe either series or parallel depends upon the ratings of system. Now-a-days, permanent magnet synchronous generator (PMSG) based WPP turbines are preferred mostly due to its higher efficiency and operates without gearbox.

This transformer ensures flexible power transfer between WPP and grid system. Hence it is important to validate the ratings of converter units and shunt connected transformers in order to withstand maximum power transfer through it. In figure, bus coupler (BC) is used to deliver power to grid and B9 is the integration point of UHVDC with grid which is named as point of common coupling (PCC).

That is, if fault occurred in V_{s2}, the transformer injects V_{ser} voltage at V_{s3} side and wise versa. Simultaneously, voltage and current distortions occurred in system can be compensated by series and shunt onshore VSC station. In this research work multi-terminal UHVDC configuration has been proposed to ensure both series and shunt compensation. This configuration encloses onshore and offshore WPP and independent converter units. Offshore station holds one converter unit and onshore station accommodate two converter units such as series and shunt converters. To integrate onshore station with grid, two parallel connected transformers (T_{r3} and T_{rn}) are required. The converter units operate under steady state and transient conditions are optimized by implementing adaptive control technique [6].

III. CONTROL SCHEME

The major part of this research work is to identify and design an optimal control technique to enhance the compensation capability and transient management schemes. Among the variety of conventional control schemes, synchronous reference frame (SRF) method is proposed in this research work because of its undesirable characteristics such as suitable for distorted/unbalanced grid conditions, no need of complicated algorithms. When severe grid fault occurs in any one of the voltage source, series transformer operates immediately and delivers series voltage at other side to protect entire system from fault. Compensation capability of existing SRF and proposed SRF has been validated using simulation software. The control scheme of UHVDC is divided into two parts such as shunt compensator and series compensator. The onshore VSC is used to regulate dc link voltage at PCC. The offshore VSC is used to deliver the power generated from WPP and thereby control the grid voltage [7]. Onshore VSC station performs dc link voltage regulation at PCC.

A. Control Structure of Shunt Compensator

The diagram of onshore and offshore shunt compensator control scheme is shown in Fig. 3. This control scheme has four major parts such as, estimation of negative sequence component, positive sequence component extraction, transient detection and management scheme using controllers and inverter pulse generation. Phase locked loop (PLL) produces angle ωt which is used to estimate positive and negative sequence component (*dq*) of the shunt compensator.

$$\mathrm{I_L}(t) = \sum_{n-1}^{\infty} I_n \sin(\omega t + \phi_n)$$

$$= I_1 \sin(n\omega t + \phi_1) + \sum_{n-2}^{\infty} I_n \sin(\omega t + \phi_n) \quad (1)$$

The shunt compensator involves compensation against distorted source current. To achieve this, distorted three phase source current (*abc*) must be transformed into two pahse (*dq0*) components and thereby positive and negative sequence components is estimated. The transient detection and control part is done by PI controller. The reference and actual dc link voltage is the input for PI controller. The comparison of these voltage results an error signal and is applied to PI controller to regulate the transient present in the system. The output of PI controller is given to positive sequence computation unit. After the estimation of positive and negative sequence component, again a transformation is done from *dq0* to *abc*. The obtained three phase current is the reference source current and is given to pulse generation unit to produce switching pulses for shunt VSC [8]. The general equation for three phase current in stationary axis (*abc*) is transformed into two phase rotating co- ordinates (*dq0*) is given below,

$$P_L(t) = P_f(t) + P_r(t) + P_h(t) \quad (2)$$

$$P_f(t) = V_{sm} I_1 \, Sin\, 2\omega t * Cos\, \Phi_1 = V_s(t) * I_s(t) \quad (3)$$

Finally, the desired reference source current is calculated by taking inverse transformation of (*dq0*) axis into three phase (*abc*) rotating frame axis. The obtained reference source current is compared with actual source current and the resultant error signal is given to hysteresis block. The function of hysteresis block is to compare this error signal with higher and lower band level of current signal and hence generates switching signal.

B. Control Structure of Series Compensator

The equation for series voltage with phase angle is given below,

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

From the above equation, the positive sequence component of voltage magnitude and phase angle can be separated as,

$$|V_{ser}| = \sqrt{(V_{s3}\cos\delta - V_{s2,F}\cos\delta')^2 + (V_{s3}\sin\delta - V_{s2,F}\sin\delta')^2} \quad (5)$$

$$\rho = \tan^{-1}\left(\frac{V_{s3}\sin\delta - V_{s2,F}\sin\delta'}{V_{s3}\cos\delta - V_{s2,F}\cos\delta'} \right) \tag{6}$$

From the above expressions, the reference positive sequence voltage is determined by the pre fault grid voltage and measured grid voltage and is named as $V^{+}_{ser.dq,ref}$. When a fault is created at V_{s2} side, the compensation is done at shunt side V_{s3}. The total power delivered at series UHVDC system is given by,

$$P_{tot,ser} = P_{ser} + P_{\cos}\cos(2\omega t) + P_{\sin}\sin(2\omega t) \tag{7}$$

The total active power $P_{tot,\ ser}$ is divided into three parts, series average power, cosine power and sine power and this power can be derived as given below, Fig. 4 shows diagram of series compensator control scheme. The series converter produces compensation signal against voltage imperfections, higher transient and severe grid fault. When the fault is created at any one of the voltage source (V_{g1} or V_{g2}) the power transfer within the system is gets affected. To protect the WPP turbines based UHVDC system from fault disturbances and severe transient, a series converter provides series voltage V_{ser}. This voltage is injected into the system at PCC through series transformer [9].

$$\begin{bmatrix} P_{ser} \\ P_{\cos} \\ P_{\sin} \end{bmatrix} = \begin{pmatrix} I^{+}_{ser.d} & I^{+}_{ser.q} & I^{-}_{ser.q} \\ I^{-}_{ser.d} & I^{-}_{ser.q} & I^{+}_{ser.q} \\ I^{-}_{ser.q} & -I^{-}_{ser.d} & I^{+}_{ser.d} \end{pmatrix} \begin{bmatrix} V^{+}_{ser.d} \\ V^{+}_{ser.q} \\ V^{-}_{ser.d} \\ V^{-}_{ser.q} \end{bmatrix} \tag{8}$$

From the above expression, $V_{ser,\ dq}$ and $I_{ser,\ dq}$ is the series voltage and current *dq* component. The sine and cosine terms of power is cancelled and equated to zero by the generation of reference negative sequence component of series voltage $V_{ser\text{-}dq,\ ref}$. Finally, the three phase voltages are given to pulse generation block to generate firing pulses for series VSC system [10].

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.

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 proposed controller. The simulation waveform during low frequency and high frequency transient is shown in Fig.4. In this case study, the different operating conditions are conventional frequency and variable frequency estimated by proposed SRF control under low and high frequency transient conditions. This demonstration confirmed that the better minimization transients and better control of DC link voltage is achieved by the proposed SRF controller based UHVDC system.

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 5 and Fig. 6. From the plot, it is observed that, peak overshoot present in conventional system has been reduced by proposed SRF control technique.

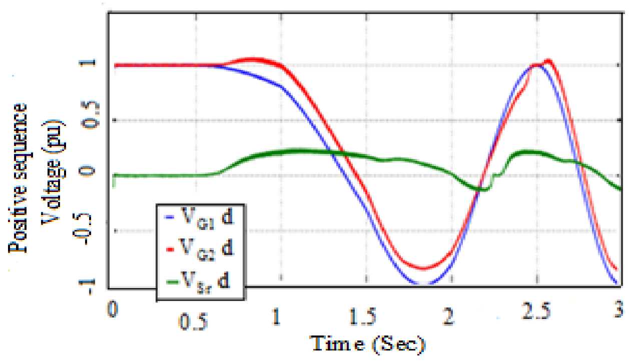

Fig 2. d- axis positive sequence voltage during low frequency transient

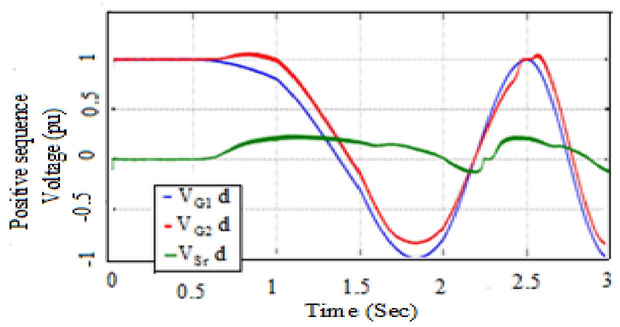

Fig 3. d- axis positive sequence voltage during high frequency transient

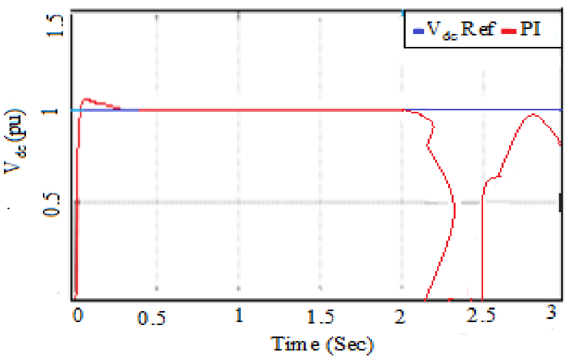

Fig .4. DC link Voltage control using PI controller, at low frequency transient

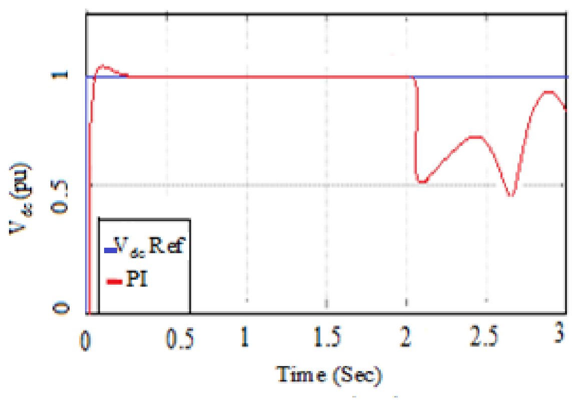

Fig.5. DC link Voltage control using PI controller, at high frequency transient

This section investigates on power transfer between offshore WPP and onshore power grid. The source power i.e., grid 1 real power (P_s), load power i.e., grid 2 real power (P_L), series compensator real power (P_{sr}) and shunt compensator real power (P_{sh}).

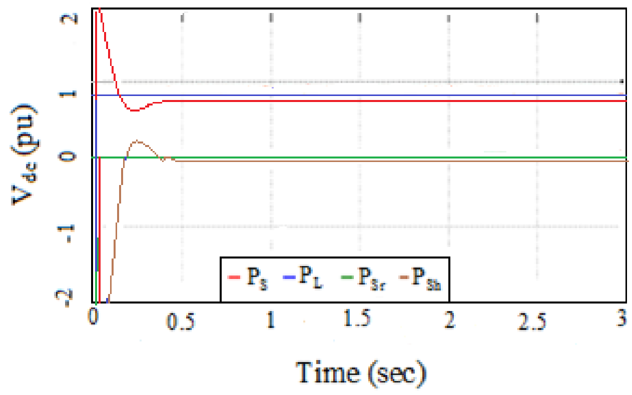

Fig.6. Power flow for low frequency transient using NN controller

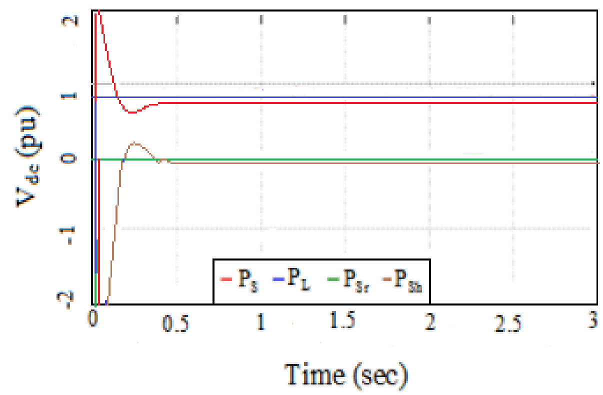

Fig.7. Power flow for high frequency transient using NN controller

The simulation responses for real power transfer under low and high frequency transients using constant frequency SRF is shown in Fig. 7 and Fig.8 using proposed SRF configuration. Optimum transfer of power determined by maintaining of positive sequence. SRF has better maintaining positive sequence voltage and hence successful real power transfer within the system is achieved. This benefit resulted in optimal transfer of real power.

V. CONCLUSIONS

The proposed configuration assures smooth power transfer and fast response during grid fault and transient conditions. The entire system is investigated under low frequency and high frequency transient conditions and the simulation analysis has been done elaborately From the overall results, it is observed that synchronous reference frame control scheme based unified HVDC transmission provides optimal DC link voltage regulation and thus it has better compensation capability to reduce transients and ensures better power transfer between WPP and onshore grid.

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