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Improved Transient Compensation Using PI-SRF Control Scheme Based UHVDC For Offshore Wind Power Plant

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Abstract - *In this paper PI controller based UHVDC for offshore wind power plant is presented to compensate transient. To achieve fast power transfer and transient management scheme, high voltage direct current transmission (HVDC) is preferred in between offshore wind power plant (WPP) and onshore station. The configuration of this HVDC system comprises of both series and shunt compensator named as unified HVDC (UHVDC). To achieve smooth power transfer, DC link voltage regulation and fast fault clearance during transient conditions, PI controller based synchronous reference frame technique (SRF) is used. The proposed system is designed and results are evaluated using Matlab/Simulink platform.*

Key Words: Transient Compensation, PI controller, HVDC, wind power plant, and Unified HVDC (UHVDC).

1. INTRODUCTION

Wind energy conversion system is the promising renewable energy source which has the potential to satisfy the world's increasing energy demand. Generally the turbines of wind power plant (WPP) is based on either permanent magnet synchronous generator (PMSG) or doubly fed induction generator (DFIG) [1]. The more attention is given to PMSG based WPP because of its benefits of higher efficiency and it doesn't requires gearbox [2]. The interconnection of wind power plant with grid system is done using back to back voltage source converter (VSC). This ensures increased system reliability and cost efficient. The interconnection of such large scale offshore wind plant is carried out through high voltage direct current (HVDC) transmission system.

HVDC is a high power electronic technology which has been widely used in electric power system to transmit large amount of power for long distance, asynchronous interconnection, power flow control. Thus the VSC-HVDC system provides independent control of active and reactive power flow in a transmission system. The important consideration during the bulk power transmission of HVDC system is grid fault disturbances which lead to stability problem.

This paper proposes series and shunt compensator named as Unified based HVDC system (UHVDC) with enhanced fault ride through (FRT) capability. The proposed system has the series and shunt compensation devices to provide symmetrical and asymmetrical fault condition, smooth power transfer, regulated dc link voltage, transient management and hence improved reliability. To achieve this control technique is needed and this paper proposes PI controller based SRF control strategy. The performance of this entire system depends upon the operation of inverter switches and hence it must be regulated [3]. The proposed system assures to reduce the transients, dc link regulation. This proposed large scale WPP with UHVDC system is designed and the results of different case studies are analyzed with MATLAB/ SIMULINK environment.

2. SYSTEM CONFIGURATION

The offshore WPP contains the PMSG based number of wind turbines connected either in series and shunt configuration. The power transfer between offshore WPP and onshore grid is achieved through high voltage direct current (HVDC) transmission system. The proposed configuration has voltage source converter (VSC) based compensator units. It employs modern semiconductor switches such as IGBT/GTO which is compact in size compared to classic thyristor valve based converters. It is based on self- commutated pulse width modulation (PWM) technology. Also IGBT has the ability to turn ON and OFF with much higher frequency and does not requires any reactive power support [4]. Hence this enables easy in changing the reactive power flow within the system. The different configurations of VSC-HVDC system is monopole, bipole, back-to-back or asymmetric, multi terminal [3]. The figure 1 shows the system configuration of proposed multi-terminal VSC-HVDC system for wind power plant. The proposed configuration is called as UHVDC system which provides both series and shunt compensation. The WPP of proposed system has offshore and onshore VSC station. The Offshore station accommodate one converter and the onshore station contains two independent converters namely series and shunt converters. The onshore VSC station is connected with the electrical grid system through two shunt connected transformers (T_{r3} and T_{rn}) and this assures power transfer between WPP and grid system.

The converters of both onshore and offshore station should be capable to handle the power generated by the wind farms and the power is delivered to the electrical grid through HVDC system. The advantage of proposed

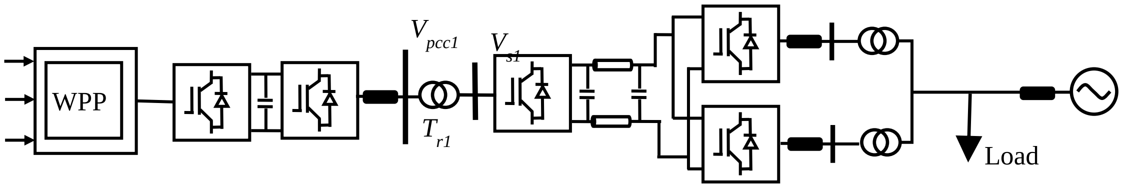

Fig -1: Configuration of UHVDC with WPP system

Configuration is to give series and shunt compensation to the system during any grid fault without requiring any additional compensation device. This helps to reduce the additional converter costs and hence the proposed system is a cost effective one.

If the fault is occurred in any one of the voltage source, the series transformer delivers the series voltage to prevent the entire system from the severe grid fault. Simultaneously, the proposed system provides voltage and current compensation by series and shunt VSC of onshore station. The changeover from one operation into another during both steady state and transient condition is achieved by the proper handling of converter switches in UHVDC system [5]. The operating principle of the proposed system is discussed in next chapter.

2. CONTROL SCHEME OF SHUNT AND SERIES COMPENSATOR

Here the control scheme of onshore and offshore VSC-HVDC system is discussed under steady state and faulted conditions. 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 control the grid voltage. Conventional control structure of the system has fast inner current control loop and slower outer control loop [6].

3.1 Control Structure of Shunt Compensator

The control scheme of onshore and offshore shunt UHVDC system is shown in figure 2. From the figure, it is observed that there will be four parts of the control scheme of shunt converter of UHVDC station. The first part is used to extract the negative sequence component and the second part performs computation of positive sequence component. The third part deals with transient detection and management scheme.

The transient detection and management is successfully achieved by PI controller. Here the reference and actual DC link voltage is compared and the error signal is given to PI controller unit. PI controller has system parameters such as Kp and Ki. The function of PI controller is totally depends on this system parameter values chosen. Therefore it is very important to choose the value to get actual DC link voltage tracks very close to that of its reference value. The performance of this SRF control is based on the result obtained from this PI controller. The regulation of DC link voltage delivers smooth and fast power transfer within the system and hence improved transient is also achieved meanwhile.

The final part is pulse generation part for shunt VSC. The transformation is done from three phase (*abc* to *dq0*) to find out the positive and negative sequence (*dq0*) components. The *dq0* components are extracted directly from the voltage and current of the offshore station. The shunt VSC performs the current compensation and hence it deals with transformation of distorted three phase current to *dq0* quantities. Finally the transformed reference current is given to pulse generation block to produce the required firing pulse of converter station [7, 8]. The general equation for three phase current in stationary axis (*abc*) is transformed into two phase rotating co- ordinates (*dq0*) is given below,

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \begin{pmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} \quad (1)$$

Finally, the desired reference current is calculated by taking inverse transformation of (*dq0*) axis into three phase (*abc*) rotating frame axis and is derived by the following eqn (2).

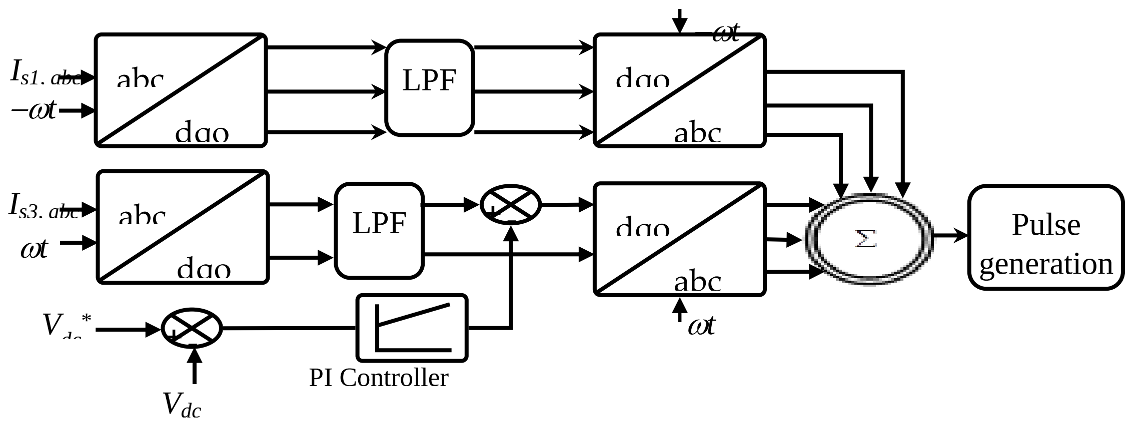

Fig -2: control technique for shunt compensator using PI controller

$$\begin{bmatrix} i_{sa^*} \\ i_{sb^*} \\ i_{sc^*} \end{bmatrix} = \begin{pmatrix} \sin\theta & \cos\theta & \frac{1}{2} \\ \sin(\theta - \frac{2\pi}{3}) & \cos(\theta - \frac{2\pi}{3}) & \frac{1}{2} \\ \sin(\theta + \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) & \frac{1}{2} \end{pmatrix} \begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} \quad (2)$$

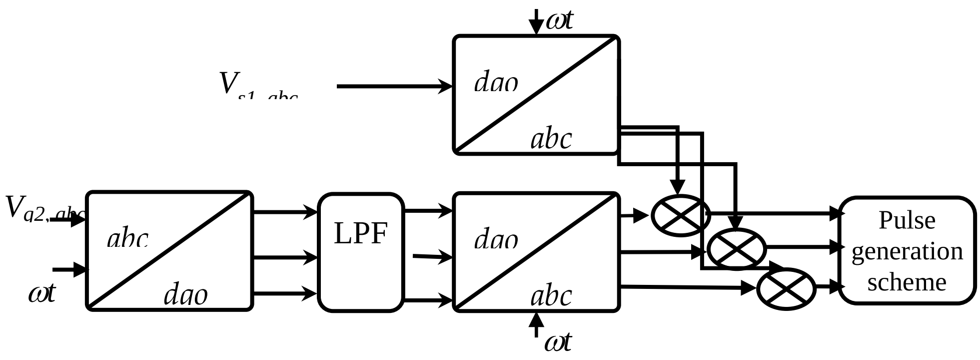

Fig -3: Control technique diagram for series compensator

3.2 Control Structure of Series Compensator

The control strategy for series onshore UHVDC diagram is shown in figure 4. The series converter provides the voltage and transient compensation. 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 HVDC 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].

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 the equation.

$$P_{tot,ser} = P_{ser} + P_{\cos}\cos(2\omega t) + P_{\sin}\sin(2\omega t) \quad (3)$$

The total active power $P_{tot,\, ser}$ is divided into three parts, series average power, cosine power and sine power and is cancelled and equated to zero by the generation of reference negative sequence component of series voltage and then this two phase voltage is again transformed into three phase abc rotating frame axis voltage by taking inverse transformation [10]. Then finally applied to switching pulse generation unit to produce pulses for series compensator.

4. SIMULATION RESULTS AND DISCUSSION

In this section simulation analysis on proposed PI controller based UHVDC system for WPP is presented. This section demonstrates the effectiveness of the proposed control technique for enhancing the compensation of transients and to provide fast power transfer under normal and faulted operating conditions. System parameter taken for this simulation study is given in table 2.

The simulation analysis on DC link voltage is shown in figure 4. From the waveform it is clear that, DC link voltage is regulated by proposed PI-SRF control strategy. The actual DC link voltage tracks its reference value by a small peak overshoot at beginning and is due to system parameter values selected for PI controller. By proper tuning of Kp and Ki this overshoot will be reduced. Simulation analyses on d-axis positive sequence voltage for low and high frequency transient is shown in Fig 5. In Fig 5, 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 controller based SRF 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.

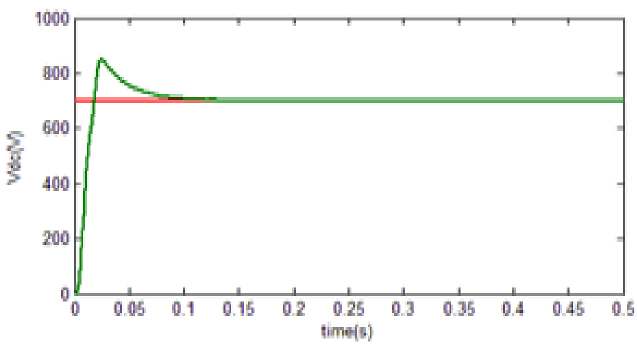

Fig. 4. DC link voltage regulation after compensation

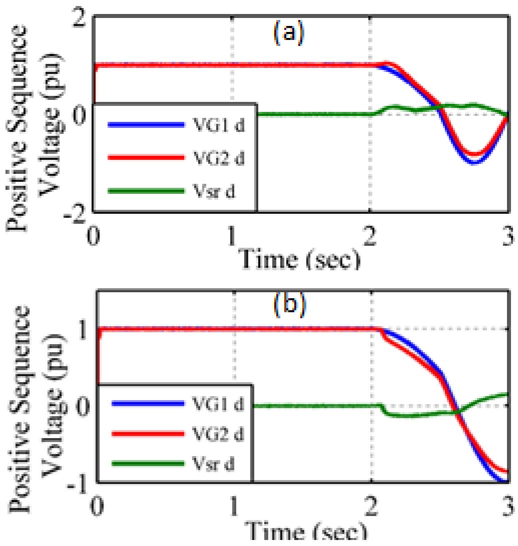

Fig -5: d- axis positive sequence voltage during (a) low frequency transient, (b) high frequency transient

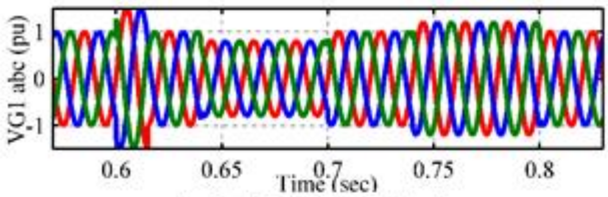

Fig. 6. a Three phase grid 1 voltage

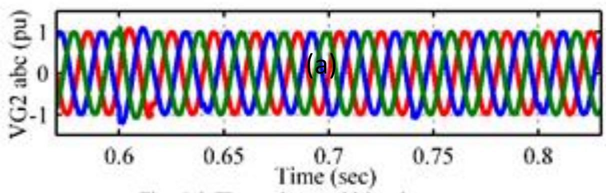

Fig. 6. b Three phase grid 2 voltage

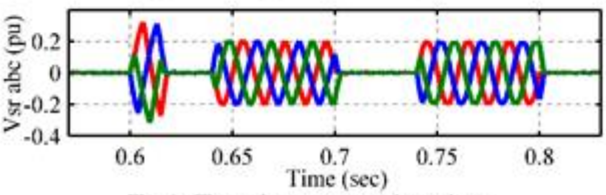

Fig. 6.c Three phase compensation voltage

The simulation results of regulation of positive sequence voltage V_{G1}, V_{G2} and V_{sr} in d axis using PI controller based SRF control scheme 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. 6.a, Fig. 6.b and Fig. 6.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 -1: Analysis on proposed PI-SRF control scheme

Operation Condition	**DC link Voltage Control**		**Time taken for transient compensation (msec)**
	Peak Overshoot (%)	**Settling Time (msec)**	
Initial condition	18.6	400	530
WPP side disturbances	11	112	190
Grid Side Disturbances	20.5	340	100

4. CONCLUSIONS

PI controller based SRF control scheme for UHVDC system to achieve transient management scheme and fast power transfer between offshore WPP and onshore electric grid. The performance of the proposed system is investigated under steady state and transient conditions. From the test results, it is found that PI controller based hysteresis current control technique has better capability to compensate transients and superior power transfer between WPP and electric grid.

Table -2: 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	0.11pu

		Leakage reactance	
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	

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