International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 2

A New breed NN Based UHVDC for Offshore Wind Power Plant to Enhance the Transient Response

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ABSTRACT

In proposed system transient management of offshore wind power plant can be achieved by unified high voltage direct current transmission (HVDC) system. This advance HVDC transmission system rectifies the defect of recent AC transmission network. The design of HVDC system made up of both series and shunt compensator call by unified HVDC (UHVDC). It assures the smooth power transfer, Direct current link voltage regulation and fast fault clearance during transient conditions. The former control of Unified HVDC is designed by synchronous reference frame technique (SRF) which leads poor performance in frequency variation. The mentioned problems are overcome by advance technique of proportional integral (PI) controller and neural network controller. These proposed systems are designed and transient responses are evaluated by Matlab/Simulink software.

Keywords: *Transient management, PI controller, HVDC, wind power plant, and Unified HVDC (UHVDC).*

1. INTRODUCTION

Wind energy conversion system is the convenient renewable energy resource to fulfill the world's needing energy demand. Usually the turbines of wind power plant (WPP) are operate on either permanent magnet synchronous generator (PMSG) or doubly fed induction generator (DFIG) [1]. The more importance is given to PMSG based developed WPP since its advantage of higher efficiency and it won't required any gearbox [2]. The WPP with grid system is connected by using back to back voltage source converter (VSC). This assures the system reliability and cost effectiveness. The connection of such large scale offshore wind plant is traveled out through the high voltage direct current (HVDC) transmission system. HVDC is a advance high power electronic technology. It has been widely used in electric power system to transmit the large amount of power for long distance, asynchronous interconnection, power flow control. Thus the VSC-HVDC system issue independent control of active and reactive power flow in a transmission system. The main consideration while the bulk power transmission of HVDC system is grid fault disturbances. It lead a stability problem.

The problem of transient is overcome by the series and shunt compensator denote as Unified based HVDC system (UHVDC) with augmented the 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 necessity and this paper proposes neural network 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 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.

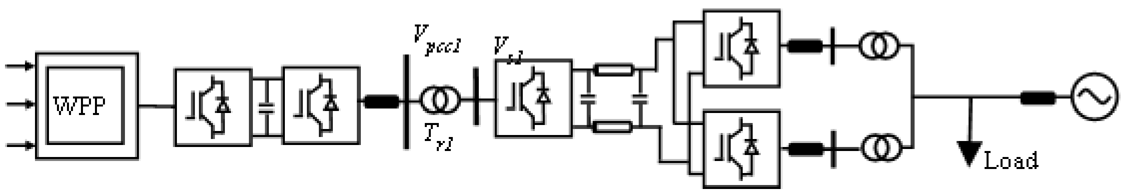

Fig -1: Configuration of UHVDC with WPP system

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.

3. Existing Conventional SRF Scheme

The performance of UHVDC is examined using conventional SRF control scheme. The investigations are carried out under different case studies such as low frequency transient and high frequency transient. The DC link voltage for low and high frequency transients is controlled at rated value for case 1 only and remaining cases DC link voltage is failed to maintain at rated value. This problem is mainly due to the control scheme is depends on supply frequency. To overcome the above problems the PI and NN are introduced fatherly.

4. 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.

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

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,

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

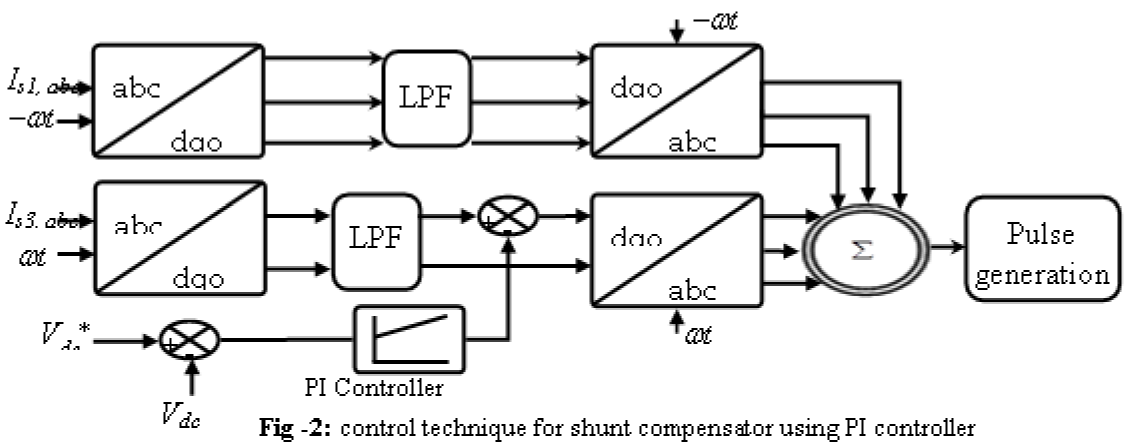

Fig -2: control technique for shunt compensator using PI controller

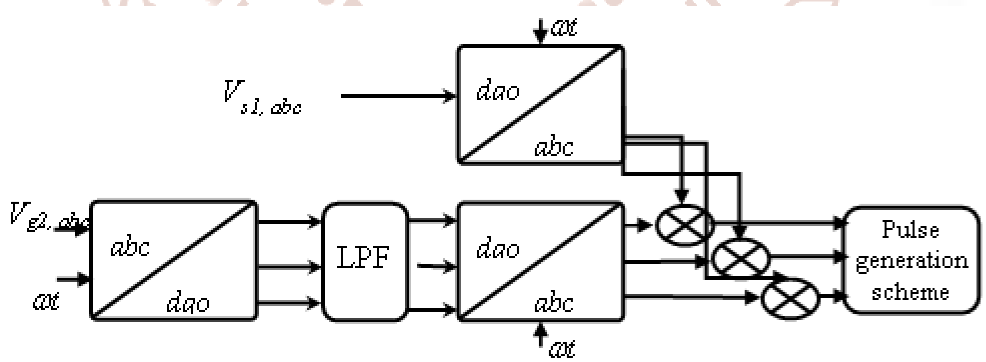

Fig -3: Control technique diagram for series compensator

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).

5. 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.

6. Analysis on DC Link Voltage Using PI Controller

The DC link voltage for low and high frequency transients are analyzed using the PI scheme with constant frequency method which is shown in figure 4 and 5. The DC link voltage is controlled at rated value up to 4 cases and remaining cases DC link voltage is failed to maintain at rated value. This problem is mainly due to the PI control scheme depends system parameters.

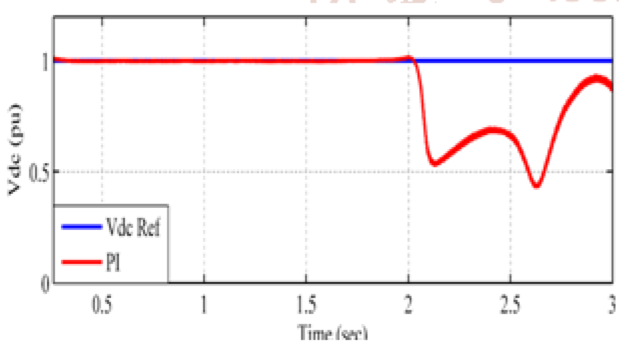

Fig-4: DC link Voltage control using PI, at low frequency transient

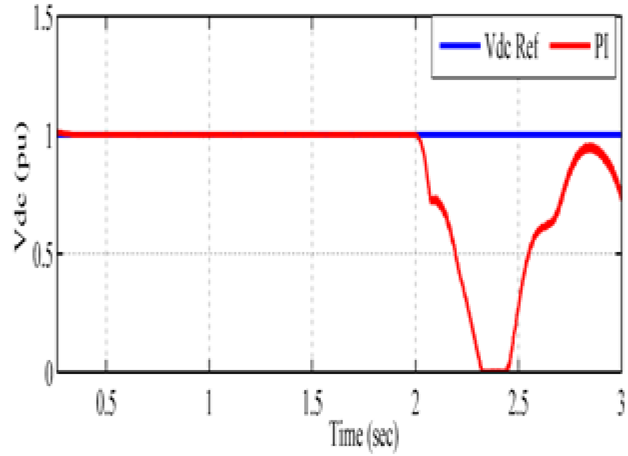

Fig-5: DC link Voltage control using PI, at high frequency transient

7. Analysis on DC Link Voltage Using NN Controller

The DC link voltage for low and high frequency transients are shown in figure 6and 7. using the NN scheme. The DC link voltage is controlled at rated value for all cases. This can be achieved by NN control is inherent of system parameter.

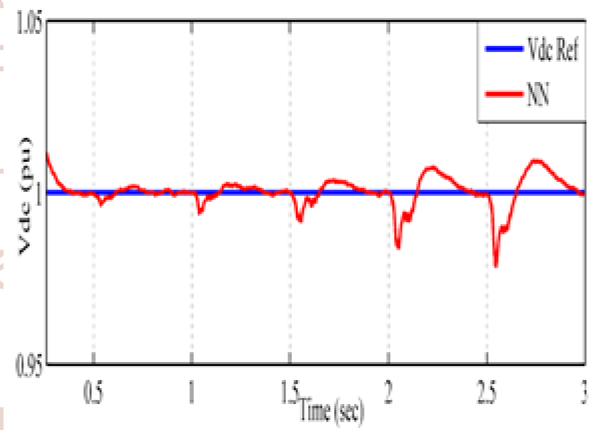

Fig-6: DC link Voltage control using NN controller, at low frequency transient

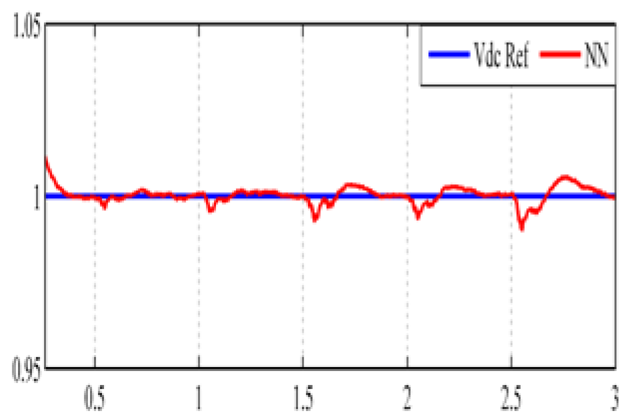

Fig-7: DC link Voltage control using NN controller, at high frequency transient

8. Simulation Analysis On PI and NN system

The simulation on proposed configuration applied with IEEE 9-bus system. The performance and compensation capability of proposed test system is analyzed with control SRF, PI-SRF and NN-SRF control schemes and the obtained test results are plotted. The analysis are conducted under low and high frequency transient conditions of varying load.

8.1 Analysis on Frequency Estimation Using PI and NN Controller

The simulation responses for estimation of frequency using PI and NN controller based SRF under low and high frequency transients are shown in Fig 8and Fig.9 respectively. These analysis are take out for load varying condition.

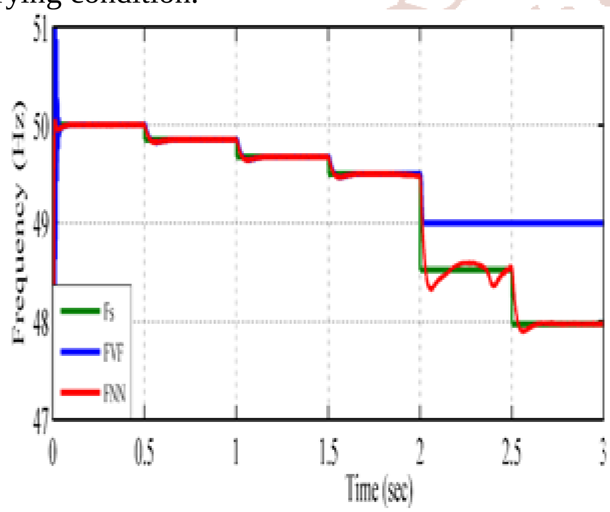

Fig-8 Frequency Estimation using PI and NN controller based SRF at low frequency transient

Form the obtained results, PI- SRF delivers successful estimation of supply frequency up to 2 sec. After 2 sec, variable frequency estimation by PI-SRF method failed to tracks the supply frequency. This issue is mainly due to analytical method highly depends on system parameter. The proposed NN based SRF is provides excellent compensation under all conditions. For NN based SRF, the supply frequency is successfully estimated under low and high frequency transient states. Hence the proposed control scheme is suitable for practical applications.

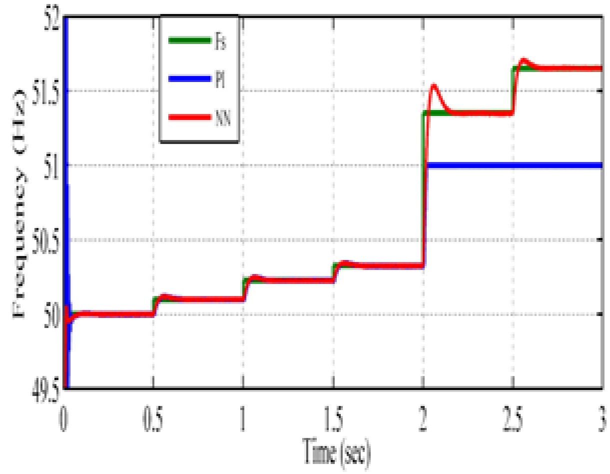

Fig-9 Frequency Estimation using PI and NN controller based SRF at high frequency transient

8.2 Analysis on DC Link Voltage Using PI and NN Controller

For better compensation of transients and smooth power transfer using UHVDC is made by optimal regulation of dc link voltage. Per unit (pu) simulation responses for dc link voltage control using conventional SRF, PI-SRF and NN-SRF control technique under low and high frequency transients are shown in Fig.10 and Fig. 11 respectively and the results comparison are made in table 1 and table 2. Form the obtained results, using conventional SRF, DC link voltage is controlled until 0.5 sec only and it failed for remaining cases. This problem is mainly due to constant frequency used in the Clark park transformation. For PI based SRF method, the DC link is controlled successfully up to 2 sec. After 2 sec, PI-SRF method failed to estimate the supply frequency.

This issue is mainly due to supply frequency is failed to estimate by this method. For NN based SRF, the DC link voltage is successfully controlled under all conditions of load variation. Hence NN SRF based UHVDC has ability to compensate transients and effective power transfer. The simulation waveform of DC link voltage regulation at voltage disturbance is plotted in Fig. 11.

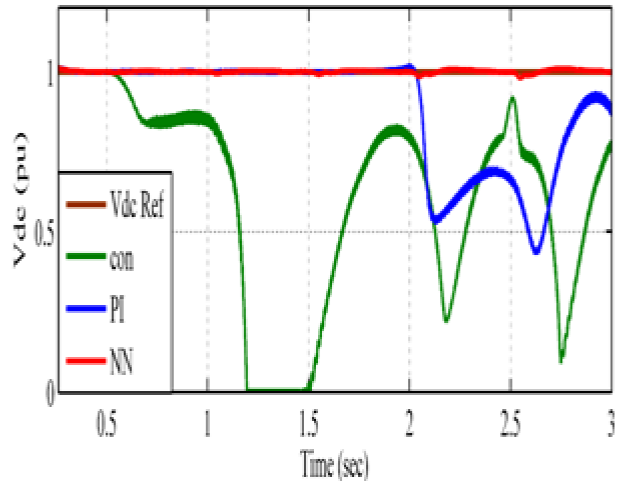

Fig.10 DC link Voltage control using conventional, variable frequency and NN at low frequency transient

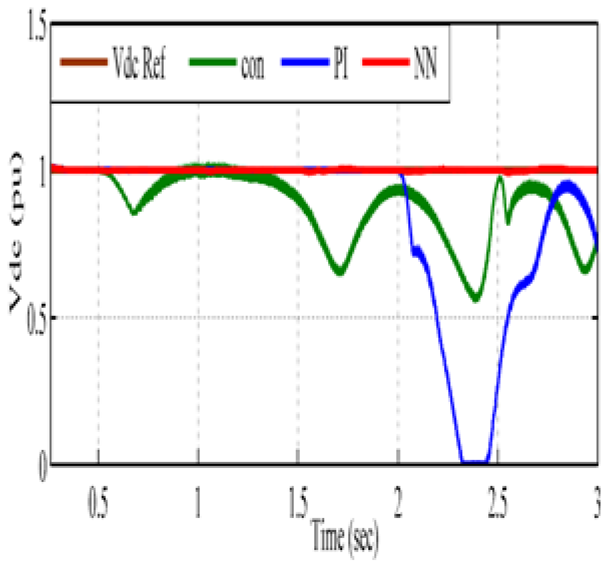

Fig 11 DC link Voltage control using conventional, variable frequency and NN at high frequency transient

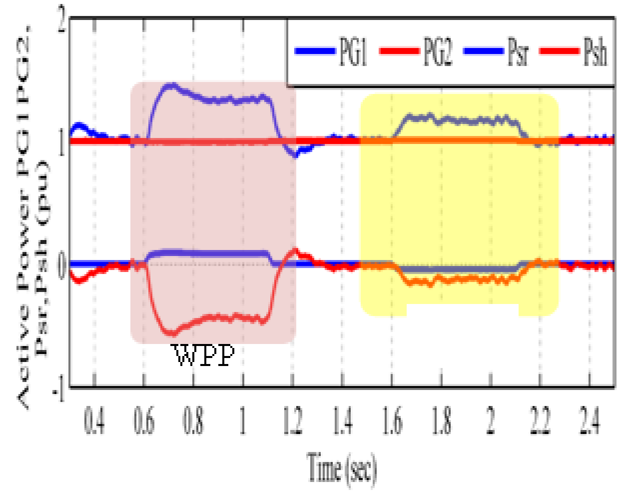

Fig -12 Real power transfer using PI controllers

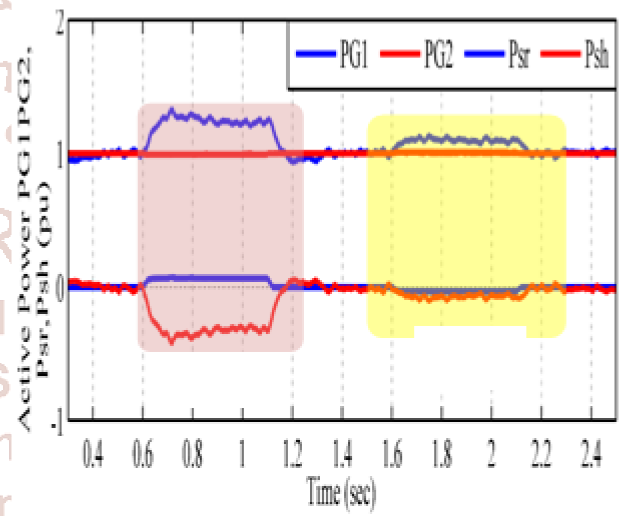

Fig-13 Real power transfer using NN controllers

8.3 Analysis on Real Power Transfer Using PI and NN Controller

The simulation analysis on real power transfer using conventional, PI-SRF and NN-SRF are plotted. Here 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}). The simulation responses for real power transfer under fault created at wind power plant and grid side fault using PI and NN controller is shown in Fig.12 and Fig.13.

Table 1: Performance Comparison of PI and NN Control

Operation Condition	DC link Voltage Control				Time taken forTransient Compensation (msec)	
	Peak Overshoot(%)		Settling Time (msec)		PI	NN
	PI	NN	PI	NN		
Initial condition	18.3	1.41	450	380	600	450
WPP side disturbances	11	5	160	100	250	100
Grid Side Disturbances	20.5	4	500	250	280	110

Table 2: System Parameter

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	

CONCLUSION

For transient compensation of offshore wind power plant and onshore electric grid is achieved by a proposed neural network DQ control technique based UHVDC .The performance of the proposed neural network control methodology is interrogated under various disturbances in both WPP and electric grids and results are compared with PI controller. From the interrogated results, it is clear that neural network based control technique is better ability to compensate transients and superior power transfer between WPP and electric grid.

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