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Original Article

Off shore Wind Power Plant with UHVDC-Based Transient Management Scheme

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Abstract: *This research discusses enhanced transient management between an onshore high voltage direct current transient system and an offshore wind power plant using PI controllers. The suggested setup is known as unified VSC-HVDC, orUHVDC, and it includes both series and shunt compensation. This setup improves the fault clearance and transient management capabilities by using variable frequency extraction for the SRF control scheme. The entire system is built to reduce both minor and major grid failures. Modeling of the test system is done with MATLAB/SIMULINK.*

Keywords: *Wind Power Plant, DC Link Voltage, HVDC, PI Controller, and Transient Management.*

INTRODUCTION

Energy demand is currently the world's most important issue. One modern way to counteract the rising energy demandis to integrate renewable energy sources into the grid. The most promising renewable energy source that can meetenergy demand is the wind energy conversion (WEC) system [1]. Power converter units and wind power plants (WPPs)are the two components of a wind energy conversion system that produce and distribute electricity. The permanent magnet synchronous generator (PMSG) is a component of the WPP arrangement [2]. A grid-connected wind powerplant is setup with voltage source converters connected back-to-back.

The grid is integrated with the wind power plant configuration via a high voltage direct current (HVDC) transmissionsystem. System reliability is increased and cost-efficiency is ensured by HVDC systems [3]. As a result, the producedelectrical power is transferred via an HVDC transmission system over great distances. Bulk power transmission, asynchronous connectivity, autonomous regulation of active and reactive power flow, and therefore higher system efficiency are some benefits of HVDC transmission[4].

An important limitation to consider in bulk power transmission is grid failures and other grid-related disturbances. Maintaining system stability in the face of failures/outages is a difficult task. To ensure the stability of the system with rapid depletion, voltage source transformation-based HVDC (VSC-HVDC) has been added to the power transmission system recently [5]. It shouldbe noted thata large WPP and VSC HVDC system should include the ability to deal with fault management capability. The modern transmission system uses unified VSC-HVDC(UHVDC) to compensate for series and shunt distortions, which are a problem of line communication interference. The combined VSC station includes IGBT switches for better efficiency and a power switch [6].

The enhanced fault clearance is achieved by implementing appropriate control technique and hence fast response isattained without any deviation in power transferof 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 powertransfer and improved system reliability. The whole system is modeled and simulation analysis has been done usingMATLAB/SIMULINK environment.

SYSTEMCONFIGURATION

PMSG-based multiple wind turbines are formed in series and shunt to form wind power(WPP)[3]. HVDC with power transformers is used to transfer the electricity produced by the power plant to the network. Modern power electronics use a voltage source converter(VSC) to connect networks [8]. The VSC-HVDC system overcomes the limitations observed in the conventional power transmission system, such as large dimensions, requiring thyristor valves. It containsacompactIGBT/GTO solid-stateswitch andisbasedon self-switching PWMtechnology. IGBT is mostly used because it can operate at higher frequency. The conventional CSC-HVDC system uses reactivepower support, but the proposed IGBT-based VSC-HVDC works without a reactive power source [9]. That's why it offers.Independent control of active and reactive power flow. This makes the proposed system suitable for changing power flowdirection under dc link voltage is maintained in the network. VSC-HVDC system can be configured as monopole, bi-pole, back to back, asymmetric and multi-terminal [5], [10]. Here multi terminal VSC-HVDC system has been presented. In thispaper, unified VSC-HVDC (UHVDC) configuration of both series and shunt compensation has been presented. The Fig.1shows the power circuit of proposed UHVDC for wind energy conversion system. WPP contains on shore and offshore

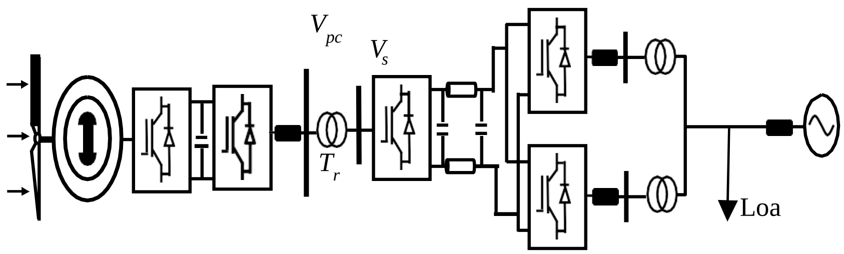

Figure.1.Configuration of UHVDC connected to offshore WPP and on shore grid

VSC base. There are separate converter units at every station. There is one converter unit at the off shore station and two at the onshore station. Series and shunt converters is the name of the onshore converter station. Between the on shore station and the electricity grid are two shunt-connected transformers known as Tr3 and Trn [11]. Power transfer fromWPP to the utility grid system is made possible by this shunt coupled step-up transformer via an HVDC transmission system. As a result, the transformer and converter units have to be able to manage the bulk power produced by WPP. The term point of common connection (PCC) refers to the central location where the utility grid and HVDC are coupled. The main benefit of the suggested arrangement is that the UHVDC system can conduct compensation without the requirement for further compensation devices.

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 witch over from one operation to another under steady state and transient conditions[13].The next section discusses about mathematical modeling of converter stations.

ON SHORE AND OFF SHORE WIND POWER PLANT SYSTEM CONTROL SCHEME

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 referenceframe control technique has been covered in this paper because of its undesirable characteristics such as suitable fordistorted/unbalanced grid conditions, no requirement of complicated algorithms [14]. The control technique is divided into two major categories 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.

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 forinverter.

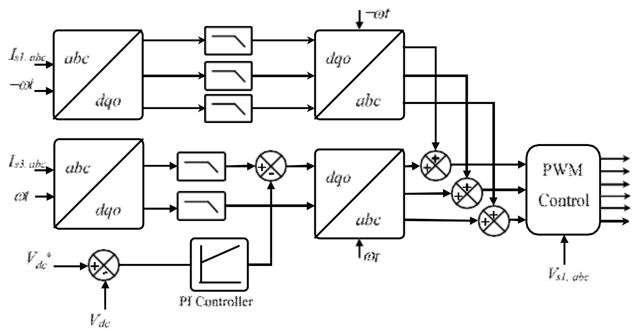

Figure.2.ControlSchemefor onshoreand offshoreshuntUHVDCsystem

PI controller with SRF technique produces better accurate result by tuning PI parameters such as Kp and Ki. PI controllerd elivers fundamental current by make a comparison of actual and referenced clink voltage[15].There sultan terror signal is given as,

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

(1)Where, e(t)be the error, Vdc and Vdc refbe the actual and referenced c link voltage respectively .This error signal is given to control technique part to produce reference source current. The transformation from three phase distortedsource current to two phase rotating dq frame is given as, 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 references our ce current signalas,

Control Scheme for Series Compensator

The on shore WPP has series converter to compensate series grid voltage fault and transient management scheme.Fig3

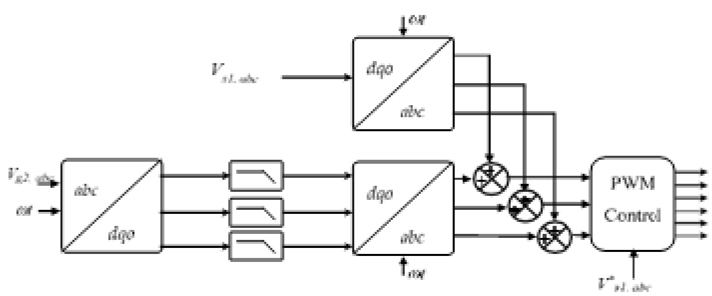

Figure3.ControlSchemeforseriesVSCofoffshoreWPPbasedUHVDC

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.

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

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

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

The total power includes sine, cosine and series average power. The final part is, obtained series voltage is delivered tofiring pulse generation scheme to produce switching pulses for inverters. The next section discusses about frequencyestimation using PI control scheme. This section discusses estimation of frequency using PI control for SRF controlscheme. The SRF control scheme requires supply frequency for its operation. This frequency has been estimated usingPI control block and the diagram for this process is shown in Fig4. Here the three phase grid voltage is converted intotwo phase d-q component to estimate quadrature component grid voltage. The actual q-axis voltage is compared with itsreference value and the resultant error signal is given to PI control unit. The obtained output is summed with constantfrequencyvalueandthen giventointegratorparttodeliver requiredfrequencyforSRFcontroltechnique[16].

SIMULATION RESULTS AND DISCUSSION

In this section, the enhancement of compensation capability of proposed SRF control scheme has been elaboratelydiscussed. The proposed test system is designed to compensate high transient, series grid fault and analysis has beenmade under normal and faulted condition. The proposed system is designed in such a way to give fast response andenhanced compensation to reduce overshoot. The voltage rating of the network is 230KV and the rating of HVDC is250KVAwhich is equivalent to the offshore WPP. Parameter taken for simulation is given in table2

.

The compensation capacity of UHVDC system has been determined by the optimal control of dclink voltage at its rated voltage. Here dc link voltage is controlled at 400KV using PI controller. The tracking of estimated frequencyusing 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 table1

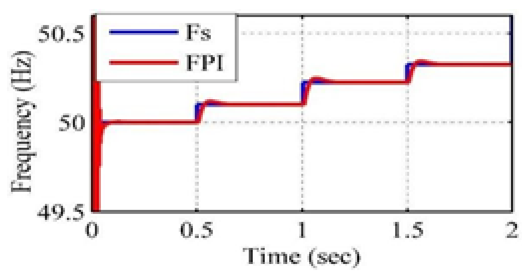

Figure4.High frequency transient estimation using conventional and PI control

This demonstration confirmed that the better minimization transients and better control of DC link voltage is achieved by theproposedPIcontroller.

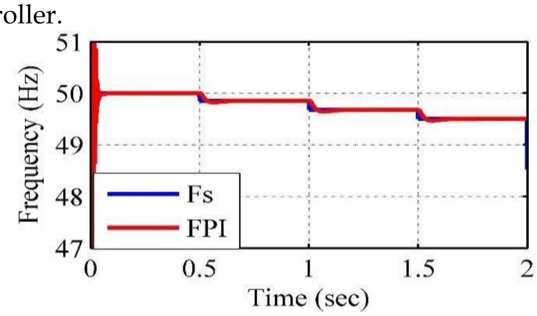

Figure5.LowfrequencytransientdetectionusingPIcontroller

Simulation analyses on d-axis positive sequence voltage for low and high frequency transient using conventional SRFand 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 PIcontrol technique. Under conventional system more peak over shoot and higher oscillation is identified. While using PIcontroller grid voltage and series injected voltage are successfully controlled with minimum oscillation and hence achieved optimally.

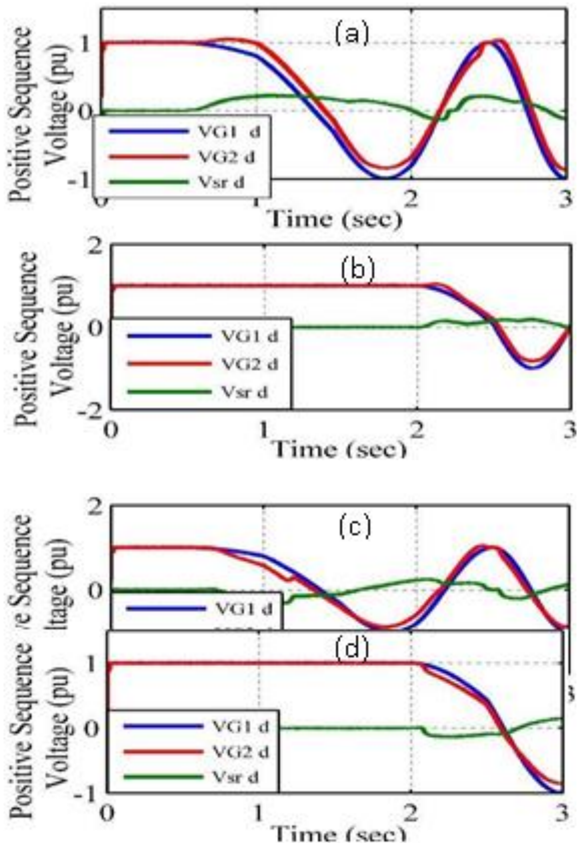

Figure7.d-axis Positive sequence voltage for low frequency transient - (a) Conventional, (b) Variable frequency, for high frequency transient-(c)Conventional, (d)Variable frequency

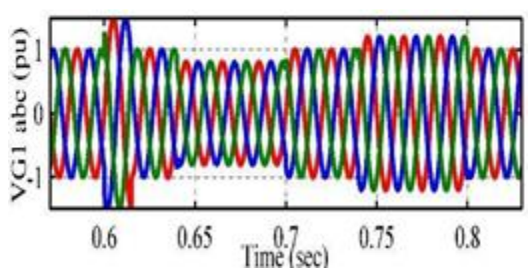

Figure7.aThree phase grid 1voltage

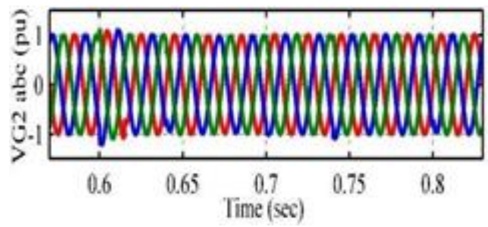

Figure7.bThree phase grid 2 voltage

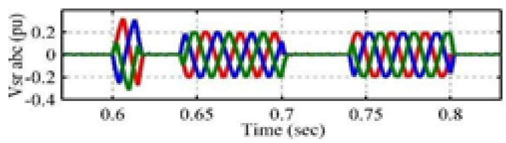

Figure7.cThree phase compensation voltage

The simulation results of regulation of positive sequence voltage VG1, VG2and Vsrin d axisusing PI controller hasbeen successfully achieved. The main objective of the proposed configuration is to maintain rate voltage 230KV atPCC. Under normal operating conditions, VG1and VG2are in equal and Vsr is found to be zero. For under voltagecondition, 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 there by rated voltage is maintained. While using conventional system, transient detection is found to be poor and it requires more time tocompensate 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 inFig. 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.

TABLEI

ANALYSIS ON COMPENSATION FOR LOW AND HIGH FREQUENCY TRANSIENT

Power Frequency(Hz)		EstimatedFrequency(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 II 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	ACFilterL1	40mf
Transmission Line Impedance	0.2pu	ACFilterC1	100uf
On shore 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 Filter2SeriesL2s	20mh	AC Filter2SeriesL2s	46mh
AC Filter 2SeriesC2s	100uF	AC Filter 2SeriesC2s	152uF
DC Link			
DC Link Voltage		400KV	
DC Capacitance		1600uF	
DC cable resistance		0.004ohms/km	
DC cable capacitances		11.3uF/km	

CONCLUSIONS

This research proposes the use of PI-SRF control technology for the transient management and smooth power transmission between offshore WPP and on shore grid using UHVDC system. The PI control variable frequency method is used to extract the variable frequency for the SRF control methodology. Reduced peak overshoot andincreased transient under distorted and grid fault circumstances are guaranteed by the suggested solution. The entiresystem is examined in both high-frequency and low-frequency transient scenarios, and a thorough simulation study has been performed. According to the findings of there search, the suggested architecture offers superior power transmission between the on shore grid and WPP and has a higher compensating capacity to lower transients.

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