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Impact Of VSC-HVDC In Frequency Regulation Of Offshore Wind Farms

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Abstract—The emerging large offshore wind farms represent a promising and efficient power production technology. The generating capacities of offshore plants are much large when compared to onshore plants. This is because of availability of high wind penetration at offshore sites. These offshore wind farms are subjected to random variation of turbine speed, due to the high wind penetration. This leads to abnormal variation of frequency of output power generated and fed to the AC power grid. The offshore wind farms are however required to provide a rapid frequency regulation as like the conventional power plants utilizing synchronous generators. But the inertial support of the wind farm may lead to damage of wind turbines, rotating at high speeds. Thus the integration of large offshore wind farms with AC power grid becomes a difficult task. To overcome this various technologies are available. This work presents a Voltage Source Converter based High Voltage DC transmission system (VSC based HVDC) which represents the most competitive and feasible solution for integration of offshore wind farms with AC power grid. Thus providing an efficient frequency regulation for the system. The results are obtained from simulations performed through MATLAB simulink software.

Keywords—Offshore wind farm, frequency regulation, voltage source converter based high voltage DC transmission.

I. INTRODUCTION

The installation of large offshore wind farms is picking up attraction in many parts of the world recently. The generation capacities of a large offshore wind farms will be in range of dozens of megawatts to even hundreds of megawatts, as like the generation of conventional power plants. With the expanding coordination of huge offshore wind farms with AC power grids, it definitely prompts the retirement of conventional power plants. In this manner, to keep up the stability of power systems with high wind penetration, these wind farms are required to work like conventional power plants. They are not only bound to provide other ancillary services like frequency response control and voltage regulation.

The recent research on Voltage Source Converter (VSC) based High Voltage DC (HVDC) transmission empowers building offshore Wind Farms (OWFs) in far distant places with adequate availability of wind. These WFs are decoupled from the AC power grid by the HVDC link. Subsequently, wind turbines are unaware of the frequency fluctuations of main AC grid and the Grid Side VSC (GS-VSC) turns into the means through which frequency support can be provided. Suitable control structures to execute these services are at present being examined. On account of the long distance and the conversion stages included in the HVDC transmission system, there is a concern in respect to the reliability and the response time to effectively provide system inertia. Keeping in mind the end goal to make the system robust to the loss of communication between the GS-VSC furthermore, the WF-VSC, it is proposed to interpret the frequency of the AC power grid to a equivalent variation of the HVDC link voltage which is controlled by the GS-VSC which is detected at the WF-VSC and imparted to the wind turbines. An alternative method is proposed, where it is recommended that the vitality put away in the limit of the HVDC connection could be utilized alone to give inertial support.

VSC based HVDC transmission moreover has different other advantages, such as, completely controlled power flow, independent controlling of active and reactive power, and independent control of reactive power at each AC end. On one hand, WFs would not be directly influenced by onshore grid system disturbances because of the decoupling of VSC-HVDC. On one hand, this decoupling would keep OWFs from immediate reacting to system disturbances of the onshore AC power grid system. For a disturbance in system frequency, it is apparent that WFs cannot give immediate response following the frequency transient because of communication delay. VSC-HVDC, which performs good on support of voltage. The interaction of VSC-HVDC-connected WFs in the system frequency regulation is examined. Be that as it may, every one of these studies focused just on creating artificial coupling strategies between offshore and onshore systems utilizing the VSC-HVDC join, yet did not test into the potential recurrence bolster ability of VSC-HVDC itself.

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II. FREQUENCY RESPONSE CONTROL OF WIND FARM

Providing small term support for frequency deviation requires adjusting the power injected to the AC power grid depending on the fluctuation. Two unique terms must be considered: one which is corresponding to the rate of change of frequency, which copies the supposed inertial response of a synchronous machine, and the other which is corresponding to frequency deviation, which compares to the primary control. According to the grid codes [8], frequency regulation can be given by every generator on the system, by droop setting of a high virtue, with a droop setting of 4%. Primary Operating Reserve (POR), the available reserve somewhere around 5 and 15 s consequent to an event, relates to 75% of the largest in feed onto the system. POR sources incorporate spinning reserve from creating units online and static reserve, and the extent of the POR gave by static and spinning reserve sources differs with time of day. Static reserves comprises of pieces of store that are accessible momentarily when stumbled by the framework recurrence falling underneath the foreordained recurrence setting of every square. This frequency settings extent somewhere around 49.5 and 49.3 Hz. For instance, during the evening, amid lessened burden pumped capacity station may be working in pumping mode, which trip when the foreordained recurrence levels are come to, to give static store. All in all, the commitment of the pumped stockpiling station to POR relies on upon the operational mode in which it is running and changes relying upon system conditions and time of day. The apparent reference estimation of dynamic force of the wind turbine generator is given by

(1)

The grid frequency is obtained by the GS-VSC and an request of issued power variation to the WFs. The motion between the grid support power request and the power actually injected by the GS-VSC can be acquired by presenting the communication delay. The general arrangement of frequency control by means of conversion from AC to DC and then from DC to AC by power converters for frequency control of a wind farm is shown in Fig 1.

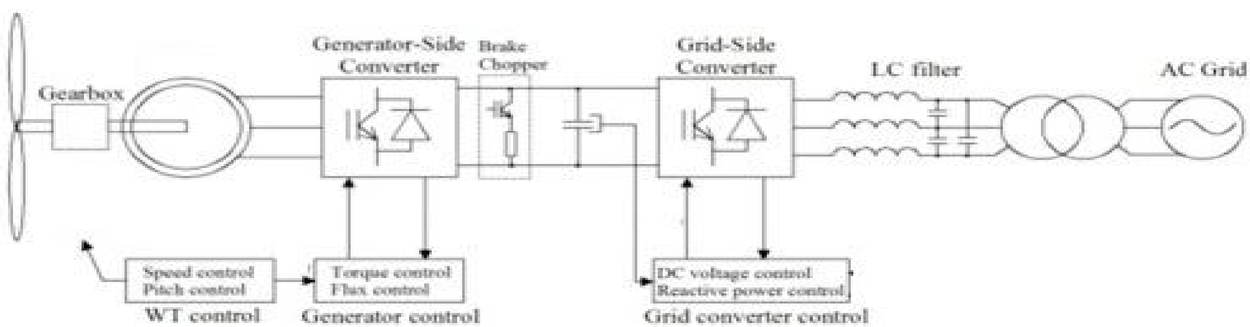

Fig.1. General control methodology for frequency control of wind farm

III. FREQUENCY RESPONSE CONTROL OF WIND FARM

A. Need For HVDC Transmission

The analyzing of two transmission systems, from the technical perspective, the HVDC transmissions overcomes the issues which are generally connected with the AC transmissions. In this manner, as far as possible are overcome when a HVDC transmission is utilized because of the way that the power transfer capacity of DC lines is not affected by the distance of transmission. On account of the HVAC transmission the power flow in the AC lines is corresponding on the phase angle which increments with the distance and consequently the power transferred is constrained.

B. VSC-HVDC Methodology

In case of VSC- based HVDC transmission system the transfer of power is controlled in the same line as on account of an installed HVDC transmission. The inverter side controls the active power, while the rectifier side controls the DC voltage. Considering the power transmission between two AC networks, the flow of power can be bidirectional. In any case, if the VSC-based HVDC system is utilized to transfer power from a WF, the flow of active power is unidirectional (the onshore side is transferring active energy to the onshore side itself and not the other way around).

The layout of a VSC based HVDC transmission for an offshore wind farm is as shown in Fig 2.

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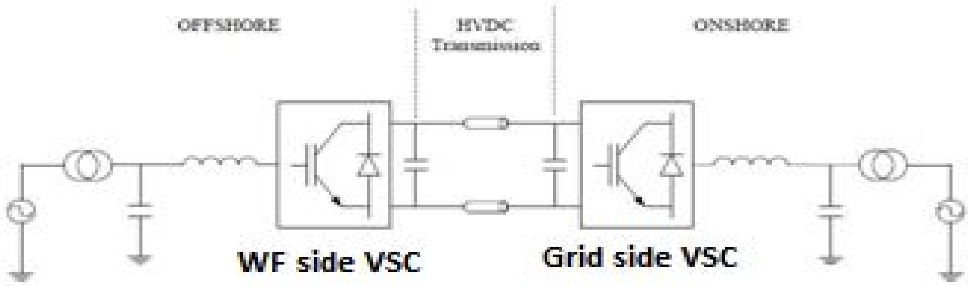

Fig 2. Layout of VSC based HVDC system for Offshore Wind Farm

The control of the converters in both sides (Grid side converter-GSC and Wind farm side Converter) can be carried out in various methods.

C. Control For VSC- HVDC

An auxiliary dc voltage controller is utilized, and the ancillary onshore VSC control is as shown in Fig. 3. The extra dc voltage reference Vd∗cf is resolved by the frequency deviation, which is passed to a lag in first-order with a gain Kf. To control the discharging rate of the dc capacitors, the time consistent Tf of the first-order lag is moreover tuned as far as the correspondence's inactivity interface of the VSC-HVDC system. This estimation of Vd∗cf is restricted to ±0.1 p.u. of the nominal dc voltage, however in sensible applications, it is determined to be resolved as for protection necessities, functional of PWM and so forth. In such a way, when the frequency deviation is perceived, the change rate of dc voltage is controlled agreeing to the correspondence between the stations of VSC HVDC. The voltage changes faster when the idle time is shorter what's more, slower when the idle time is longer. That additionally speaks to that the dc capacitors have the capacity to discharge its vitality persistently until wind turbines begin to respond to the network recurrence deviation. The auxiliary dc voltage controller is initiated when the grid frequency is out of the extent 49.8–50.2 Hz. Once the grid frequency is lower than 49.8 Hz, the dc voltage is controlled down to 0.9 p.u. to discharge a piece of the put away vitality in the dc capacitance. At the point when the frequency is higher than 50.2 Hz, the dc voltage is controlled up to 1.1 p.u. to retain the power transmitted from the offshore VSC. Since the dc capacitance furthermore, voltage variety for a certain VSC-HVDC are constrained, the energy discharged/consumed by the dc capacitance is likewise constrained. Hence, in this study, the VSC-HVDC is controlled to give proficient frequency support until the offshore wind turbine sense the onshore frequency fluctuation influence and begin to respond.

(2)

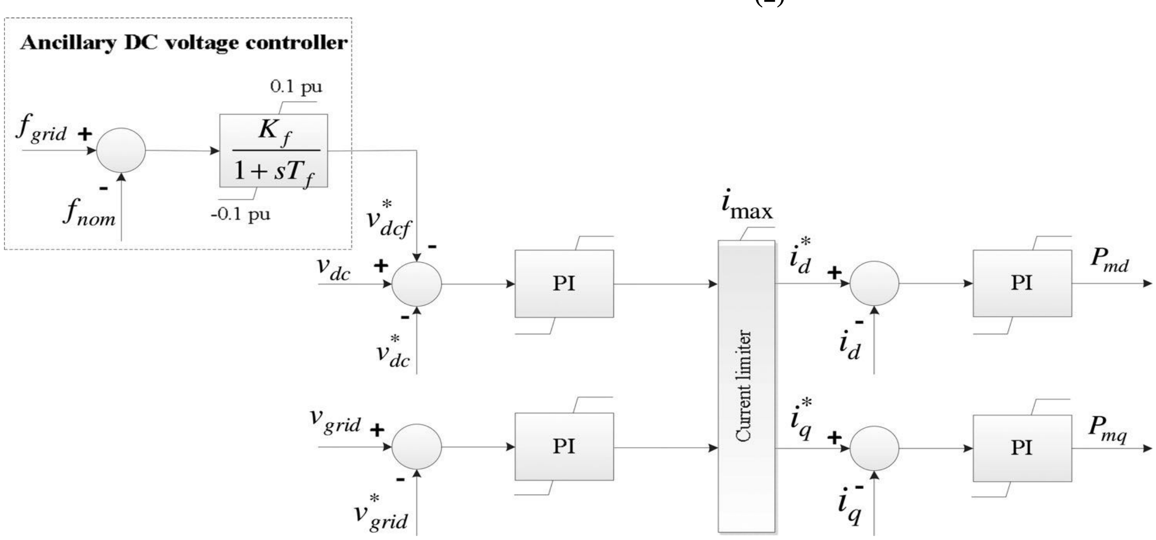

Fig 3. Ancillary frequency control of VSC- HVDC system

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IV. TEST SYSTEM AND ITS DISCUSSION

A. Layout Of Test System

The layout of the proposed test system is as shown in Fig.4. This consists of Wind farm side converter (WFSC) and Grid side converter (GSC) are connected with a HVDC link in between.

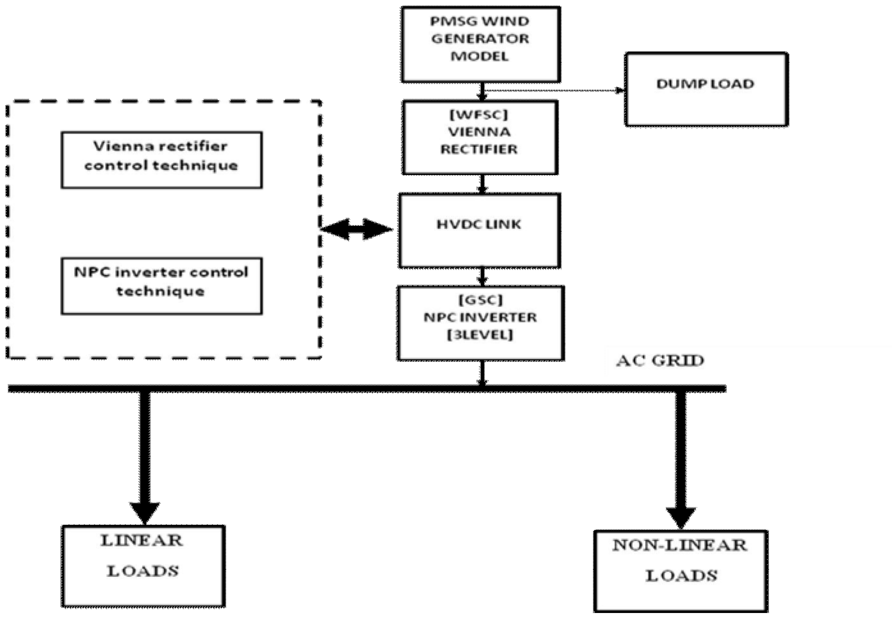

Fig.4. Layout of test system

B. Simulation And Control

The simulation of test system was done using MATLAB simulink software. The simulation layout of complete system is as shown in Fig.5.

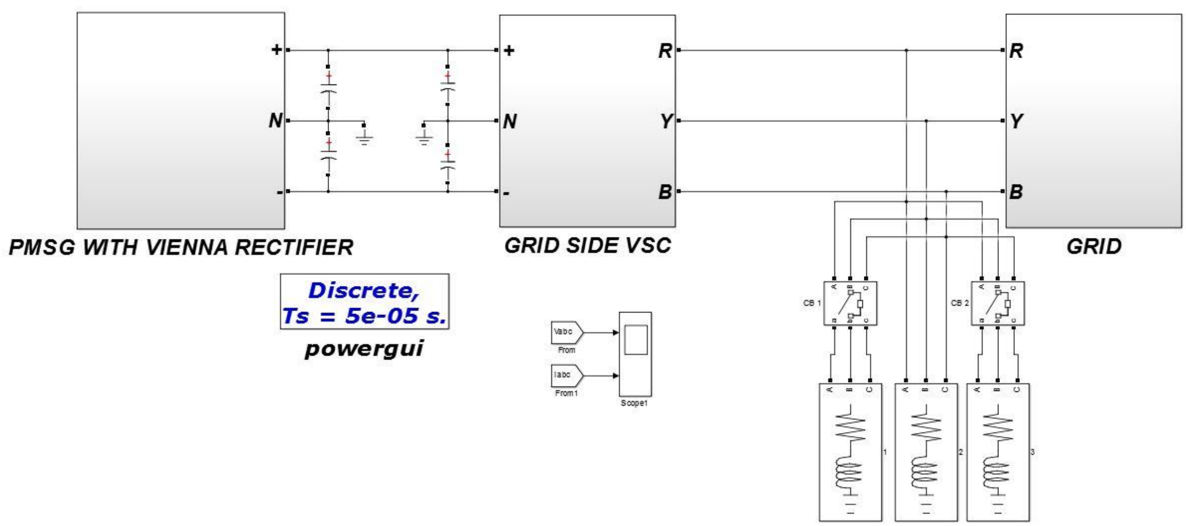

Fig.5 Layout of complete simulation in MATLAB

C. Vienna Rectifier (Wind Farm Side Converter-WFSC)

A Vienna rectifier model is utilized as wind side Converter. Vienna rectifier as generator-side converter of wind energy conversion system (WECS) utilizing a permanent magnet synchronous generator (PMSG) has a few focal points contrasted with conventional back to back inverter [10], for example, improved efficiency and enhanced total harmonic distortion. The simulation model of a Vienna rectifier connected with a PMSG (permanent magnet synchronous generator) is as shown in Fig.6.

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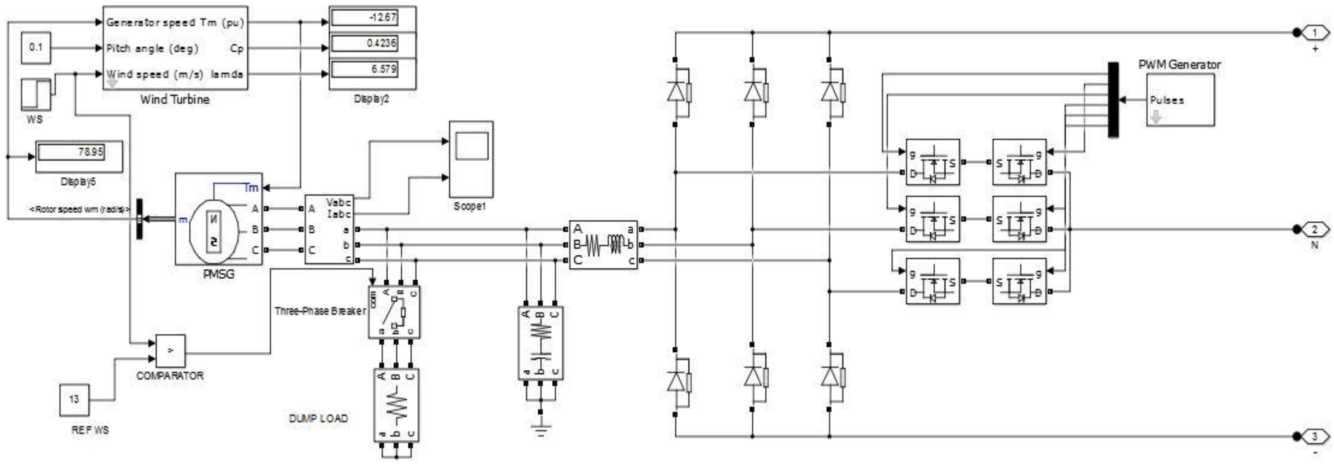

Fig.6 Vienna rectifier connected to PMSG drive in MATLAB

D. Neutral Point Clamped Multilevel Inverter (Grid Side Converter-GSC)

The three level neutral point clamped multilevel inverter is presently demonstrated innovation for medium/high voltage high-control applications, for example, reactive energy compensation, marine drives, steel rolling plants, and other variable-speed drives. A few manufacturers have popularized its utilization in movable rate drive frameworks and different applications. In spite of its few favorable circumstances, for example, harmonic reduction, stress of reduced level, across switching devices, achieving high-voltage and high-control abilities without dangerous series–parallel associations of exchanging gadgets, it has a natural issue of uneven voltages across over dc-join capacitors because of load unbalancing, non uniform dissemination of charges, and non identical properties of dc-connection capacitor. The simulation model of a 3 level neutral point clamped multi level inverter is as shown in Fig.7.

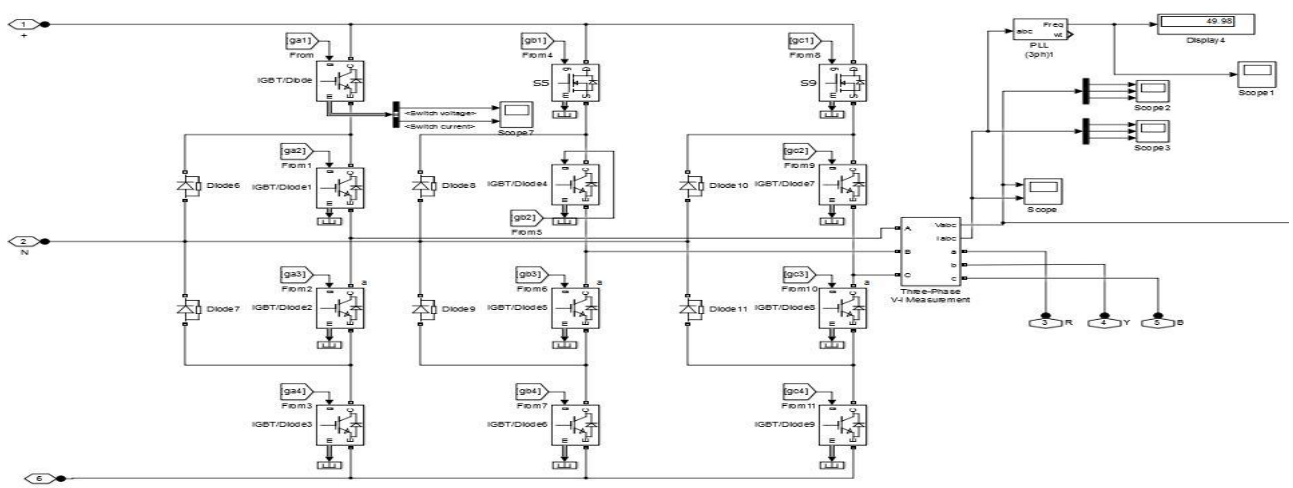

Fig.7 Three level neutral point clamped multilevel inverter simulation model in MATLAB

The neutral point clamped inverter is controlled by neutral point potential control as explained further.

E. Neutral Point Potential (NPP) Control

The configuration of a simple neutral point potential (NPP) controller for a three-level diode-clamped inverter utilizing a sine-triangle controller in addition with a close loop controller with lesser losses in switching [10]. The principle of regulator depends on including a continuous variable offset voltage which manages the midpoint capability of the dc transport. The novelty of the NPP controller is in the determination of the magnitude of variable offset voltage based upon the nominal, peak to peak, and total harmonic distortion, in NPP. Besides keeping up dc-bus voltage balanced, the proposed controller prompts a critical diminishment in the voltage disturbance at the NP, results in the reducing of the required dc-bus capacitance. It likewise decreases the inserting so

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as to exchange misfortunes of the inverter the "no-switching" zone inside of every half cycle of the fundamental voltage wave.

By controlling the Voltage and active power of the system the frequency control can obtained and it explained by equation (3)

$$P_{abc} = V_{abc} I_{abc} C \qquad (3)$$

The simulation for neutral point potential control is done using MATLAB simulink software, which controls the neutral point clamped inverter output fed to the AC grid. This model can be shown as in Fig.8.

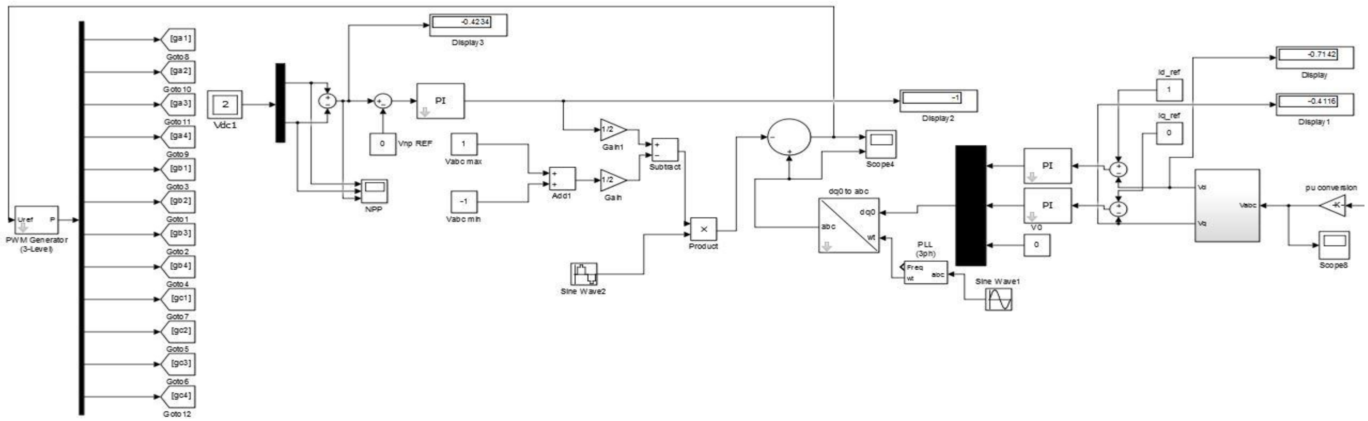

Fig.8 Neutral point potential control model in MATLAB

V. RESULTS AND DISCUSSION

A. *Output Of Grid Side Converter*

The simulation results of output voltage and current fed to the AC grid is shown in Fig.9. From the grid side converter, here a three level neutral point clamped multilevel inverter is used as grid side converter.

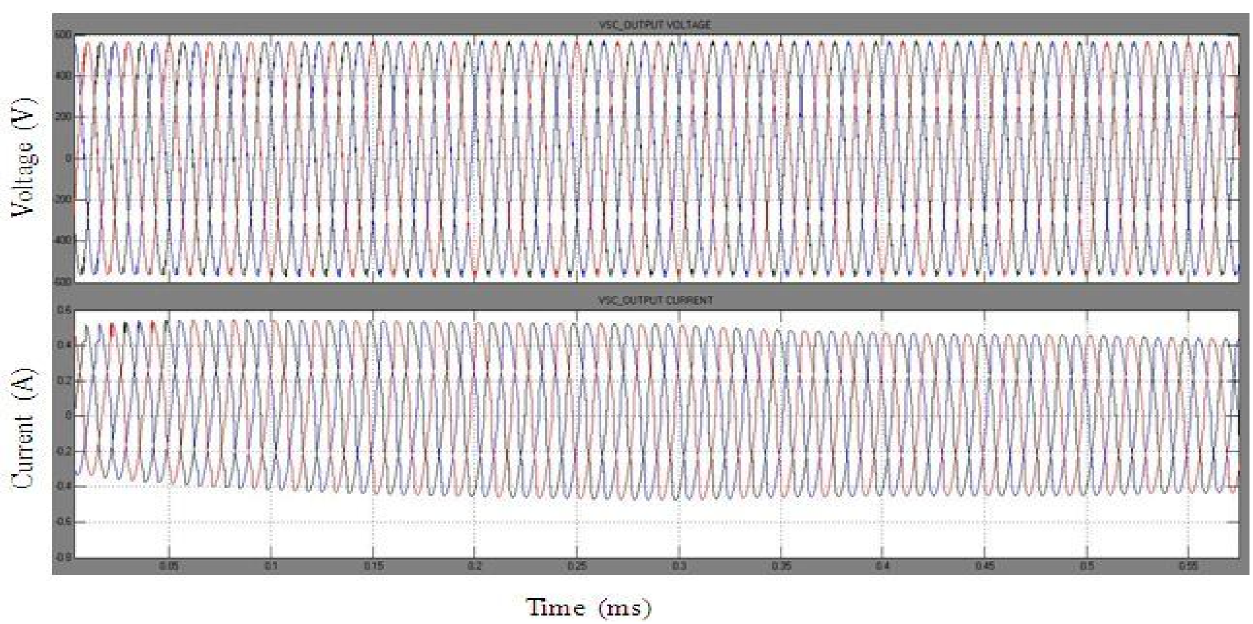

Fig.9 Output of grid side converter

It is observed that the voltage of the AC grid is not distorted due to variation in load conditions. As well the requirement of filter circuits is eliminated by using the NPC inverter.

B. Frequency Regulation

The frequency response of the test system for varying load conditions is shown in Fig.10.

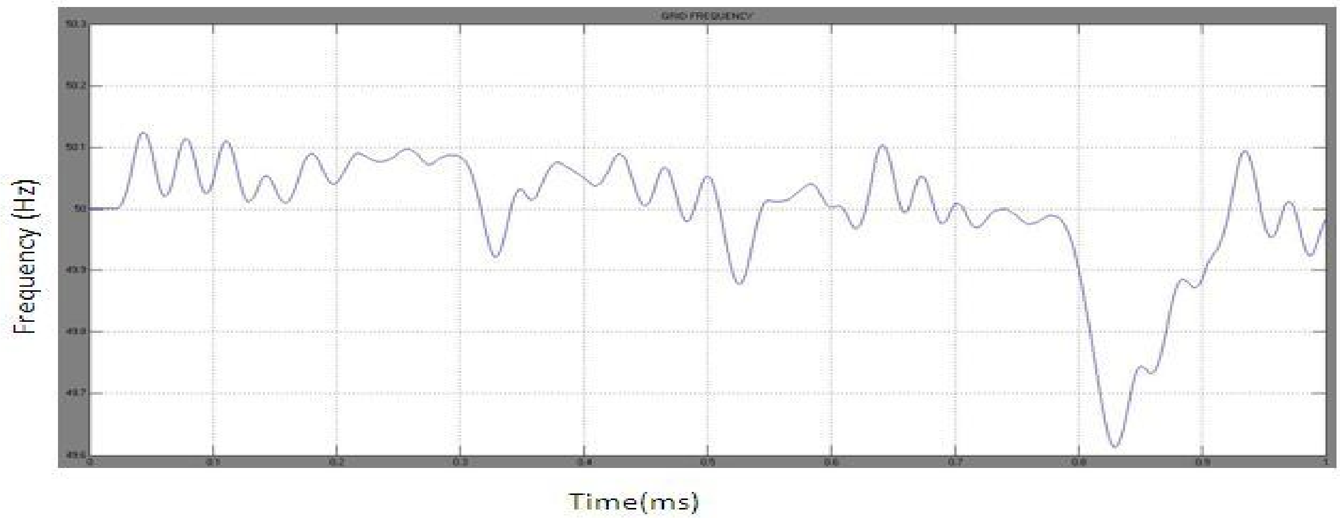

Fig.10 Frequency response of test system

It is observed that the frequency response of the test system is maintained in the range of 49.65Hz to 50.2 Hz, despite of the load variation.

VI. CONCLUSION

The frequency response of the offshore wind farm is improved by utilizing a voltage source converter based high voltage DC transmission system, with an efficient control strategy has been designed. The control strategy is attained by modifying the wind farm side converter with a Vienna rectifier, and the grid side converter with neutral point clamped multilevel inverter. The frequency response attained by the system is observed that the range is maintained in the range of 49.65 Hz to 50.2Hz. Thus the objective function of the proposed model to improve the frequency response of Offshore Wind Farm (WFs) is obtained. And also by using the neutral point clamped inverter model, the requirement of large filter circuits is eliminated.

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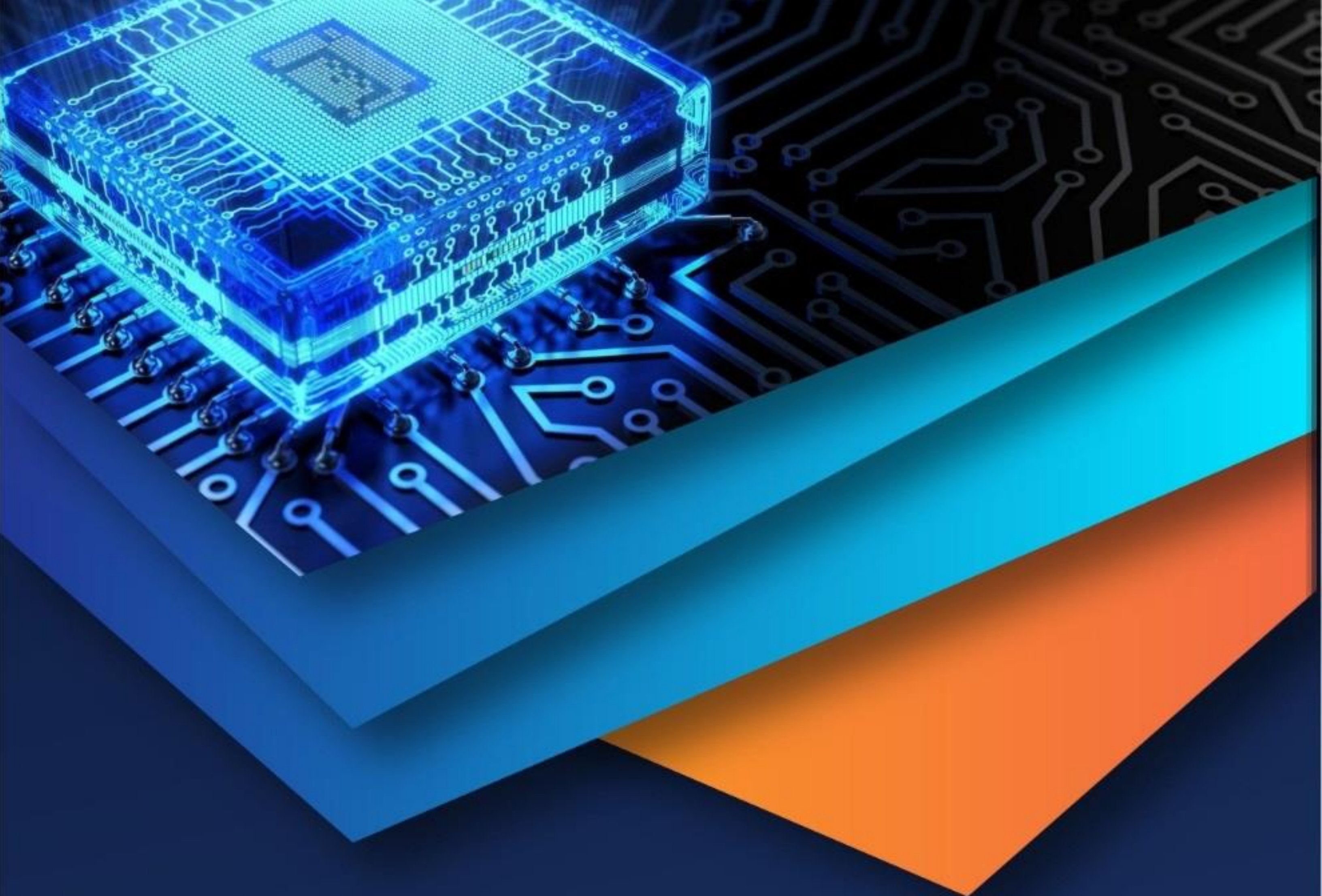

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