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STATCOM based Power Quality Improvement in Wind Farm Fed Multi-Machine System

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Abstract— In this project, the simulation results of using a static synchronous compensator (STATCOM) to achieve damping improvement of an offshore wind farm (OWF) fed to a multi-machine system is presented. The operating performance of the studied OWF is simulated by an equivalent aggregated doubly-fed induction generator (DFIG) driven by an equivalent aggregated wind turbine (WT) through an equivalent gearbox. A PI damping controller and ANN of the proposed STATCOM are designed to contribute adequate damping characteristics to the dominant modes of the studied system under various operating conditions. Abstract paper deals with modulling and simulations of fourteen bus system employing closed loop controlled STATCOM.

Two bus and fourteen bus system are modeled and simulated using MATLAB simulink and the result are presented. The response of the system with PI and neural network are compared.

Keywords- STATCOM , artificial neural network, Offshore Wind farm, Doubly-fed induction generator, Wind turbine, Alternating Current, Direct Current..

I. INTRODUCTION

The project titled **"STATCOM based Power Quality Improvement in Wind Farm Fed Multi-Machine System"** uses DOUBLY-FED induction generator (DFIG) is, currently, the most employed wind generator due to its several merits. One of the advantages is the higher efficiency compared to a direct-drive wind power generation system with full-scale power converters since only about 20% of power flowing through power converter and the rest through stator without power electronics. Another advantage of a wind DFIG is the capability of decoupling control of active power and reactive power for better grid integration. However, by connecting stator windings directly to the power grid, a wind DFIG is extremely sensitive to grid faults. Moreover, wind energy is a kind of stochastic energy, implying that the output of OWF varies in a certain range due to unstable wind characteristic. Therefore, the operating point of the power system changes from time to time when the wind power is integrated with the power system. Several published papers have discussed how to reduce the negative influences of the power grid on DFIG-based wind farms . In DFIG-based OWF connected to a power grid through a line-commutated high-voltage direct-current (HVDC) with a damping controller located at the rectifier current regulator of the HVDC link was proposed to contribute adequate damping to the OWF under various wind speeds and different disturbance conditions. But this control scheme was only suitable for the systems having a long distance from OWFs to onshore grids. In , a variable frequency transformer (VFT) was proposed to smooth the fluctuating active power generated by the OWF sent to the power grid and improve the damping of the OWF. These papers, however, just considered a power grid as an infinite bus that is not a practical power system

1.2 OBJECTIVE

The objective of the project is to **STATCOM based Power Quality Improvement in Wind Farm Fed Multi-Machine System** Comparative time-domain simulations of the studied system subject to a three-phase short-circuit fault at the connected bus have been systematically performed to demonstrate the effectiveness of the proposed STATCOM joined with the two designed damping controllers on suppressing inherent oscillations of the studied system. It can be concluded from the simulation results that the proposed STATCOM joined with the designed ANN damping controller has the best damping characteristics to improve the performance of the DFIG-based OWF fed to the studied multi-machine system under different operating conditions.

II. LITERATURE REVIEW

2.1 SYSTEM CONFIGURATION

This chapter deals with the operation principle of STATCOM. Fig. 2.1 shows the configuration of the studied system. A DFIG based OWF of 100 MW and a STATCOM of 50-MVAR are connected to bus 9 of a three-machine nine-bus system. The OWF is represented by a large equivalent aggregated DFIG driven by an equivalent aggregated variable-speed wind turbine (VSWT) through an equivalent gearbox

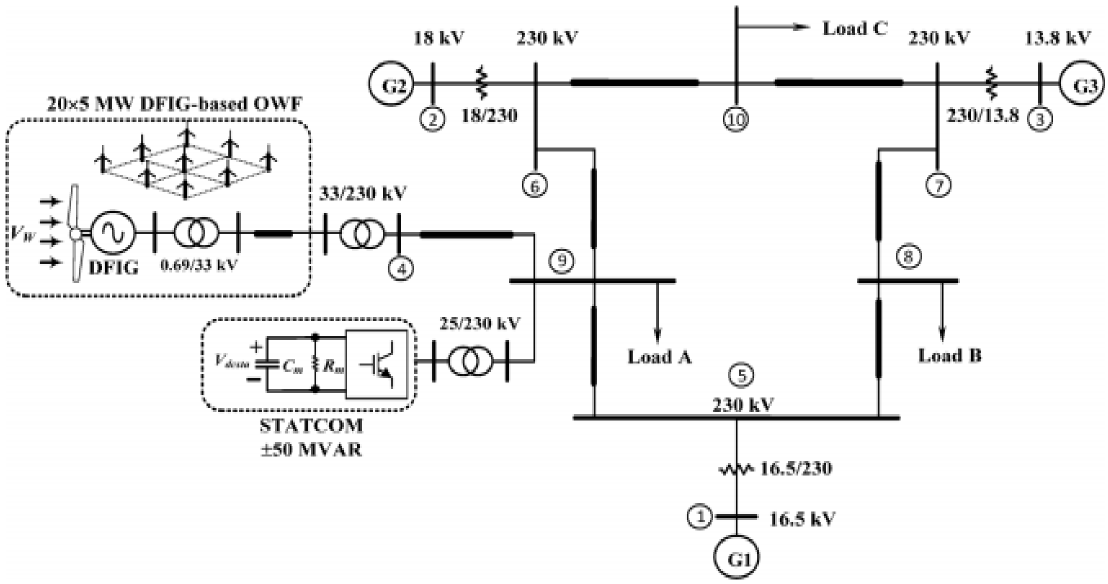


Fig 2.1 Configuration of the studied system.

2.2 DFIG-Based OWF

The stator windings of the studied wind DFIG are directly connected to the low-voltage side of the 0.69/33-kV step-up transformer while the rotor windings of the DFIG are connected to the same 0.69-kV side through a rotor-side converter (RSC), a
DC link, a grid-side converter (GSC), and a connection line. For normal operation of a DFIG, the input AC-side voltages of the RSC and the GSC can be effectively controlled to achieve the aims of simultaneous output active-power and reactive-power
control .

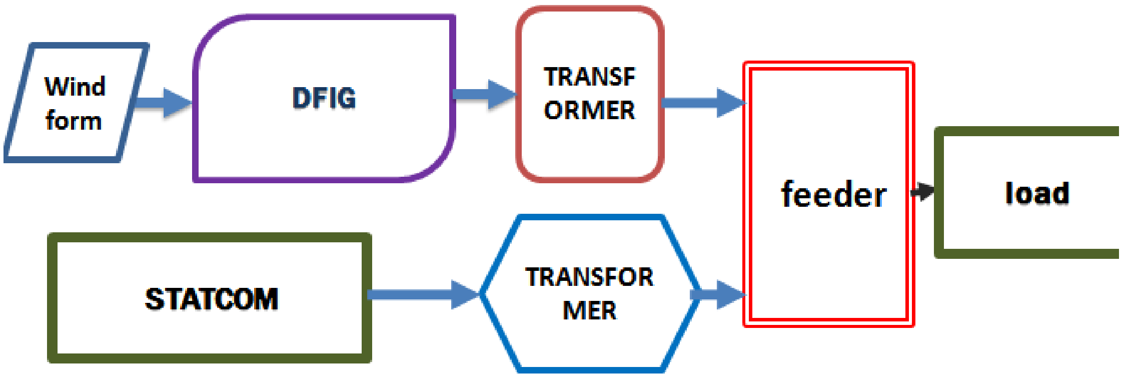


Fig 2.2 simulation block diagram

Fig. 2.2 shows the simulation block diagram of the RSC, and the operation of the RSC requires and to follow the varying reference points that are determined by maintaining the output active power and the stator-winding voltage at the setting values, respectively. The required voltage for the RSC is derived by controlling the pu - and -axis currents of the RSC. The pu - and -axis currents of the GSC, and , have to track the reference points that are determined by maintaining the DC link voltage at the setting value and keeping the output of the GSC at unity power factor, respectively. The required pu voltage of the GSC is derived by controlling the per-unit - and -axis currents of the GSC .

2.3 Three-Machine fourteen-Bus System

The well-known three-machine nine-bus power system which is widely used in power system stability studies. The complete parameters of this system can be referred to. In this paper, each synchronous generator is represented by a two-axis model whose block diagram . In this model, the transient effects are accounted for while the sub transient effects are neglected. The additional assumptions made in this model are that the transformer-voltage terms in the stator voltage equations are negligible compared to the speed-voltage terms and the rotational speed is approximate to the rated speed of 1.0 pu. Consider the multi-machine system with constant impedance loads shown in Fig. 5 whose network has three generators and three loads. Assume that the three loads are represented by three constant impedances while three generators are represented by three active sources. Therefore, all the nodes have zero injection currents except for the generator nodes. This property is used to obtain the network reduction as shown below.

2.4 Design of a PI Damping Controller

This subsection describes the design procedure and design results of the PI damping controller for the proposed STATCOM to achieve stability improvement of the studied system using a unified approach based on modal control theory. The nonlinear system equations developed in the previous section are linearized around a selected nominal operating point to acquire a set of linearized system equations in matrix form of

$$pX = AX + BU + VW$$
$$Y = CX + DU$$

where is the state vector, is the output vector, is the external or compensated input vector, is the disturbance input vector while , , , and are all constant matrices of appropriate dimensions. To design the PI damping controller for the STATCOM can be properly ignored by setting . The state vector can be partitioned into three substate vectors as , where and are referred to the system state vectors of the three SGs, the DFIG-based OWF, and the STATCOM, respectively. Because wind speed seldom reaches the rated wind speed of 14m/s, of 12m/s is properly selected as the nominal operating point for designing the PI damping controller. The eigenvalues of the studied three-machine nine-bus system without DFIG-based OWF and with the DFIG-based OWF and the proposed STATCOM are listed . The following points can be found by examiningthe system eigenvalues listed .

1) All modes of the system are almost fixed on the complex plane regardless the addition of the designed PID
damping controller for STATCOM.

2) The modes and relating to the rotor angle deviation between G1 to G2 and the rotor angle deviation between G1 to G3 , respectively are changed and these modes can be improved by damping controllers. The control block diagram of the STATCOM including the designed PID damping controller. The PI damping controller with a first order wash-out term senses the rotor speed deviation of the G1 and G2 to generate a damping signal in order to improve the damping ratios of two modes of studied system . Hence, the output signal in the input vector.

2.6 Advantages

1. Reduced losses.
2. High stable system.
3. Reduced voltage drop.
4. High Efficiency.
5.

2.7 Applications

1. Power Systems.
2. Distribution Systems.

2.8 Conclusion

This chapter has presented STATCOM, aits operation , PI controller, and bus topology.

III. SIMULATION RESULTS OF TWO BUS SYSTEM

Simulation has become a very powerful tool on the industry application as well as in academics, nowadays. It is now essential for an electrical engineer to understand the concept of simulation and learn its use in various applications. Simulation is one of the best ways to study the system or circuit behavior without damaging it .The tools for doing the simulation in various fields are available in the market for engineering professionals. Many industries are spending a considerable amount of time and money in doing simulation before manufacturing their product. In most of the research and development (R&D) work, the simulation plays a very important role. Without simulation it is quiet impossible to proceed further. It should be noted that in power electronics, computer simulation and a proof of concept hardware prototype in the laboratory are complimentary to each other. However computer simulation must not be considered as a substitute for hardware prototype. The objective of this chapter is to describe simulation of impedance source inverter with R, R-L and RLE loads using MATLAB tool.

Simulation results

3.1 ANN controlled system

The simulink model of the ANN controlled 2 bus system is shown in Fig 3.1. STATCOM is used to compensate the output voltage when ever the voltage sag occurs in the system.

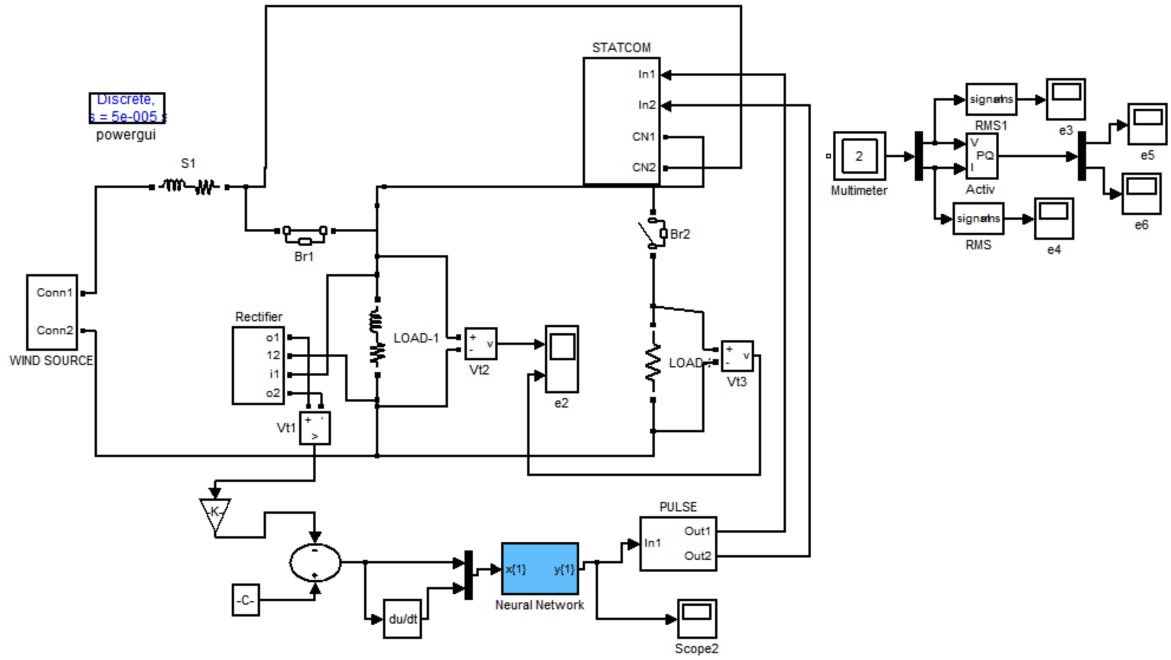


Fig 3.1 Simulink model of the STATCOM controlled system with ANN

The voltage across loads 1 & 2 are shown in Figs 3.2 and 3.3 respectively. The load is switched on at the 2.5s seconds. Thus the dip in voltage has occurred at the load. So the STATCOM is connected to mitigate the voltage sag. The RMS voltage voltage is shown in Fig 3.4.

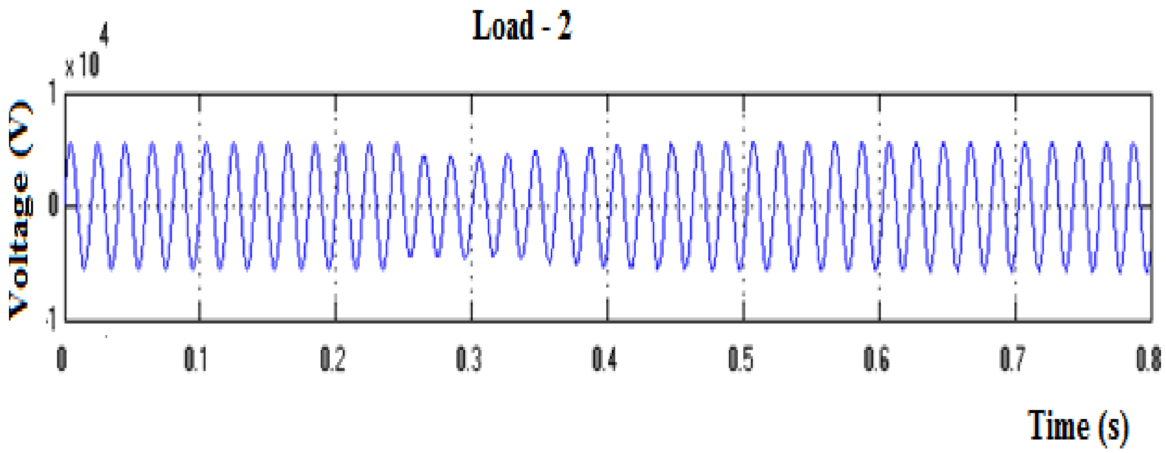


Fig 3.2 output voltage waveform across load 1

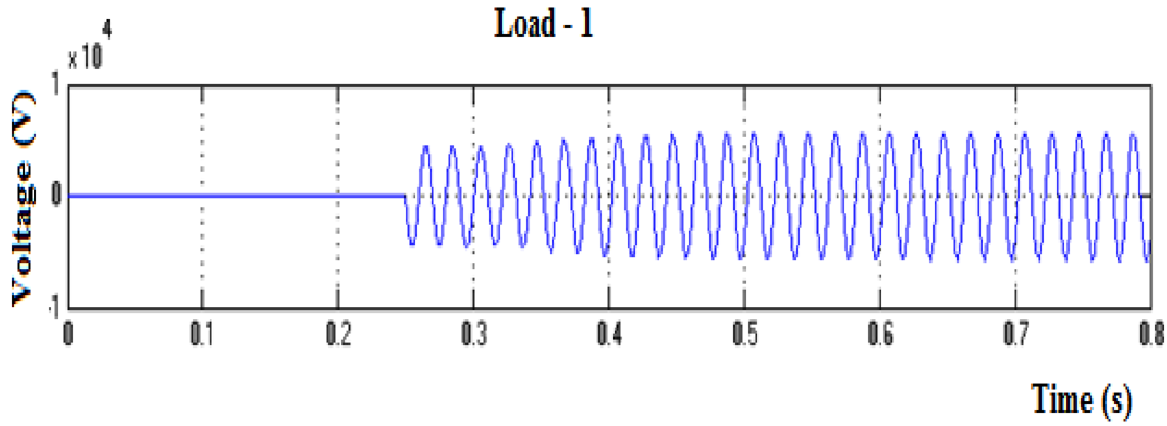


Fig 3.3 output voltage waveform across load 2

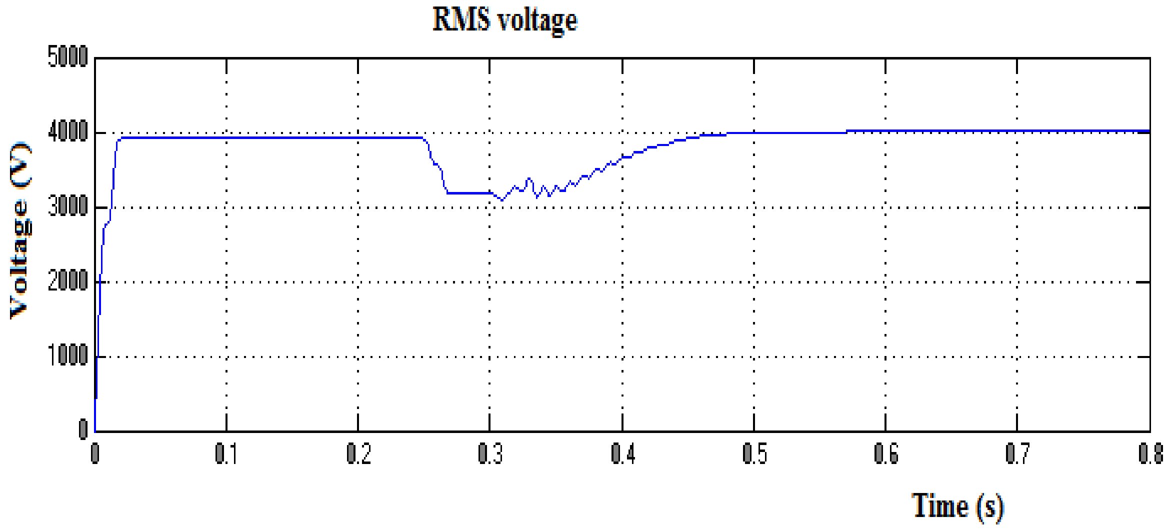
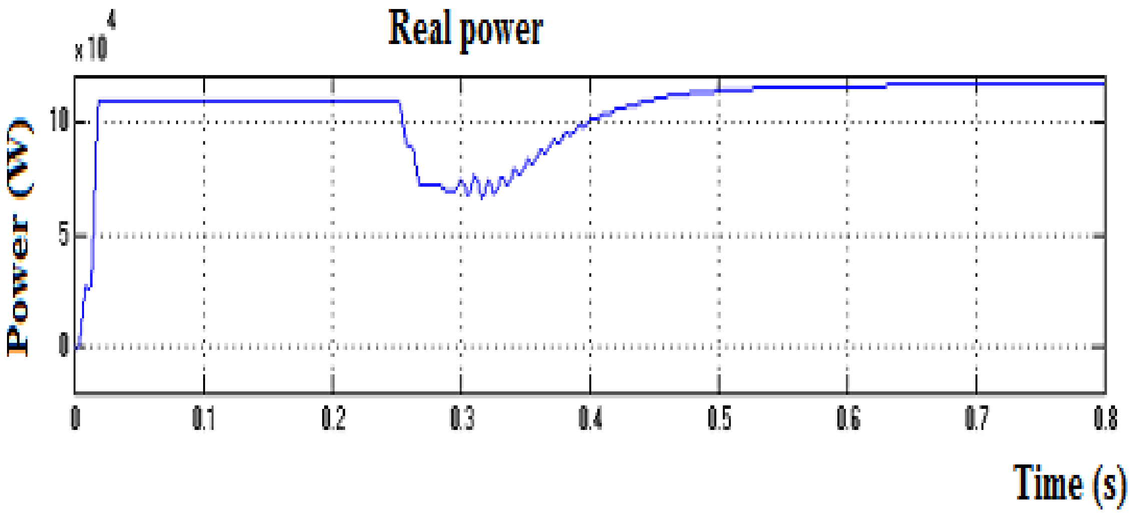


Fig 3.4 RMS output voltage waveform across load

The corresponding real and reactive power are shown in Fig 3.7 and 3.8 respectively



Fig

3.5 real power waveform

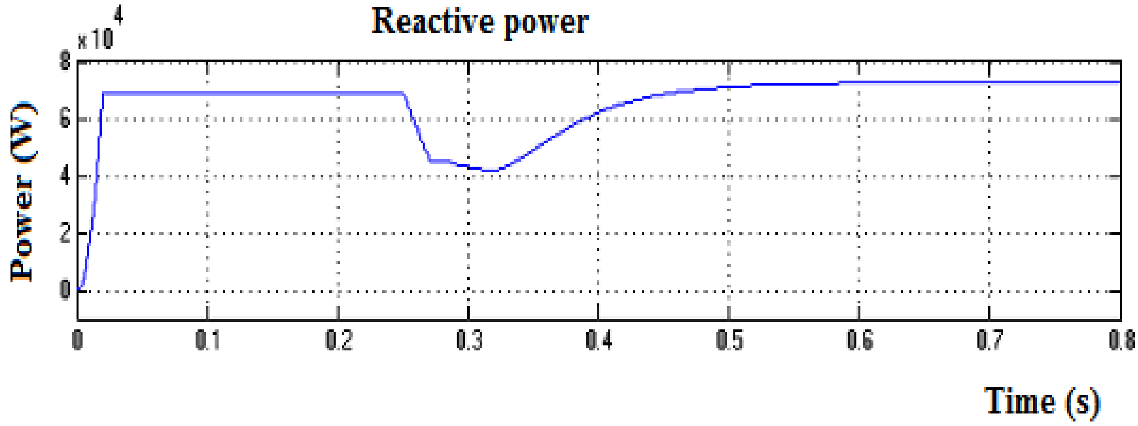


Fig 3.6 reactive power waveform

3.2 PI controlled system

The simulink model of the PI controlled 2 bus system is shown in Fig 3.7. STATCOM is used to compensate the output voltage when ever the voltage sag occurs in the system.

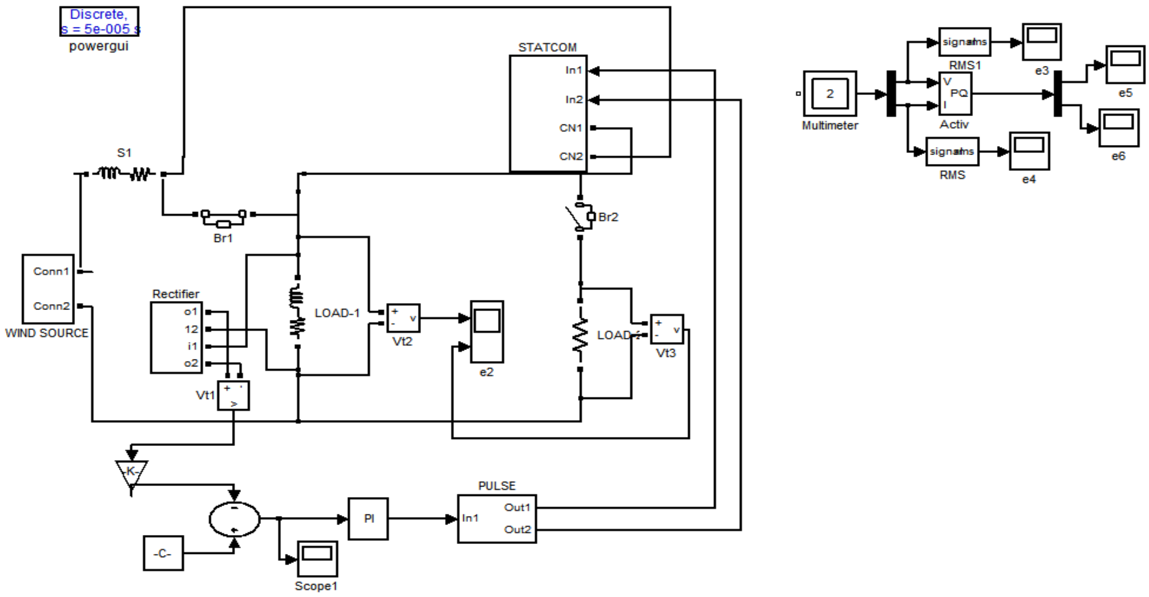


Fig 3.7 Simulink model of the STATCOM controlled system with PI controller

The voltage across loads 1 & 2 are shown in Figs 3.8 and 3.9 respectively. The load is switched at t= 2.5 seconds. Thus the dip in voltage has occurred at the load. So the STATCOM is connected to mitigate the voltage sag. The RMS voltage voltage is shown in Fig 3.10.

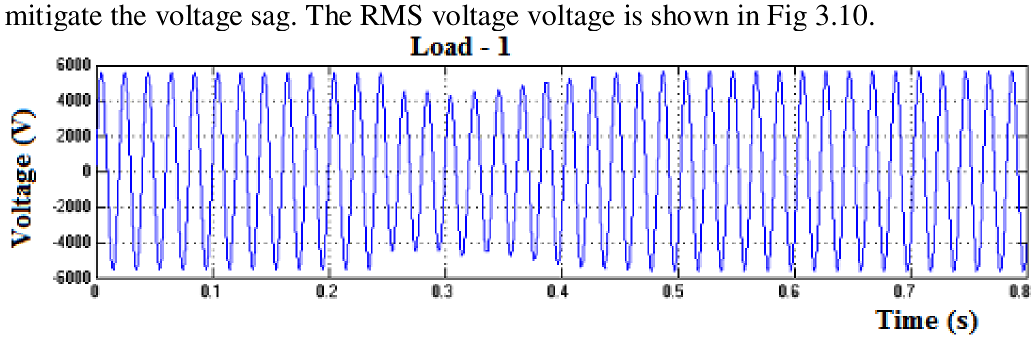


Fig 3.8 output voltage waveform across load 1

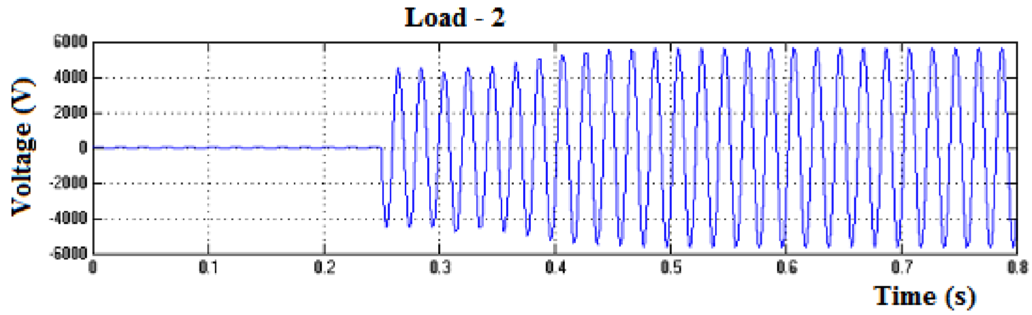


Fig 3.9 output voltage waveform across load 2

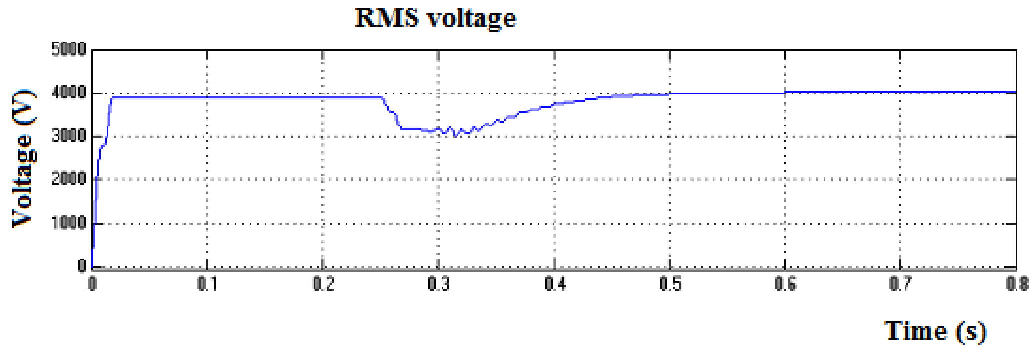


Fig 3.10 RMS output voltage waveform across load

The corresponding real and reactive power is shown in Figs 3.11 and 3.12 respectively

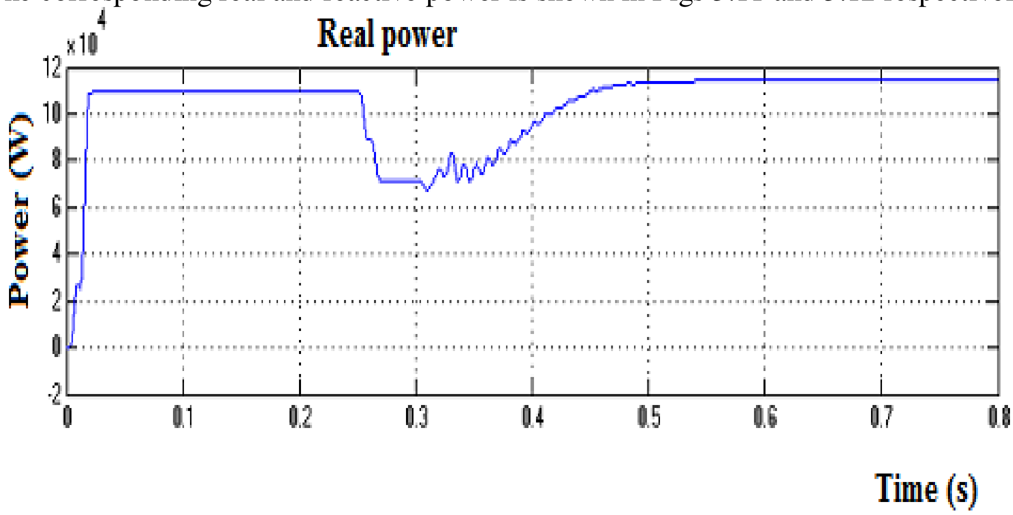


Fig 3.11 real power waveform

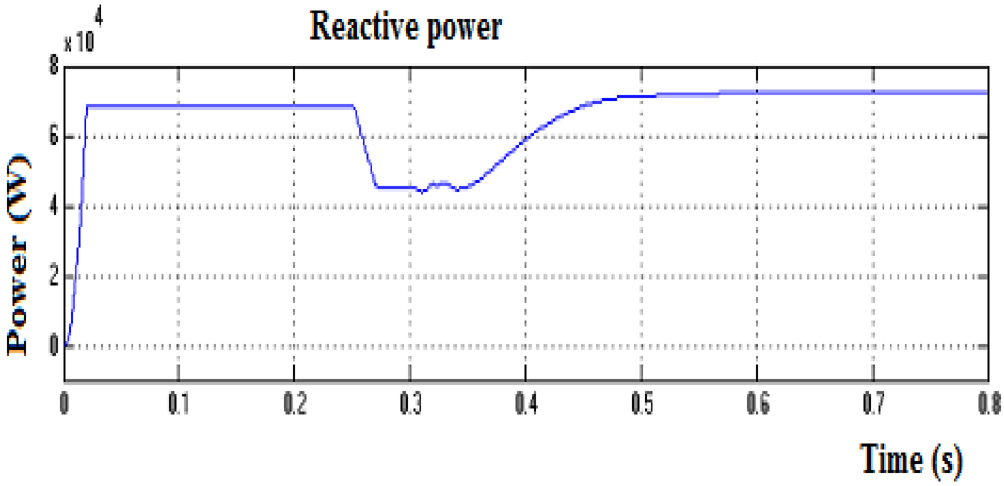


Fig 3.12 reactive power waveform

The comparsion of the closed loop system with PI controller and ANN is lised in Table 1.

Table 1

Controllers	Settling time (s)	Steady state error (V)
PI controller	0.5	5
ANN	0.43	1

3.6 CONCLUSIONS

The response of two bus system for both PI controller and ANN is compared. It is observed that ANN acts faster in the mitigating the sag compared to the PI controller.

IV. CONCLUSION

This work has presented the power quality improvement of multibus system using a STATCOM. The STATCOM is proposed and is connected to the connected bus of the OWF to the multi-machine system.

Two bus and fourteen bus systems are modelled and simulated successfully and the simulations result are reported. The voltage is controlled using PI and neural network controllers. The response is found to be smother by using ANN controller.

This work has presented the result of two bus and fourteen bus system .the thirty bus and fifty bus system can be simulated in future.

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