A Comparative Study on Power Quality Improvement in a Hybrid System Using DVR and STATCOM vs. Distributed Power Flow Controller (DPFC)

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Abstract - According to growth of electricity demand and the increased number of non-linear loads in power grids, providing a high quality electrical power should be considered. The use of renewable energy resources to meet the load and to reduce the use of finite resources are also increased. In this paper, voltage sag and swell of the power quality issues due to the load and a wind turbine system are studied. A power system is said to be more reliable when it is stable and is able to supply the load without any harmonics and power fluctuations. The use of flexible ac transmission (FACT) devices can be used to mitigate the power quality issues. The distributed power flow controller (DPFC) is used to mitigate the voltage deviation and improve power quality. The DPFC is a new FACTS device, which its structure is similar to unified power flow controller (UPFC) which is a combined series-shunt compensator. Thus a comparative study on the use of a series and shunt fact controller with a combined series-shunt fact controller is done. A system with Static Synchronous Compensator (STATCOM), which is a shunt compensator and Dynamic Voltage Restorer (DVR), a series compensator is studied. These FACT devices are replaced by DPFC. The system is studied in MATLAB/Simulink environment. The presented simulation results validate the DPFC ability to improve the power quality.

***Key Words*:** FACTS, Power Quality, Sag and Swell Mitigation, Distributed Power Flow Controller

1. INTRODUCTION

The power quality issues have become an increasing concern in distribution system due to the wide applications of sensitive load and disturbances. Poor power quality results in power disruption for the user and huge economic losses due to the interruption of production processes. Electrical power is perhaps the most essential raw material used by commerce and industry today, so that the improvement or maintaining the power quality is an important concern. There are many power quality problems in the distribution system like, voltage sag, voltage swell, voltage flicker, harmonics, power factor problems, unbalances etc. Recently, the Power electronics converters/controllers are developed to provide the quality of power for both power suppliers and consumers. Various power filtering technology i.e. passive filters, active power filters, hybrid filters have applied from time to time for giving the solution of power quality problems to users, But could not fully satisfied them.

The growing demand and the aging of networks make it desirable to control the power flow in power-transmission systems fast and reliably [1]. The increased concern in power quality issues and to get balanced, uninterrupted supply at the customer side the power electronic concept the flexible ac-transmission system (FACTS) was invented. This FACTS concept is a solution for power quality issues, both in the transmission side as well as distribution side. The flexible ac-transmission system (FACTS) that is defined by IEEE as “a power-electronic based system and other static equipment that provide control of one or more ac-transmission system parameters to enhance controllability and increase power-transfer capability” [2], and can be utilized for power-flow control. The power quality issues are considered to be serious problems, both in the transmission and distribution side. Many papers are there regarding the mitigation of power quality issues. When the system have renewable energy resources connected in the grid, the whole system may get interrupted. There’s a need to find solutions to these problems, using different technologies such as smart meters, monitoring system, controllers, remote ability. These stability issues, reliability and power quality issues which need to be solved properly.

2. POWER QUALITY ISSUES DUE TO WIND TURBINE SYSTEM

The distributed generation system and the use of renewable resources like wind farm, photovoltaic system has increased the power quality issues. The power variation from renewable sources such as wind and solar can cause voltage fluctuations. The use of electrical system for interfacing the system to utility system can cause power quality issues. The chief power quality issue associated with wind generation is voltage regulation. Wind generation tends to be located in sparsely populated areas where the electrical system is weak relative to the generation capacity [3]. This results in voltage variations that are difficult to manage. Thus, it is sometimes impossible to serve loads from the same feeder that serves a wind farm.

The power fluctuation from wind turbine during continuous operation causes voltage fluctuation on grid. The amplitude of this fluctuation depends on grid strength, network impedance, and phase angle and power factor [4]. The voltage fluctuation and flicker are caused due to switching operation, pitch error, yaw error, fluctuation of wind speed. The assessment of power quality on grid connected wind turbine is defined by IEC 61400-21 and stated that the 10 minute average of voltage fluctuation should be within +/- 5% of nominal value.

Traditional wind turbine is equipped with induction generator. Induction Generator is preferred because they are inexpensive, rugged and requires little maintenance. Unfortunately induction generators require reactive power from the grid to operate. The interactions between wind turbine and power system network are important aspect of wind generation system [5].

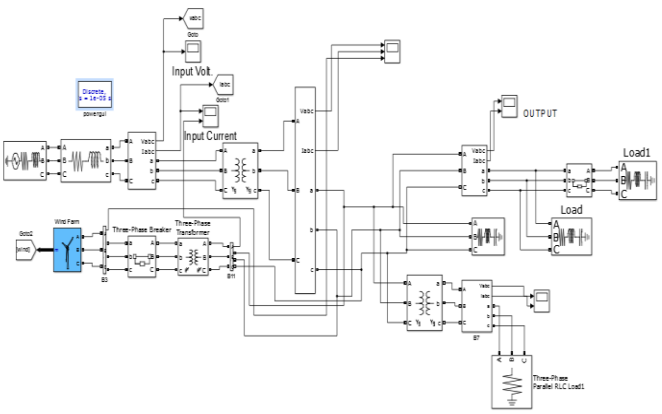


Fig -1: Wind turbine system without any FACT devices

When wind turbine is equipped with an induction generator and fixed capacitor are used for reactive compensation then the risk of self-excitation may occur during off grid operation. Thus the sensitive equipment may be subjected to over/under voltage, over/under frequency operation and other disadvantage of safety aspect. According to IEC Standard, reactive power of wind turbine is to be specified as 10 min average value as a function of 10-min. output power for 10%, 20%... 100% of rated power. Fig.1 shows the conventional WTIGS system without FACT device.

3. CONVENTIONAL SYSTEM WITH STATCOM

STATCOM is mainly used to mitigate the voltage sag and swell. There different types for control methods which can be used for the controller of a STATCOM. Here hysteresis band controller which is a common control is used in the conventional system. STATCOM is shunt compensator. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system [6].

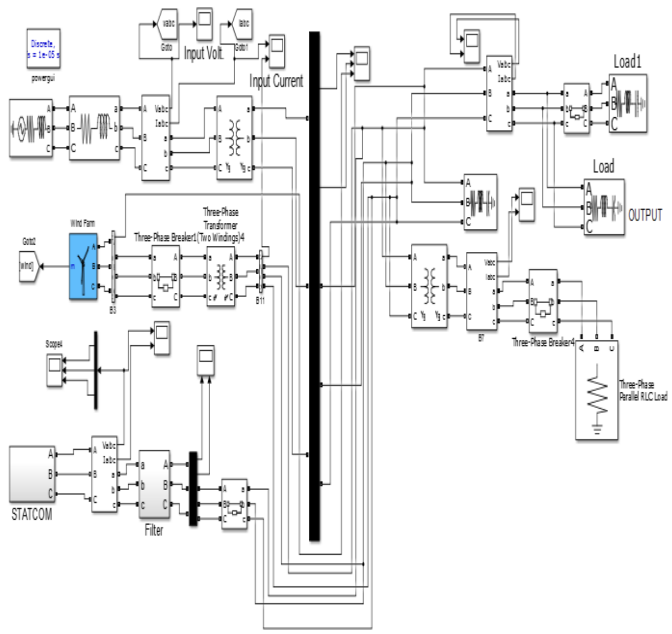
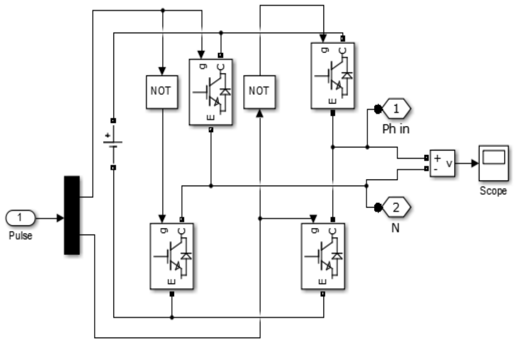


Fig -2: WTIG system with STATCOM

The current control strategy is included in the control scheme that defines the functional operation of the STATCOM compensator in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system.

Fig.2 shows the conventional system with STATCOM. The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the nonlinear load and wind generator. The source current on the grid is affected due to the effects of nonlinear load and wind generator, thus purity of waveform may be lost on both sides in the system. The inverter output voltage under STATCOM operation with load variation and the inverter control simulation is given in Fig.3.



4. CONVENTIONAL SYSTEM WITH DVR

DVR is an effective device to protect the sensitive loads from any disturbance. The DVR can also mitigate voltage sags and swells, and compensate line voltage harmonics [6]. The basic structure of conventional DVR includes voltage source inverter (VSI), an energy storage system, coupling transformer and control system. The VSI generates a three-phase ac output voltage which is controllable in magnitude and phase.

The control system of a DVR plays an important role, with the requirements of fast response in the face of voltage sags and variations in the connected load. DVR uses an open loop control for the DVR system using PLL. The PLL is to synchronize the DVR with the power system by generating a reference voltage to be compared with the actual one. To do so the control system takes the abc components of the load voltage transforms them into the synchronous reference frame dq0 and compares it to the reference voltage Vref of the system. With Vdref relative to the system and Vqref is equal to 0. They are passed by a PI controller and then the reference voltage injected is generated.

As for the control of the DVR many techniques exist to control the voltage injection, the chosen one is the Space Vector Pulse Width Modulation (SVPWM) which is proven very effective and gives a better result than conventional PWM in terms of THD and power quality. The reference phasor consists of phase, frequency and magnitude components. All will vary to some point during normal network operation [7].

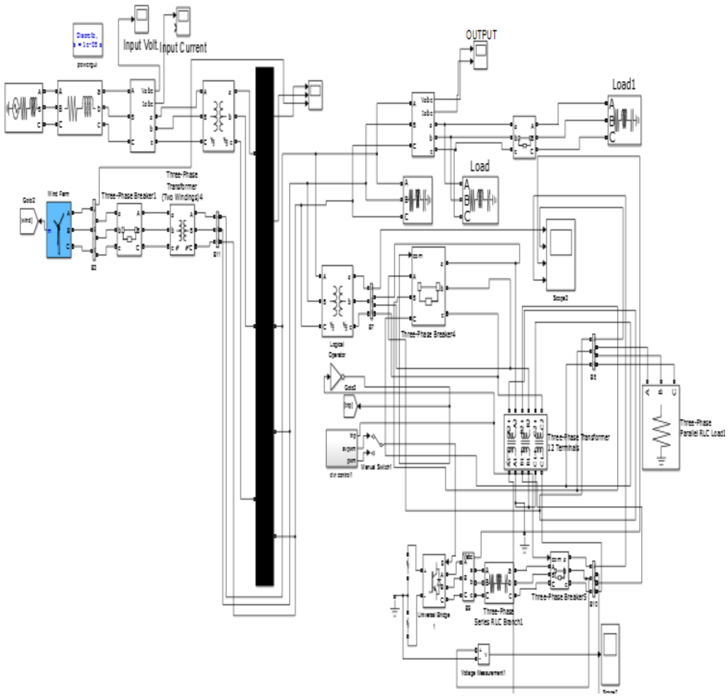


Fig -4: WTIG system and DVR

5. CONVENTIONAL SYSTEM WITH DVR AND STATCOM

The combination of DVR and STATCOM along with the conventional system will give the advantage of controlling the power quality issues and the disturbance in the load side together. The Fig.5 is the Simulink modelled conventional system with DVR and STATCOM. The Simulink diagram shows that in the conventional grid system we are using two FACT devices to get the desired output. When a wind turbine is initially connected to the grid, it needs reactive power for the induction generator to start producing electric power. This causes the voltage to drop at the PCC. At this instant the DVR should start its operation and compensate for the voltage drop at the critical load [8].

After the wind turbine is initialized and running and after the Non-Linear load is connected to the system, the voltage and current at the PCC will be distorted and need to be filtered. Here the STATCOM (Active filter) is activated and will inject the exact current into the system needed to cancel the effect of the harmonics [8]. When DVR and STATCOM are connected together in the conventional system, then only we will get desired voltage and current at the load side and there won't be fluctuation or power quality issue at PCC.

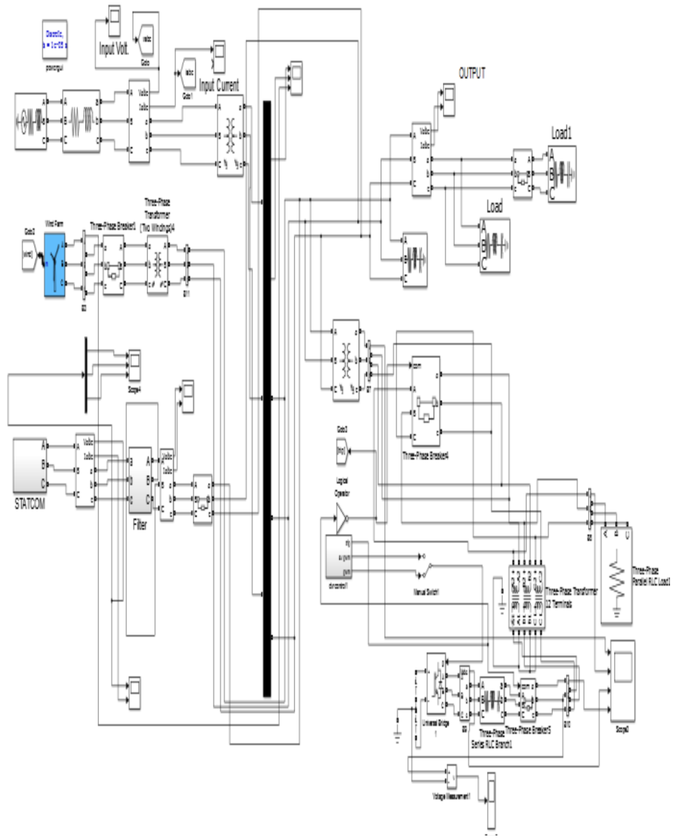


Fig -5: Conventional grid system with DVR and STATCOM

6. MODELLING OF PROPOSED SYSTEM

In the conventional grid system we are using two FACT devices to get the desired output. This led me to the proposed system of using a combined series-shunt compensator such as DPFC. DPFC is an advanced version of unified power flow controller (UPFC) which is also a combined series shunt compensator. Generally the DPFC are described to use for distribution side, but as it has the feature of both series and shunt compensator it can be designed in such a way that it can compensate the transmission side power quality problems.

To control the multiple converters, DPFC consists of three types of controllers; they are central controller, shunt control, and series control. The central control is to generate reference signals.

6.1 Serial control

The controller is used to maintain the capacitor dc voltage of its own converter by using the third-harmonic frequency components and to generate series voltage at the fundamental frequency that is prescribed by the central control [9]. The block diagram is given in Fig.6.

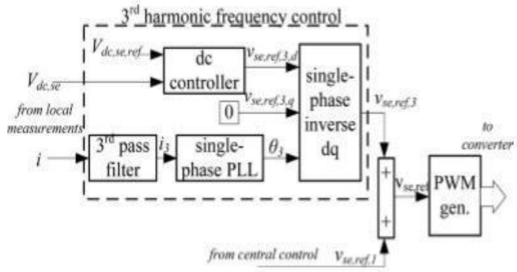


Fig -6: Series converter control

The third-harmonic frequency control is the major control loop with the DPFC series converter control. The principle of the vector control is used here for the dc-voltage control [9]. The third-harmonic current through the line is selected as the rotation reference frame for the single-phase park transformation, because it is easy to be captured by the phase-locked loop (PLL) [8] in the series converter. As the line current contains two frequency components, a third high-pass filter is needed to reduce the fundamental current. The d-component of the third harmonic voltage is the parameter that is used to control the dc voltage, and its reference signal is generated by the dc-voltage control loop.

To minimize the reactive power that is caused by the third harmonic, the series converter is controlled as a resistance at the third-harmonic frequency. The q-component of the third-harmonic voltage is kept zero during the operation. As the series converter is single phase, there will be voltage ripple at the dc side of each converter. The frequency of the ripple depends on the frequency of the current that flows through the converter.

6.1 Shunt control

The block diagram of the shunt converter control is shown in Fig.7. The objective of the shunt control is to inject a constant third harmonic current into the line to provide active power for the series converters. The third-harmonic current is locked with the bus voltage at the fundamental frequency. A PLL is used to capture the bus-voltage frequency, and the output phase signal of the PLL is multiplied by three to create a virtual rotation reference frame for the third-harmonic component.

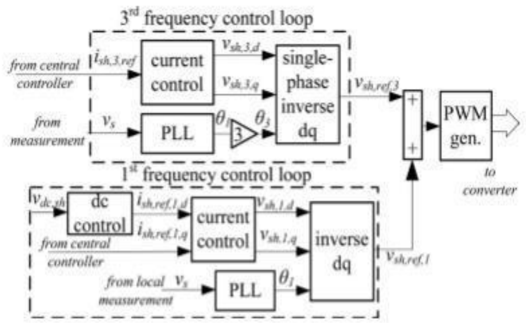


Fig-7: Shunt converter control

The shunt converter's fundamental frequency control aims to inject a controllable reactive current to grid and to keep the capacitor dc voltage at a constant level. The q-component of the reference signal of the shunt converter is obtained from the central controller, and d-component is generated by the dc control. The Fig.8 shows the conventional system with proposed DPFC system.

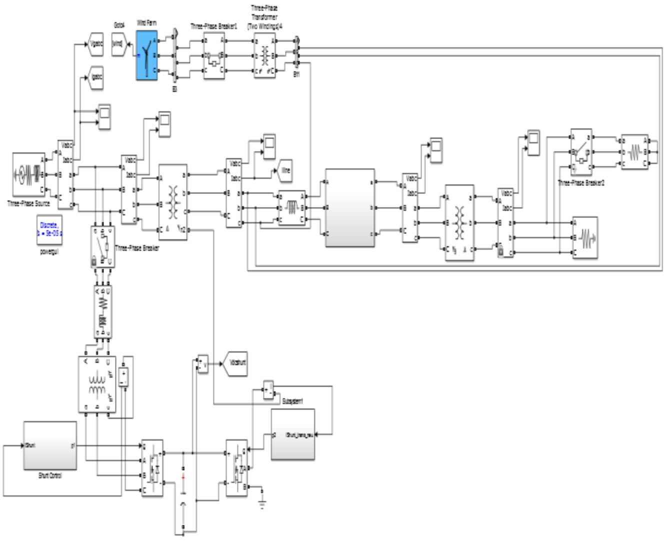
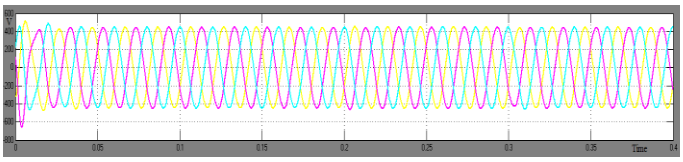


Fig-8: Conventional WTIGS system with proposed DFPC FACT device

7. SIMULATION RESULTS AND COMPARISON

The study is mainly done to find out whether a combined series shunt compensator can be used to replace the use of a STATCOM and DVR. Fig.2 is the MATLAB Simulink diagram of STATCOM with WTIGS system. The result of the respective simulation is given in the Fig.9.



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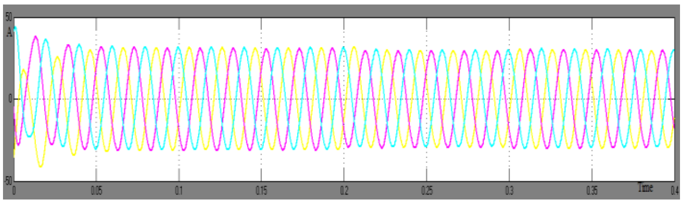

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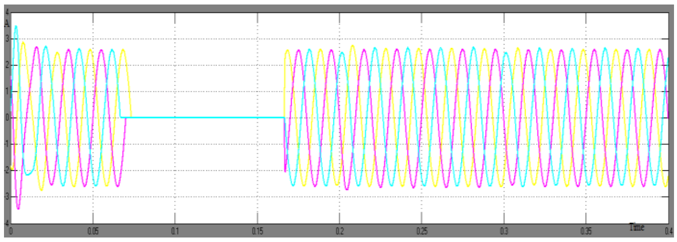
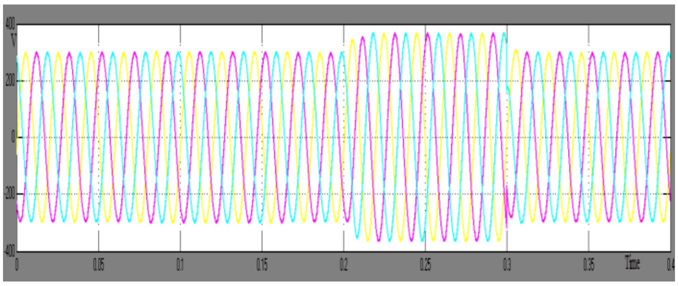


Fig-9: MATLAB/SIMULINK result using STATCOM (a) voltage at PCC, (b) current at PCC, (c) Current at non-linear load

The simulation result shows that the STATCOM have influence only on the PCC not at the load side. Similarly DVR simulation result is given in the Fig.10.



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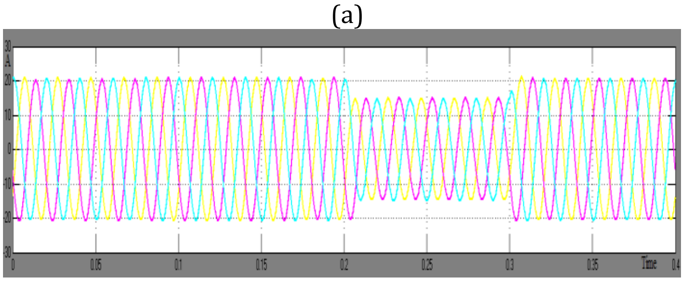

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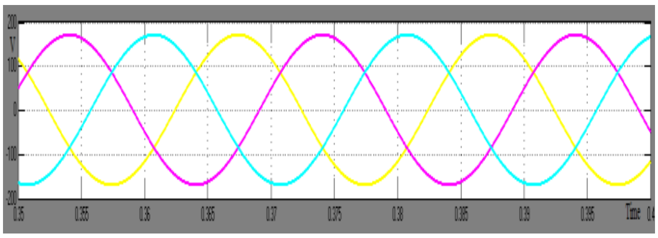
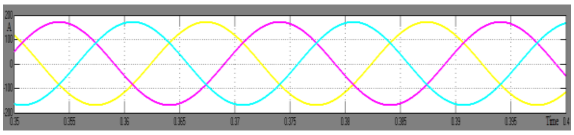


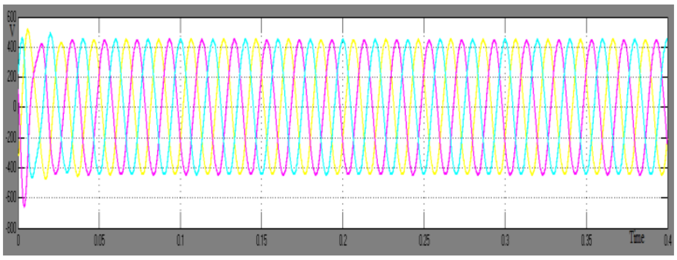
(c)

Fig-10: MATLAB/SIMULINK result (a) voltage at PCC, (b) current at PCC, (c) Voltage at non-linear load

From Fig.10 it is clear that DVR influences load side alone as the voltage at load side is without any sag or swell. But at PCC the voltage and current has swell and sag. This might be considered as a power quality issue even after the use of FACT device. But when the MATLAB Simulink diagram Fig.7 was studied, the use of DVR and STATCOM together compensate the power quality issues



of load and issues at PCC. The simulation result is given in Fig.11.



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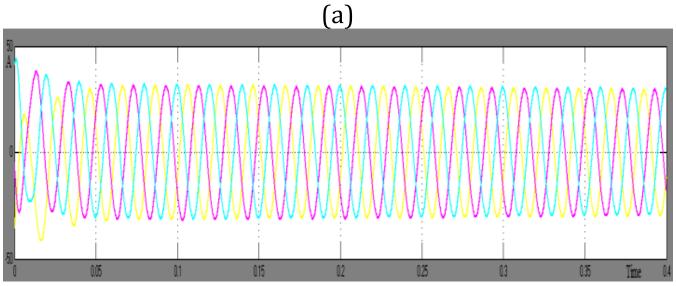

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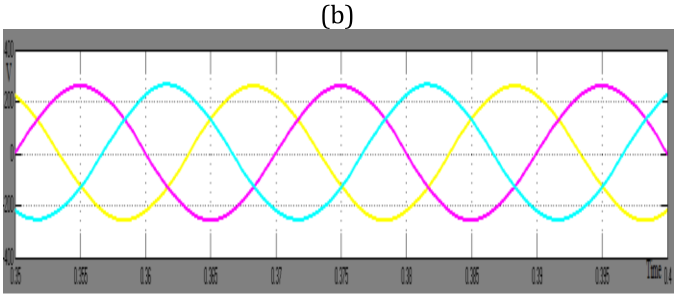
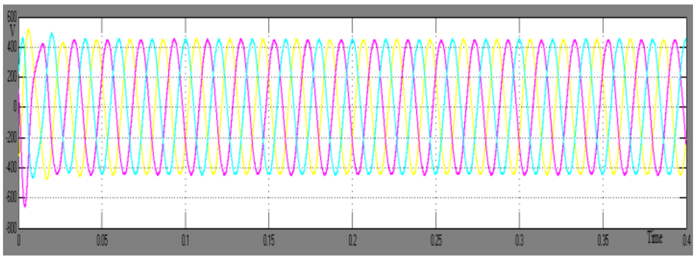


(c)

Fig-11: MATLAB/SIMULINK result sing DVR and STATCOM (a) voltage at PCC, (b) current at PCC, (c) Voltage at non-linear load

The simulation result of MATLAB Simulink diagram with DPFC in conventional is given in Fig. 12. The result shows that the use of DPFC instead of DVR and STATCPM is efficient as it mitigates the voltage sag and swell at both PCC and load at a time.



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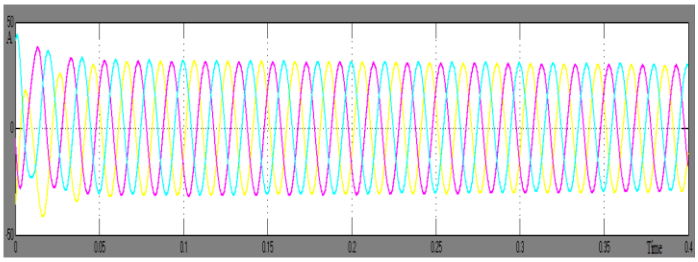

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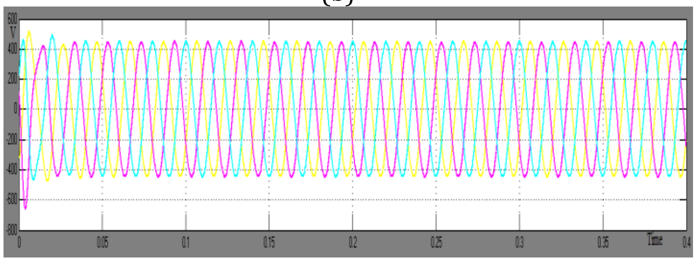

(c)

Fig-12: MATLAB/SIMULINK result sing DPFC (a) voltage at PCC, (b) current at PCC, (c) Voltage at non-linear load

8. CONCLUSIONS

The performance of the device has been tested with simulations at 415V voltage level. Simulation results show that DPFC can replace the DVR and STATCOM in the system and can perform the same using this single FACT device. The simulation results proved that the voltage dip, swell, unbalances and harmonics can be mitigated effectively and the response of the system is satisfactory. The proposed system introducing less distortions and noises into the system than in the case of conventional topology and there is no case of overlapping of the control methods as in conventional technique.

REFERENCES

[1] J.F.G.Cobben, W.L.Kling, J.M.A.Myrzik, "Power quality aspects of a future micro grid",*Future Power Systems, 2005 International Conference* on. pp. 1-5.

[2] S. Mohod and M. Aware, 'A STATCOM-Control Scheme for Grid Connected Wind Energy System for Power Quality Improvement', *IEEE Systems Journal*, vol. 4, no. 3, pp. 346-352, 2010.

[3] Raneru Nageswara Rao, "Harmonic Analysis of Small Scale Industrial Loads and Harmonic Mitigation Techniques in Industrial Distribution System", *International Journal of Engineering Research and Applications*, 3(4), pp.1511-1540, Jul-Aug 2013.

[4] M. G. Simões, S. Chakraborty, and R. Wood, 'Induction generators for small wind energy systems', *IEEE Power Electronics Society Newsletter*, vol. 18, no 3, pp. 19–23, 2006.

[5] S. Mohod and M. Aware, 'A STATCOM-Control Scheme for Grid Connected Wind Energy System for Power Quality Improvement', *IEEE Systems Journal*, vol. 4, no. 3, pp. 346-352, 2010.

[6] Fitzer, C.; Barnes, M.; Green, P. "Voltage sag detection technique for a dynamic voltage restorer", Industry Applications, *IEEE Transactions* on, vol. 40, no. 1, pp. 203 - 212, Jan.-Feb. 2004.

[7] Zhihui Yuan, Sjoerd W.H de Haan and Braham Frreira "DPFC control during shunt converter failure" *IEEE Transaction on Power Electronics* 2009.

[8] Zhihui Yuan, Sjoerd W.H de Haan, Braham Frreira and Dalibor Cevoric "A FACTS Device: Distributed Power Flow Controller (DPFC)" *IEEE Transaction on Power Electronics*, vol.25, no.10, October 2010.

[9] R. Zhang, M. Cardinal, P. Szczesny, and M. Dame. "A grid simulator with control of single-phase power converters in D.Q rotating frame," *Power Electron.*

[10] D. Divan and H. Johal, "Distributed facts—A new concept for realizing grid power flow control," in Proc. IEEE 36th Power Electron. Spec. Conf. (PESC), 2005, pp. 8–14.