

Comparison of PV Supported DVR and DSTATCOM with Multiple Feeders in Stand Alone WECS by Mitigating Power Quality Problems

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Abstract

In this paper standalone WECS (Wind Energy Conversion System) is taken in which PV supported DVR (Dynamic Voltage Restorer) or D-STATCOM (Distribution Static Synchronous Compensation) is connected to mitigate power quality problems such as voltage sag, swell, unbalance and harmonics, which are created by both source and as well as due to other feeders disturbances. DFIG (Doubly Fed Induction Generator) is used as a generator to generate three phase supply from the wind source to the load. PV (Photo Voltaic) is used as a DC source for the VSI (Voltage Source Inverter). SRFT (Synchronous Reference Frame Theory) is used for the generating reference voltages. HC (Hysteresis controller) is used to generate pulse signal for the VSI of DVR or D-STATCOM. These voltages, when injected in line by a series or shunt transformer can regulate the voltage at the load terminals against any power quality problems. Thus the protection of the loads can be achieved economically using the DVR or D-STATCOM. Simulation results are carried out by MATLAB/Simulink to verify the performance of the proposed method.

Keywords: DFIG (Doubly Fed Induction Generator), DSTATCOM (Distribution Static Synchronous Compensator), DVR (Dynamic Voltage Restorer), HC (Hysteresis Controller), PV (Photo Voltaic), SRFT (Synchronous Reference Frame Theory), The VSI (Voltage Source Inverter)

1. Introduction

Due to advancement of today's modern world, use of nonlinear loads leads to harmonics in the system. Other than harmonics some switching conditions of heavy loads and faults leads to power quality problems¹. This power quality problem may leads to malfunction or even stop working of the sensitive devices. To protect these devices CPD (Custom Power Devices) are installed in between source or PCC point and the load point². Some of the Power quality problems are of Voltage sag, swell, unbalance, interruption, harmonics and fluctuations. Using of renewable energy in electricity generation is very important nowadays due to its abundant availability and it is pollution free. Wind source of generation and solar are

the two leading renewable energy in the power industry. DFIG is the main type of wind generation currently in use due to their variable speed operation, active and reactive power capability and reduced power losses.

The voltage sag magnitude ranges from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min caused mainly due to energization of heavy loads. Swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min and magnitudes are between 1.1 and 1.8 p.u caused mainly due to de-energization of heavy loads. Unbalance is defined as the magnitudes of three phase supply are not in equal. This is caused due to using of single phase loads in three phase circuit. Voltage unbalance is restricted to within 5%. Interruption is defined as the supply voltage

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decreased less than 0.1p.u caused due to system faults. Waveform distortion is defined as steady state deviation in the voltage or current waveform from an ideal sine wave. There are many different methods to mitigate these problems, but the use of a custom power device is the most efficient method. The term custom power means, the use of power electronics controller in a distribution system. There are different types of custom power devices used to improve supply from power quality problems. Each of the devices has its own benefits and limitations.

Custom power devices are of three types, they are series connected, shunt connected and by both. Dynamic Voltage Restorer (DVR) is a series connected custom power device³. The two types of DVR are Rectifier supported DVR and Capacitor supported DVR⁴⁻⁶. Distribution Static Synchronous Compensator (D-STATCOM) is a shunt connected custom power device⁷⁻⁹. UPQC Unified Power Quality Conditioner is connected by both series and shunt connection¹⁰⁻¹².

2. Dynamic Voltage Restorer

The basic structure of a standalone WECS using PV supported DVR is shown in Figure 1. It is normally installed in a distribution system between the supply and load. As shown in Figure1 DFIG (Doubly Fed Induction Generator) used for 3 phase AC supply from wind source to the load. The same source feeds number of distribution load feeders with sag and swells conditions and at the same time fault on feeder 1 and 3 affects the pcc point which leads to voltage sag, swell and unbalance on the feeder 4. Hence voltage correction is needed in feeders 4 and it is accomplished by using DVR. Thus the power quality problems are mitigated to the load by using PV supported DVR. It is divided into five categories:

- **DFIG:** Wind turbines using a Doubly-Fed Induction Generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based converter modelled by voltage sources. The stator winding is connected directly to the 50 Hz load. While the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

- **Injection Transformer:** The Injection transformer is a specially designed transformer that attempts to limit the coupling of noise and transforms energy from the primary side to the secondary side.
- **Harmonic Filters:** Filters are used to convert the inverted PWM waveform into a sinusoidal waveform by eliminating the harmonic components generated by VSI action.
- **Inverter:** A VSI is a power electronic system which consists of switching device, which can generate a sinusoidal voltage at any required frequency, magnitude and phase angle from dc storage.
- **Capacitor:** DVR has a large DC capacitor to ensure stiff DC voltage input to inverter.
- **PV Array:** The purpose is to supply the necessary DC to the VSI via a dc link for the generation of injected voltages.

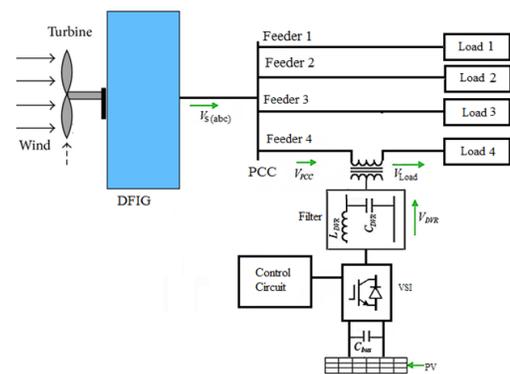


Figure 1. DVR with WECS.

3. Distribution Static Synchronous Compensator

The D-STATCOM has been used to mitigate the majority of the power system disturbances such as voltage sags, voltage swells, flicker and unbalance at distribution level. Figure 2 shows the basic configuration of D-STATCOM. As shown in Figure 2 DFIG (Doubly Fed Induction Generator) used for 3 phase AC supply from wind source to the load. The same source feeds number of distribution load feeders with sag, unbalance and swell conditions and at the same time a fault on feeder 1 and 3 affects the feeder 4. Hence voltage correction is needed in feeders 4 and it is accomplished by using D-STATCOM. Thus the power quality problems are mitigated to the load by using PV supported D-STATCOM.

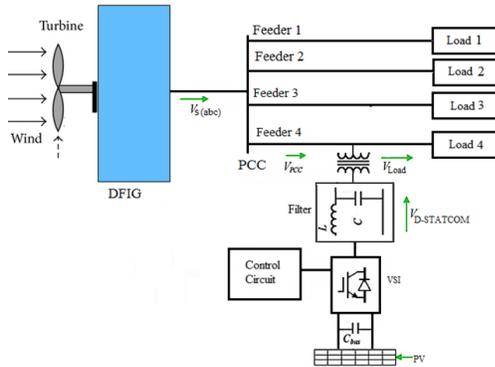


Figure 2. D-STATCOM with WECS.

The configuration of D-STATCOM mainly consists of a voltage source inverter, a control circuit, a dc energy storage device, a passive filter and a coupling transformer. D-STATCOM is a shunt device and coupling transformer is connected in shunt with the line. The VSI in the D-STATCOM generates three-phase ac output voltages which is controllable in phase and magnitude. From this the currents are injected into the line with the required magnitude, frequency and phase shift in order to restore the load voltage to its normal value. The D-STATCOM is capable of generating or absorbing reactive power but the active power injection of the device must be provided by an external energy source or energy storage system. The response time of D-STATCOM is very short and is limited by the power electronics devices.

4. Control Design of DVR and D-STATCOM

There are various types of control techniques used in DVR and D-STATCOM among them Synchronous Reference Frame Theory (SRFT) technique is used to control these devices. The block diagram is shown in Figure 3. Since the supply voltage is distorted a Phase Locked Loop (PLL) is used to achieve synchronization with supply voltage. The three phase PCC voltage (v_a, v_b, v_c) are sensed and converted into two dimension variable (v_d, v_q, v_0) using park's transformation shown in equation (1). The (v_d, v_q, v_0) obtained from park's transformation is compared with the reference to get error signal. The error signal is again converted to three phase reference signal by using reverse park's transformation as shown in equation (2).

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\omega t & \cos(\omega t - 2\pi/3) & \cos(\omega t + 2\pi/3) \\ -\sin\omega t & -\sin(\omega t - 2\pi/3) & -\sin(\omega t + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \cos\omega t & -\sin\omega t & 1 \\ \cos(\omega t - 2\pi/3) & -\sin(\omega t - 2\pi/3) & 1 \\ \cos(\omega t + 2\pi/3) & -\sin(\omega t + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} \tag{2}$$

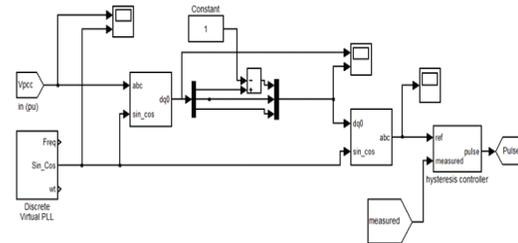


Figure 3. Control diagram of DVR and D-STATCOM.

This reference signal is given to the Hysteresis controller along with measured signal to get pulse. The pulse generated from the hysteresis controller is given to the eight switches of the VSI of DVR and D-STATCOM. The block diagram of Hysteresis Controller is shown in Figure 4. Therefore, the injected voltage by the DVR and D-STATCOM through filter cancels out the harmonics, voltage sag and unbalance present in the voltage at pcc point.

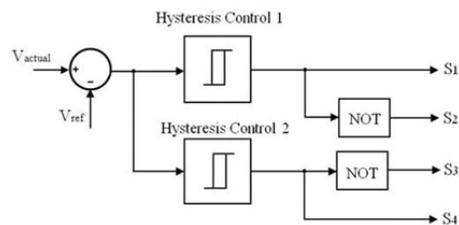


Figure 4. Control block diagram of Hysteresis Controller.

5. Simulation Results

5.1 Simulation Results - DVR

The simulation is done for standalone PV supported DVR based on SRF controller. The pulses for inverter are generated by using hysteresis controller. By switching ON DC load in feeder 1, voltage sag and harmonics are produced in all adjacent feeders. In feeder 2 resistive load and a subsystem consist of DC load is used. Fault

in feeder 3 produce unbalance in all adjacent feeders and load in feeder 4 is considered as sensitive load so that the feeder 4 is protected from sag, swell, unbalance and harmonics by connecting DVR. By switching OFF DC load in feeder 1 produces voltage swell in all adjacent feeders. Figure 5 shows the simulink diagram of DFIG. Figure 6 shows the simulink diagram of the System. Figure 7 shows Output voltage of PV which is 318.4 V, Figure 8 and Figure 15 shows the Output Voltage during Sag, Unbalance and voltage during swell respectively. Figures 9, 10 shows voltage THD value of voltage sag from wind source before and after compensation. Figures 11, 12 shows voltage THD value of voltage sag due to load before and after compensation. Figures 13, 14 shows voltage THD value of voltage unbalance due to loads before and after compensation. Figures 16, 17 shows voltage THD value of voltage swell from the source before and after compensation. Figures 18, 19 shows voltage THD value of voltage swell due to loads before and after compensation. During voltage sag normal voltage level of 1 p.u is decreased to 0.8 p.u. After compensation the load voltage is maintained at 1 p.u by injecting voltage of 0.2 p.u. During voltage unbalance condition the voltages at two phases got decreased to 0.8 p.u and the other phase remains at 1 pu. After compensation load voltage is maintained at 1 p.u by injecting voltage of 0.2 p.u at both phases and zero injection at normal phase. During voltage swell normal voltage level of 1 p.u is increased to 1.2 p.u. After compensation the load voltage is maintained at 1 p.u by injecting negative voltage of 0.2 p.u. Sag from wind source duration from 0.02 to 0.06 secs, Sag due to loads from 0.1 to 0.14 secs, unbalance duration from 0.18 to 0.22 secs and swell duration from 0.02 to 0.06 secs.

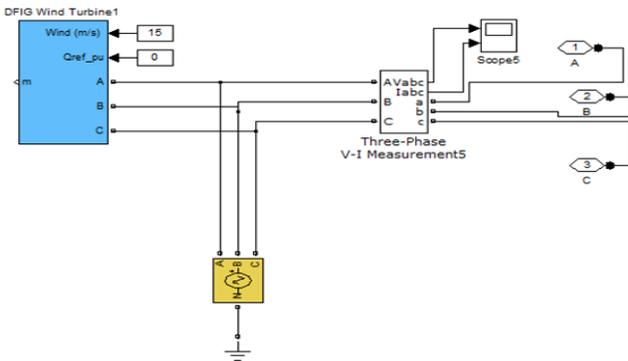


Figure 5. Simulink diagram of the DFIG.

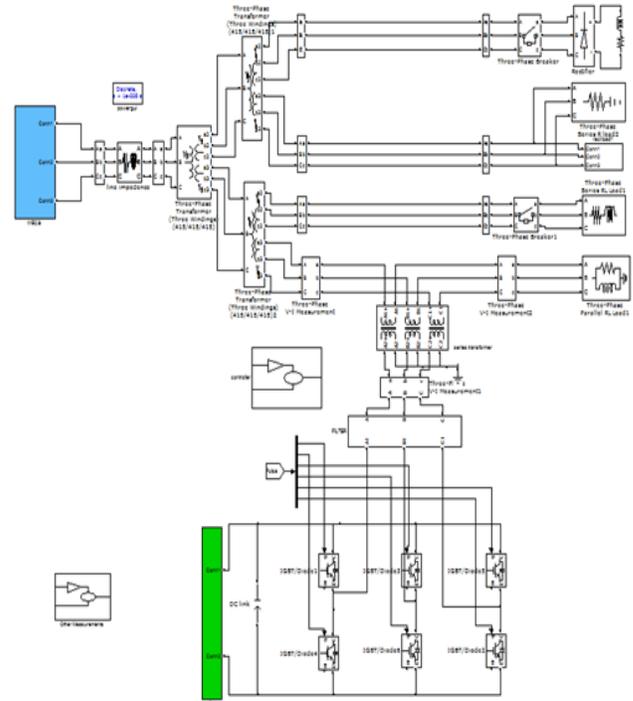


Figure 6. Simulink diagram of the DVR.

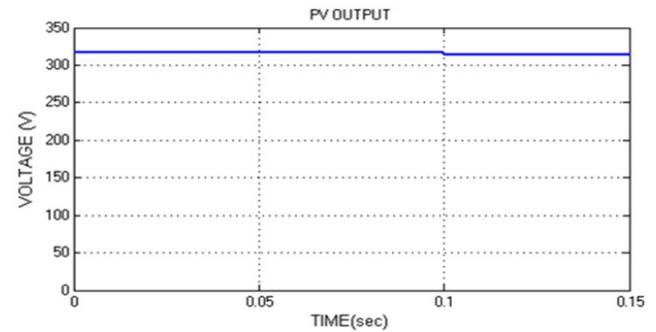


Figure 7. PV Output Voltage for DVR.

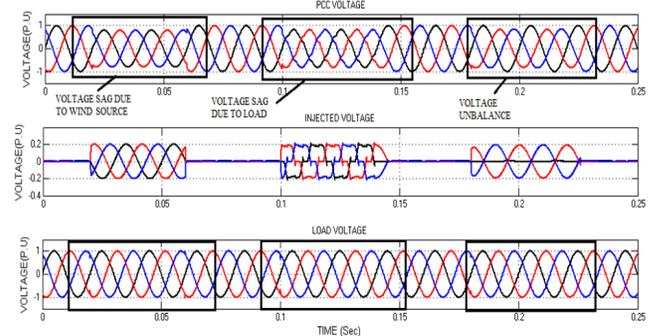


Figure 8. PCC Voltage with sag, unbalance and harmonics, injected voltage, load voltage.

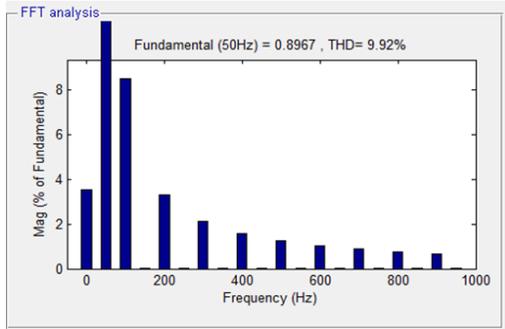


Figure 9. Voltage THD Value of Sag from wind source before compensation.

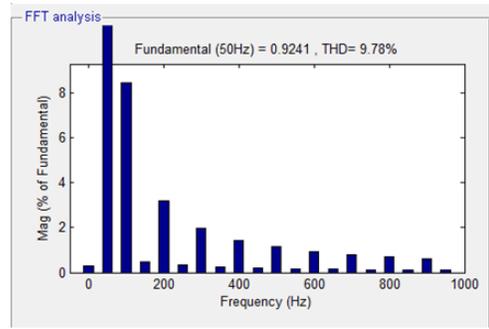


Figure 13. Voltage THD Value of unbalance before compensation.

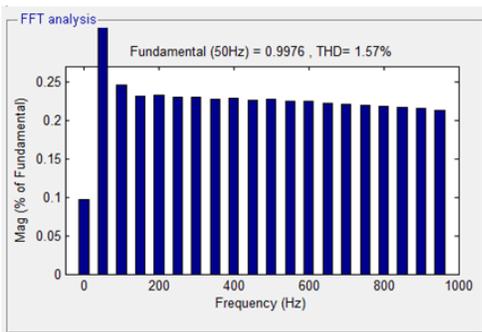


Figure 10. Voltage THD Value of Sag from wind source after compensation.

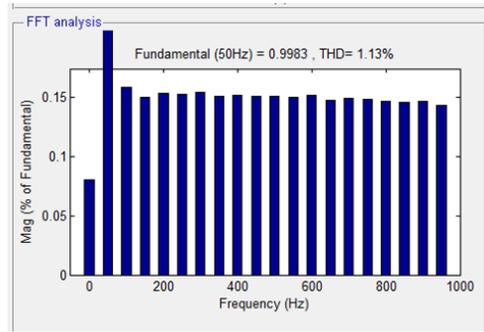


Figure 14. Voltage THD Value of unbalance after Compensation.

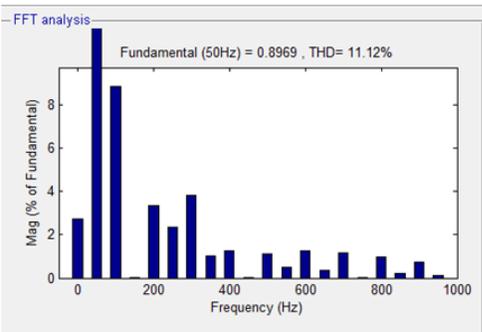


Figure 11. Voltage THD Value of sag due to loads before compensation.

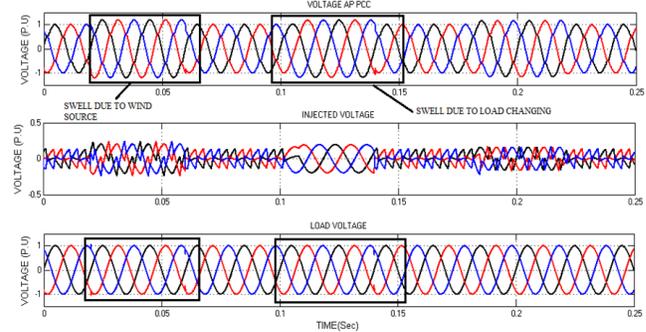


Figure 15. PCC voltage with swell, injected voltage, load voltage.

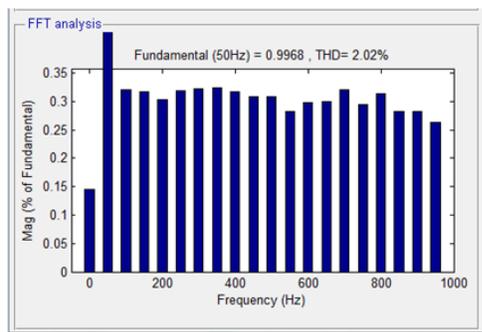


Figure 12. Voltage THD Value of sag due to loads after compensation.

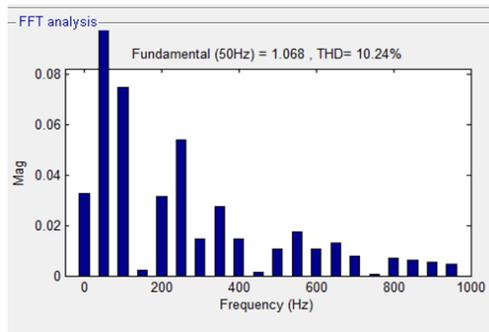


Figure 16. Voltage THD Value of Swell from wind source before compensation.

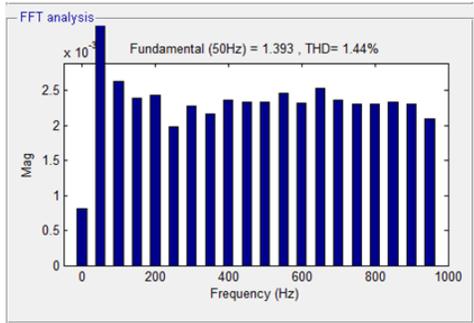


Figure 17. Voltage THD Value of Swell from wind source after compensation.

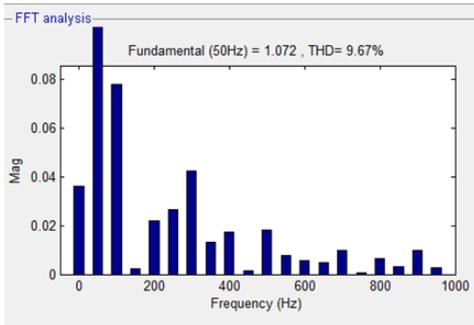


Figure 18. Voltage THD Value of Swell due to loads before compensation.

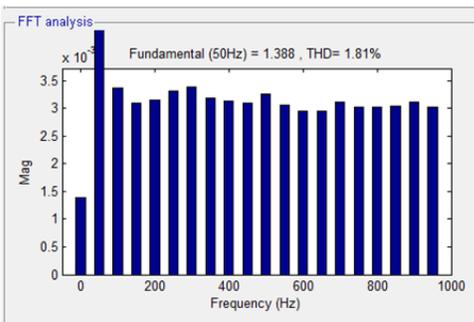


Figure 19. Voltage THD Value of Swell due to loads after compensation.

5.2 Simulation Results – D-STATCOM

The simulation is done for standalone PV supported D-STATCOM based on SRF controller. The pulses for inverter are generated by using hysteresis controller. By switching ON DC load in feeder 1, voltage sag and harmonics are produced in all adjacent feeders. In feeder 2 resistive load and a subsystem consist of DC is used. Fault in feeder 3 produce unbalance in all adjacent feeders and load in feeder 4 is considered as sensitive load so that

the feeder 4 is protected from sag, swell, unbalance and harmonics by connecting D-STATCOM. By switching OFF DC load in feeder 1 produces voltage swell in all adjacent feeders. Figure 20 shows Output voltage of PV which is 636.9 V. Figure 21 shows the simulink diagram of the System. Figures 22 and 29 shows the Output Voltage during Sag, Unbalance and voltage during swell respectively. Figures 23, 24 shows voltage THD value of voltage sag from wind source before and after compensation. Figures 25, 26 shows voltage THD value of voltage sag due to load before and after compensation. Figures 27, 28 shows voltage THD value of voltage unbalance due to loads before and after compensation. Figures 30, 31 shows voltage THD value of voltage swell from the source before and after compensation. Figures 32, 33 shows voltage THD value of voltage swell due to loads before and after compensation. During voltage sag normal voltage level of 1 p.u is decreased to 0.8 p.u. After compensation the load voltage is maintained at 1 p.u by injecting voltage of 0.2 p.u. During voltage unbalance condition the voltages at two phases got decreased to 0.8 p.u and the other phase remains at 1 pu. After compensation load voltage is maintained at 1 p.u by injecting voltage of 0.2 p.u at both phases and zero injection at normal phase. During voltage swell normal voltage level of 1 p.u is increased to 1.2 p.u. After compensation the load voltage is maintained at 1 p.u by injecting negative voltage of 0.2 p.u. Sag from wind source duration from 0.02 to 0.06 secs, Sag due to loads from 0.1 to 0.14 secs unbalance duration from 0.18 to 0.22 secs and swell duration from 0.02 to 0.06 secs. Table 1 and 2 shows Total Harmonic Distortion (THD) comparison of DVR and D-STATCOM for mitigating voltage sag, swell and unbalance which is created by both wind source and by loads used.

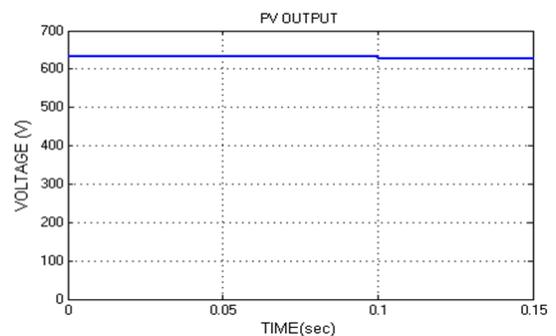


Figure 20. PV Output voltage for D-STATCOM.

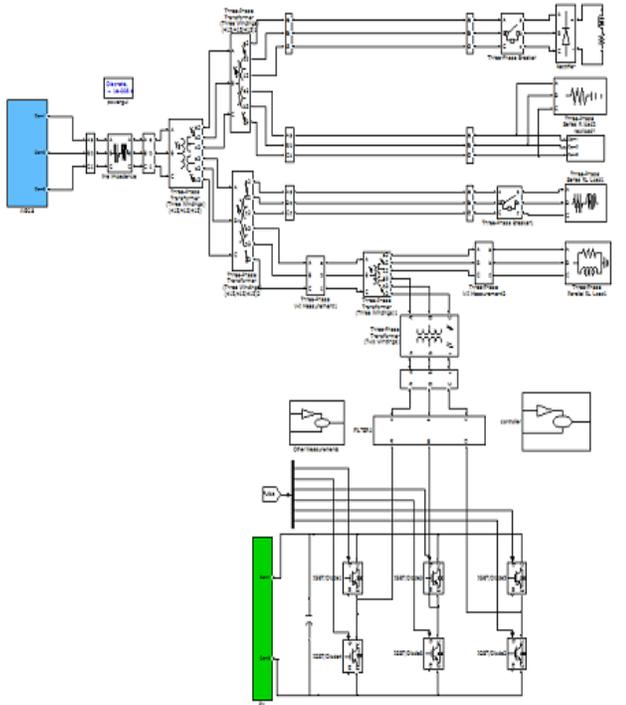


Figure 21. Simulink diagram of the D-STATCOM.

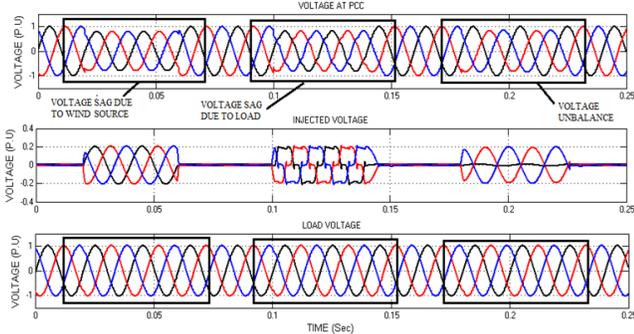


Figure 22. PCC Voltage with sag, unbalance and harmonics, injected voltage, load voltage.

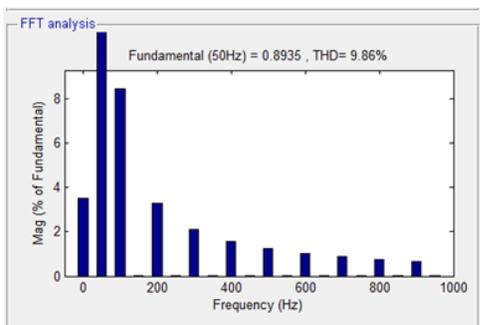


Figure 23. Voltage THD Value of Sag from wind source before compensation.

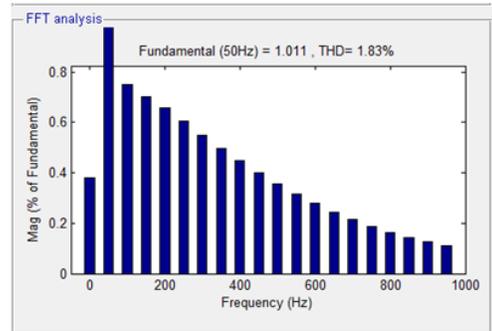


Figure 24. Voltage THD Value of Sag from wind source after compensation.

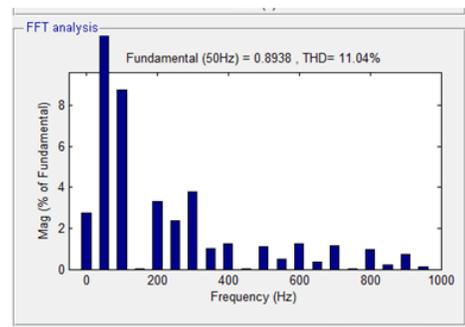


Figure 25. Voltage THD Value of sag due to loads before compensation.

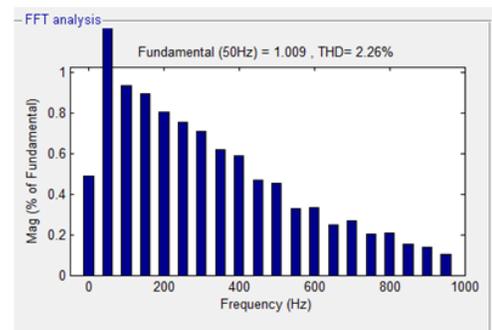


Figure 26. Voltage THD Value of sag due to loads after compensation.

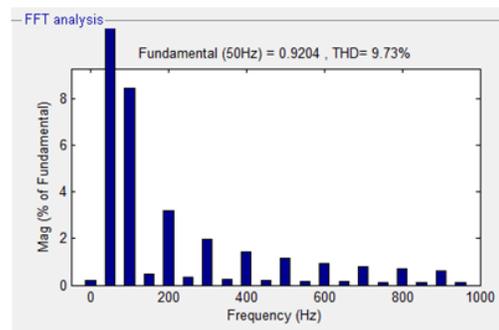


Figure 27. Voltage THD Value of unbalance before compensation.

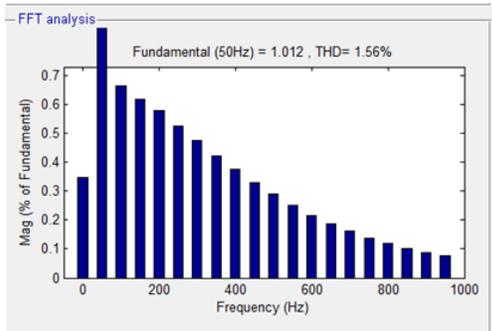


Figure 28. Voltage THD Value of unbalance after compensation.

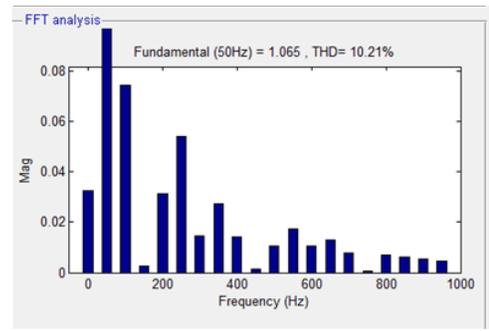


Figure 32. Voltage THD Value of Swell due to loads before compensation.

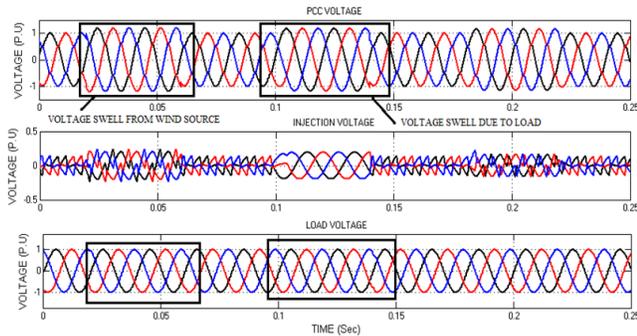


Figure 29. PCC voltage with swell, injected voltage, load voltage.

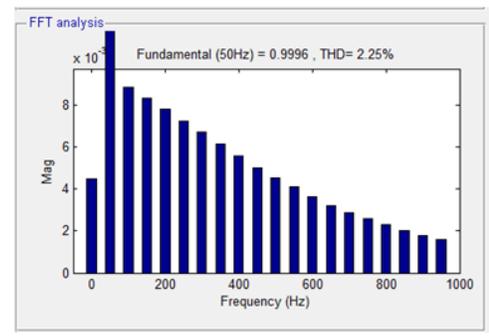


Figure 33. Voltage THD Value of Swell due to loads after compensation.

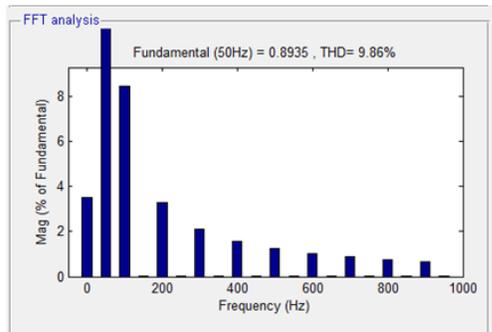


Figure 30. Voltage THD Value of Swell from wind source before compensation.

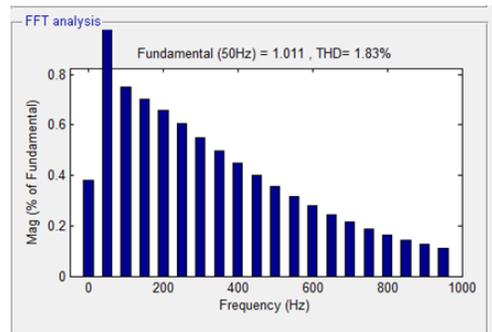


Figure 31. Voltage THD Value of Swell from wind source after compensation.

Table 1. THD Comparison of DVR

Conditions	THD before	THD after
	Compensation	Compensation
	in %	in %
Sag from wind source	9.92	1.57
Sag due to loads unbalance	11.12	2.02
Swell from wind source	10.24	1.44
Swell due to loads	9.67	1.81

Table 2. THD comparison of D-STATCOM

Conditions	THD before	THD after
	Compensation	Compensation
	in %	in %
Sag from wind source	9.86	1.83
Sag due to loads unbalance	11.04	2.26
Swell from wind source	9.86	1.83
Swell due to loads	10.21	2.25

6. Conclusion

A standalone WECS with multiple feeders using DVR and D-STATCOM supported by PV, controlled by Synchronous Reference Frame Theory technique and Hysteresis Controller is implemented to protect the loads from power quality problems. The above simulation results shows that DVR and D-STATCOM can able to mitigate power quality problems such as voltage sag, voltage swell, voltage unbalance and harmonics reduction which are created on the source side itself and also problems which are occurring due to load changing in adjutant feeders. It is found that DVR requires 318.4V DC source to mitigate all the above problems. Whereas D-STATCOM requires 636.9V DC source for mitigating same problems, which is double the requirement of DVR for D-STATCOM to mitigate these problems. Thus DVR can perform with lesser DC source voltage level than D-STATCOM. Since WECS and PV combined it is used as renewable and pollution free.

7. References

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APPENDIX

Source voltage from DFIG: 415V

Supply Frequency: 50Hz

Three winding Transformer: 415V/415V/415V

One PV cell: 0.5898V

PV one array (36 PV cell): 21.23V

Total PV voltage for DVR (15 PV array): $21.23 \times 15 = 318.4V$

Total PV voltage for D-STATCOM (30 PV array):
 $21.23 \times 30 = 636.9V$

DC Capacitor: 1500e-6f