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DESIGN AND IMPLEMENTATION OF MULTITYPE CUSTOM POWER DEVICES USING MATLAB-SIMULINK FOR MITIGATING POWER QUALITY PROBLEMS

M.Sudha, P.Malathy
PSNA College of Engg & Tech.,
Dindigul, Tamil Nadu ,India.
sudhaodc.15@gmail.com malathyme@yahoo.co.in

ABSTRACT

In this paper, it is proposed to mitigate the famous power quality problem, the voltage sag. It is also proposed to improve the reactive power support at the end user level by using, multitype custom power devices like DVR and D-STATCOM. Custom power devices are the most efficient and effective modern devices used in power distribution network. These devices have added advantages like lower cost, smaller size, and fast dynamic response to disturbances. The proposed work presents the analysis of simulating multitype custom power devices namely DVR and D-STATCOM for voltage sag reduction problem using in MATLAB-SIMULINK environment. Power quality, Custom power devices, Analysis and mitigation.

Keywords : DVR, D-STATCOM, MATLAB-SIMULINK, Voltage sag compensation.

1. INTRODUCTION

A power system is a complex interconnected structure with generation, transmission and distribution sectors as its components. The power from generation system is connected to the distribution system through long transmitting lines. The quality of power has a direct economic and financial impact on both utilities and industrial customers. Various power quality problems occur when a nonstandard voltage, current or frequency results in failure or mal-operation of end user equipments. One of the major problem is voltage sag [1,2]. To solve this problem, capacitors, reactive power compensators and voltage regulators were conventionally used.

These techniques involve inherent drawbacks. With the advancement of power electronic devices these drawbacks can be overcome easily. To reduce a severity of power quality problems, mitigation devices can be placed in the transmission and distribution systems. The concept of Flexible AC Transmission Systems (FACTS) was introduced by N.G. Hingorani to combat with the power quality issues that originates from transmission systems [3,4]. The invention of various custom power devices [5,6] such as Distribution Static Compensator (D-STATCOM), Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioner (UPQC) can be used to solve the power quality problem in economical way than by using FACTS devices. The custom power devices are broadly classified into two categories namely series and shunt devices.

DVR is connected in series with the system which is operates in voltage control mode and it is used to protect sensitive loads from sag/swell or disturbances in the supply voltage [7-9]. D-SATCOM is connected in shunt and operated in current control mode that eliminated harmonics and/or unbalance [10-12]. A better solution can be obtained by using both series and shunt devices together in the system. This thought results in the usage of multitype custom power devices in the system for the improvement of power quality [13-15].

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2. DYNAMIC VOLTAGE RESTORER

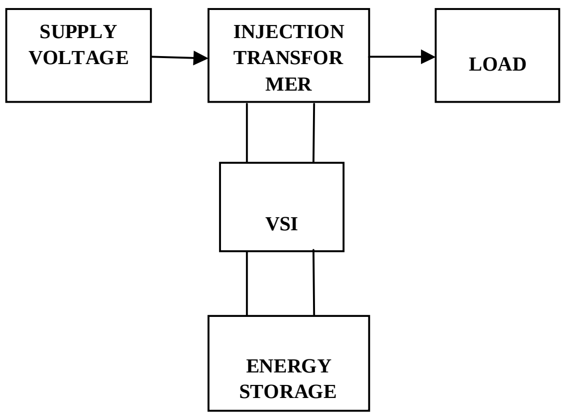

Figure 1: Block diagram of DVR

The block diagram of Dynamic Voltage Restorer (DVR) is shown in Fig 1. A DVR is a custom power device used to eliminate the supply side voltage disturbances. The magnitude and phase of load voltage is maintained at nominal value by compensating the voltage sag/swell. The dynamic voltage restorer is connected in series between the source voltage and sensitive load through injection transformer. The DVR is typically installed in a distribution system and the function of the restorer is to rapidly boost up the load-side voltage in the event of a disturbance in order to avoid any power disruption to that load.

The DVR is used to inject only the missing part ie.sag or swell voltages. The injection (booster) transformer, a harmonic filter, a voltage source inverter (VSI), DC charging circuit, control system and protection system are the major components of DVR. In most sag correction techniques, the DVR is required to inject active power into the distribution line during the period of compensation. The injection transformer is connected series between the supply side and load side voltages.

The series voltage source inverter (VSI) can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. The energy storage consist of a capacitor which gives dc input to the inverter. The inverter is responsible for converting DC to AC. It also ensures that only the swell or sag voltage is injected to the injection transformer. During voltage sag, the DVR injects a voltage to restore the load supply voltages.

2.1 Protecting sensitive loads using DVR

DVR is used to protect sensitive loads from sag/swell or disturbances in the supply voltage. The Fig 2. shows the schematic diagram of a sensitive load protected by an ideal series compensator. The DVR is represented by the ideal voltage source that injects a voltage v_f in the direction shown.

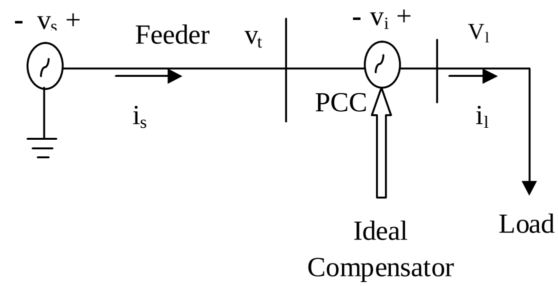

Figure 2 : Load compensation using DVR

The resulting load voltage is equal to the sum of supply voltage and injected voltage.

$$v_l = v_t + v_f \qquad (1)$$

Where v_l is the load bus voltage. The DVR can regulate the bus voltage to any arbitrary value by measuring the terminal voltage v_t and the supplying the balance through v_f.

3. DISTRIBUTION STATIC COMPENSATOR

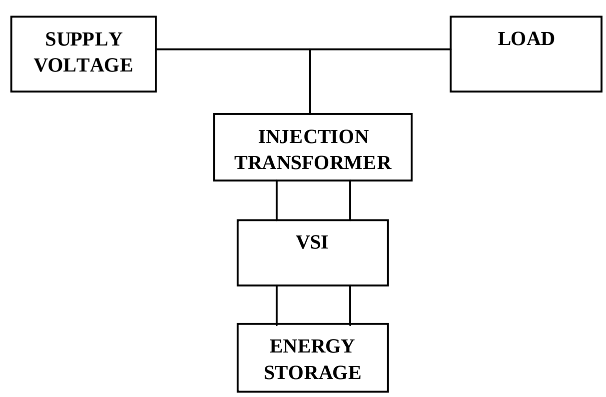

Figure 3: Block diagram of D-STATCOM

A Distribution Static Compensator (D-STATCOM) is one of the custom power device which is used to eliminate the harmonics from the

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source current. It will also provide reactive power compensation to improve the power factor. It operates in voltage control mode in which it is required to follow a set of reference voltages.

The Fig 3. shows the block diagram of D-STATCOM. It employs the same block as DVR but the only difference is the injection transformer is connected in shunt.

The D-STATCOM provides not only for voltage sags mitigation but also provides other power quality solutions such as voltage stabilization, flicker suppression, power factor correction and harmonic control.

Load compensation using DSTATCOM

The Fig 4. shows a 3-phase, 4-wire distribution system compensated by an ideal shunt compensator (DSTATCOM). Load-2 is assumed as reactive, nonlinear, and unbalanced. In the absence of the compensator, the current I_s flowing through the feeder will be unbalanced and distorted and hence the Bus-1 voltage will also be distorted.

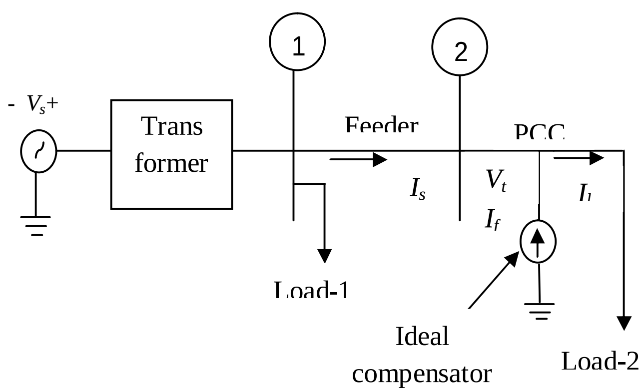

Figure 4 : Load compensation using D-STATCOM

To alleviate this problem, the compensator must inject the current such that the current I_s becomes fundamental and positive sequence. In addition, the compensator can also force the current I_s to be in phase with the Bus-2 voltage. The point at which the compensator is connected is called the utility-customer Point of Common Coupling (PCC). Denoting the load current by I_l the KCL at the PCC yields

$$I_s + I_f = I_l$$

$$I_s = I_l - I_f \qquad (2)$$

The desired operation of the compensator is that generate a current I_f such that it cancels the reactive component. The ideal compensator will inject current (I_f) that cancel from the load current and balance the load and also forces the current drawn from the source to be unity power factor.

Voltage regulation using DSTATCOM

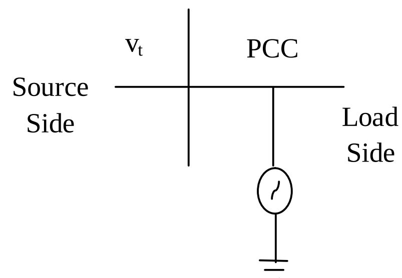

Figure 5(a) : Ideal voltage controller

The Fig 5 (a). shows an ideal shunt compensator acting as a voltage regulator. This ideal compensator is represented by a voltage source and it is connected to the PCC. However it is rather difficult to realize this circuit and alternate structure is shown in Fig 5 (b). It has the advantage that the harmonics can be bypassed by the filter capacitor C

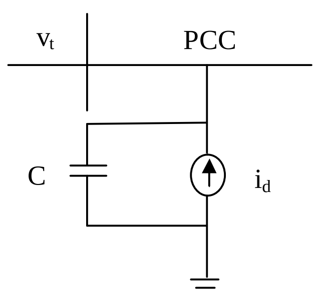

Figure 5 (b) : Practical realization of D-STATCOM

The basic idea is to inject the current i_d in such a way that the voltage v_t follows a specific reference. The compensator must be operated such that it does not inject or absorb any real power in the steady state.

4. RESULTS AND DISCUSSION

The proposed 14 bus system [21] is designed, simulated and analyzed for double line to ground fault (LLG) with multitype custom power

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devices namely DVR and D-STATCOM connected at bus 11 and bus 14. Fig 6. shows the MATLAB-SIMULINK model with DVR and D-STATCOM at bus 11. Similarly analysis is carried out by connecting the devices at bus 14 and suitable parameters are calculated.

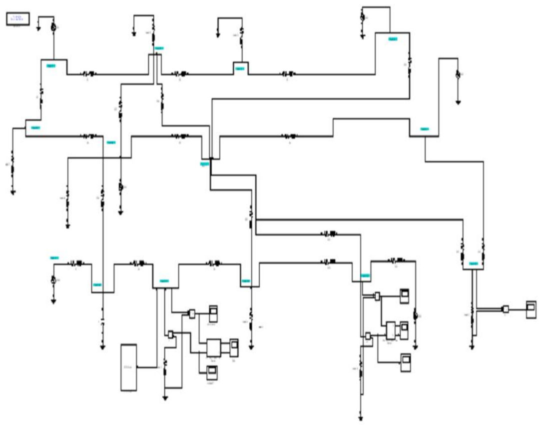

Figure 6: 14 bus system with DVR & D-STATCOM

Numerical Analysis

Table 1. DVR and D-STATCOM at bus-11

Measuring parameter	Without device	with DVR & DSTATCOM
Real Power (KW)	48.1	49.75
Reactive Power (KVar)	0.4008	0.4146
Bus Voltage (V)	69.3	69.8
Bus Current (A)	0.694	0.7125

Table 1. shows the comparative analysis of various parameters of the 14 bus system without and with DVR and D-STATCOM connected at bus 11. It is inferred that the real power (P), reactive power (Q), bus voltage (V), bus current (I) are improved with the presence of the proposed multitype custom power devices DVR and D-STATCOM.

Table 2. shows the comparative analysis of various parameters of the 14 bus system without and with DVR and D-STATCOM connected at bus 14. It is inferred that the real power (P), reactive power (Q), bus voltage (V), bus current (I) are improved with the presence of the proposed multitype custom power devices DVR and D-STATCOM..

Table 2. DVR and D-STATCOM at bus-14

Measuring parameter	Without device	With DVR & DSTATCOM
Real Power (KW)	39.32	39.75
Reactive Power (KVar)	0.3277	0.3313
Bus Voltage (V)	88.63	89.5
Bus Current (A)	0.885	0.895

Graphical Analysis

The Fig 7 (a-c) shows the real power graphical analysis of the proposed 14 bus system simulated for double line to ground fault (LLG) without and with multitype custom power devices connected at bus 11 and bus 14 using MATLAB SIMULINK V7.12.0, Internal Core Processor 2.2GHz.

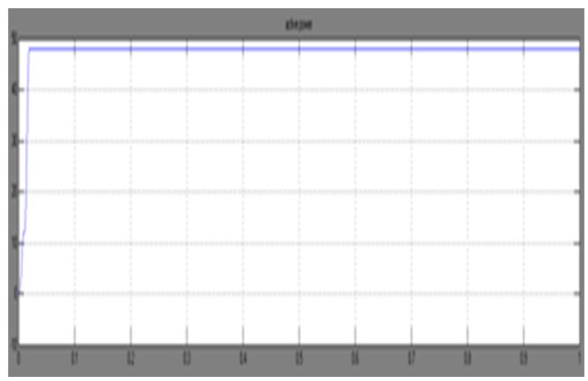

Figure 7 (a): Real power (P) without custom power devices

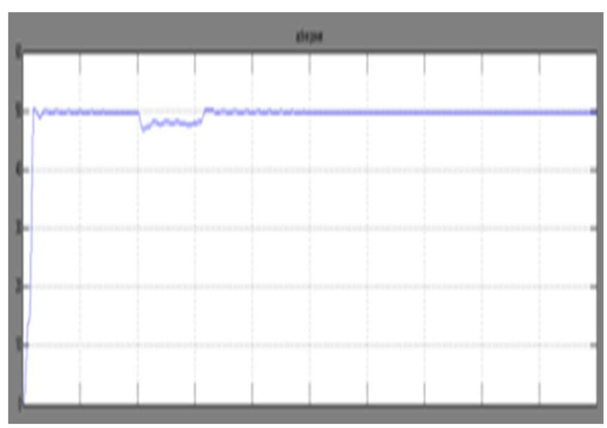

Figure 7 (b): Real power with DVR & D-STATCOM at bus 11

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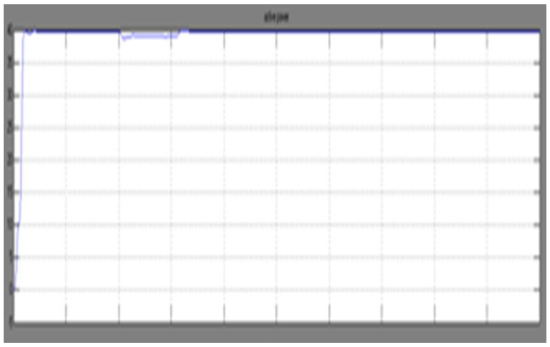

Figure 7 (c): Real power with DVR & D-STATCOM at bus 14

The real power output without any device is 48.1 KW. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the real power output for the later is more than the former case by a value of 1.65 KW. The real power output with device placed at bus 14 is 39.32 KW. It is observed that the real power output for the later is greater than the former case by a value of 0.43 KW.

The Fig 8 (a-c) shows the reactive power graphical analysis of the proposed 14 bus system simulated for double line to ground fault (LLG) without and with multitype custom power devices connected at bus 11 and bus 14.

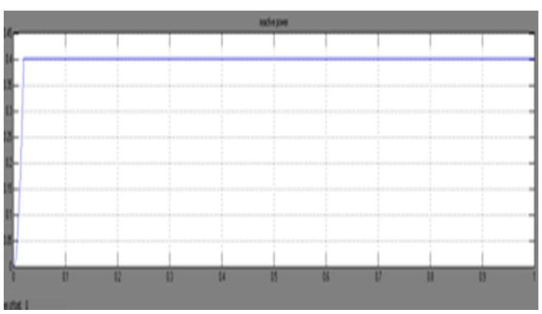

Figure 8 (a): Reactive power without custom power devices

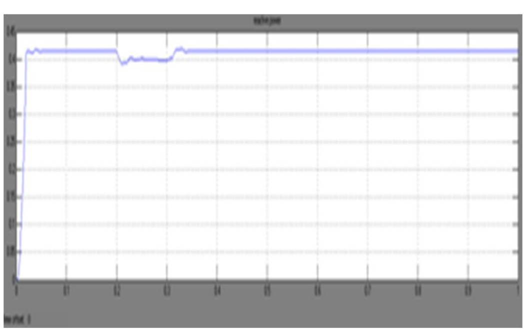

Figure. 8 (b): Reactive power with DVR and D-STATCOM at bus 11

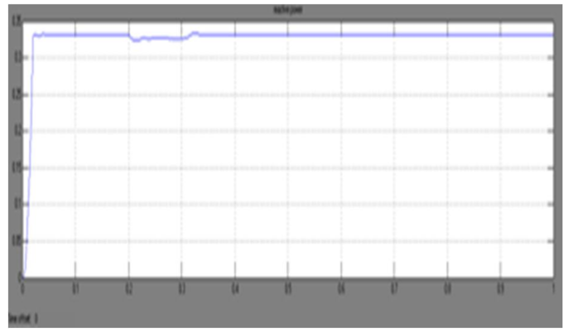

Figure 8 (c): Reactive power with DVR and D-STATCOM at bus 14

The reactive power output without any device is 0.4008 KVar. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the real power output for the later is more than the former case by a value of 0.0138 KVar. The real power output with device placed at bus 14 is 0.3277 KVar. It is observed that the real power output for the later is greater than the former case by a value of 0.0036 KVar.

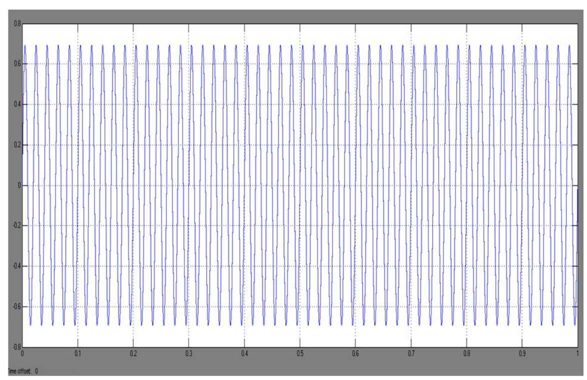

Figure 9 (a): Bus voltage without custom power devices

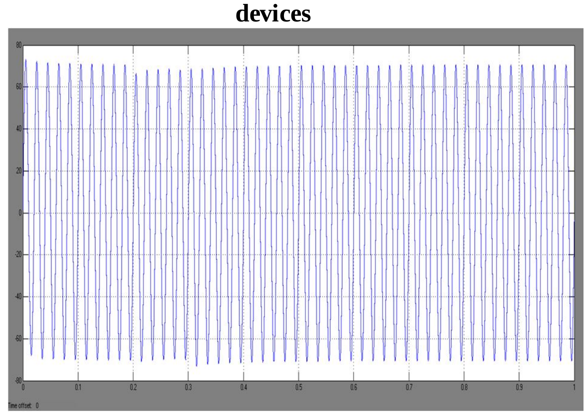

Figure 9 (b): Bus voltage with DVR & D-STATCOM at bus 11

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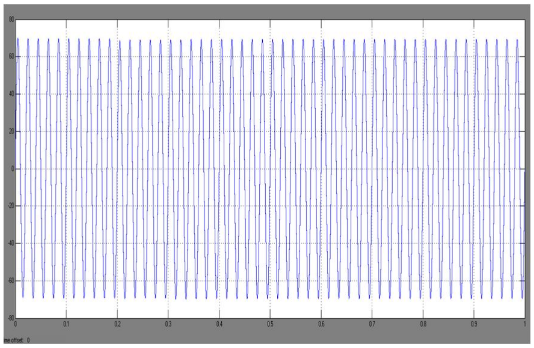

Figure 9 (c): Bus voltage with DVR & D-STATCOM at bus 14

The Fig 9 (a-c) shows the graphical analysis of voltage simulated for double line to ground fault (LLG) without and with multitype custom power devices connected at bus 11 and bus 14.

The output voltage without any device is 69.3 V. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the reactive power output for the later is more than the former case by a value of 0.5 V. The reactive power output with device placed at bus 14 is 88.63 V. It is observed that the reactive power output for the later is greater than the former case by a value of 0.87 V.

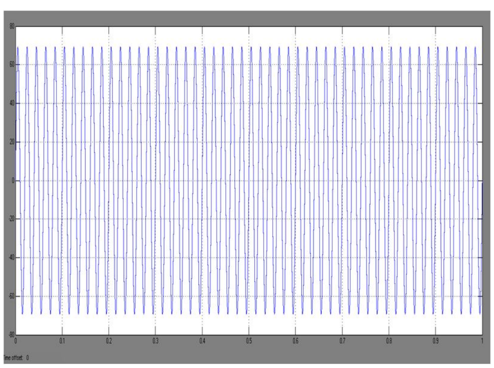

Figure 10 (a): Bus current without custom power devices

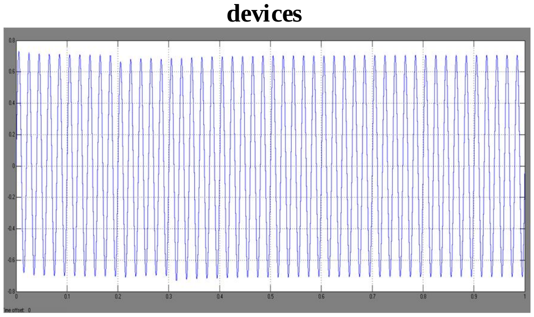

Fig ure10 (b): Current with DVR & D-STATCOM at bus 11

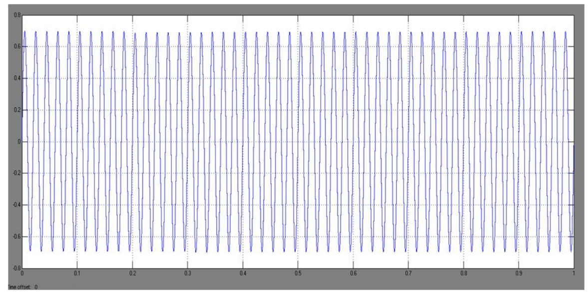

Figure 10 (c): Current with DVR & D-STATCOM at bus 14

The Fig 10 (a-c) shows the graphical analysis of current simulated for double line to ground fault (LLG) without and with multitype custom power devices connected at bus 11 and bus 14. The output current without any device is 0.694 A. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the output current for the later is more than the former case by a value of 0.0185 A. The output voltage with device placed at bus 14 is 0.885 A. It is observed that the real power output for the later is greater than the former case by a value of 0.10 A.

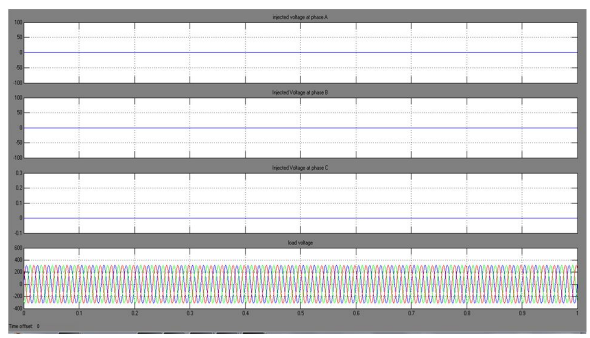

Figure 11: 3Φ voltage waveform for without fault without device

Fig 11 shows the 3Φ voltage waveform of without custom power device and without fault. The waveform is smooth without any voltage sag.

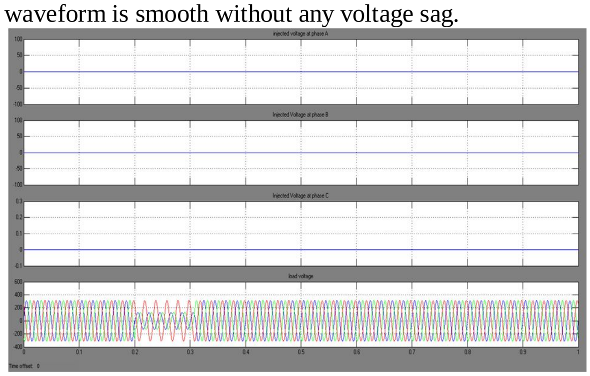

Figure 12 (a): 3Φ voltage waveform for with fault without device

The 3Φ voltage sag waveform of without custom power device and with LLG fault (fault on phase A and phase B) shown in Fig 12 (a).

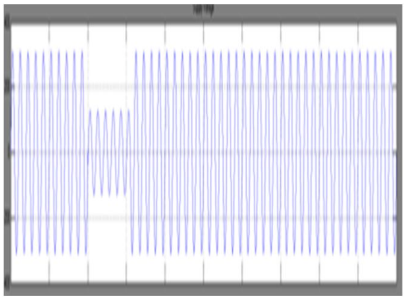

Figure 12 (b): Voltage sag waveform for without device on phase A

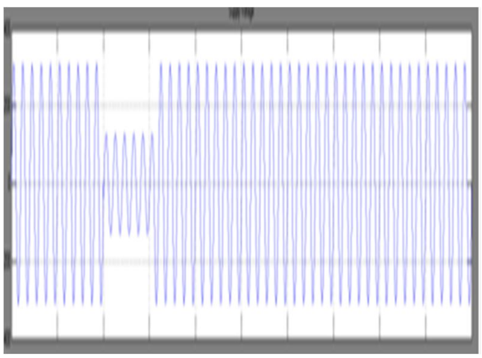

Figure 12 (c): Voltage sag waveform for without device on phase B

The Fig 12 (b) and Fig 12 (c) shows the simulation result of voltage sag on system with LLG fault on phase A and phase B without placing any custom power device.

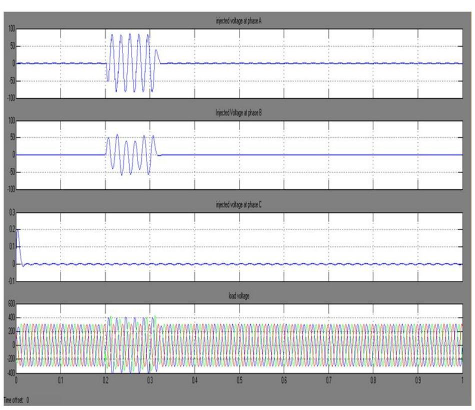

Figure 13: 3Φ voltage sag waveform for with DVR on phase A &B

The Fig 13. shows the graphical result of three phase voltage waveform of dynamic voltage restorer with LLG fault occur in phase A and B.

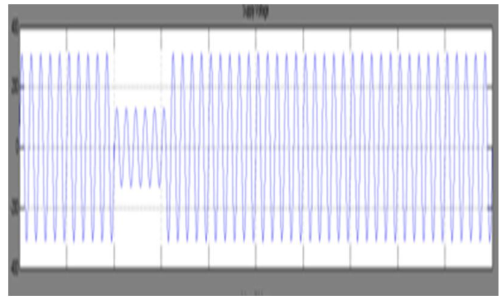

Figure 14 (a): Voltage sag waveform on phase A with fault

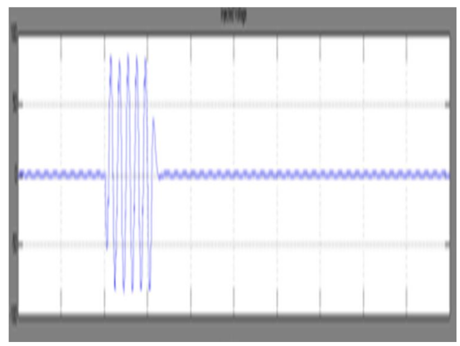

Figure 14 (b): Injected voltage at phase A

The Fig 14 (a). shows the voltage sag in phase A. The duration of voltage sag ranges between 0.2 to 0.3 seconds. To overcome this problem the injection transformers are used to inject the phase A voltage in Fig 14 (b).

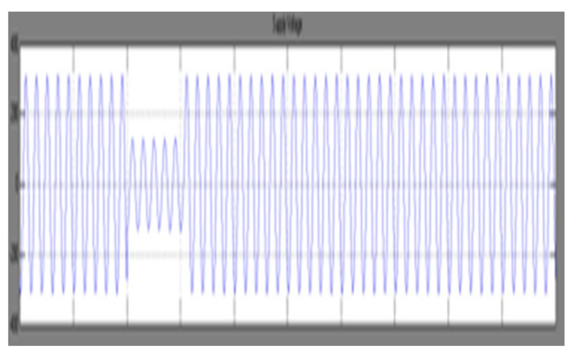

Figure 15 (a): Voltage sag waveform on phase B with fault

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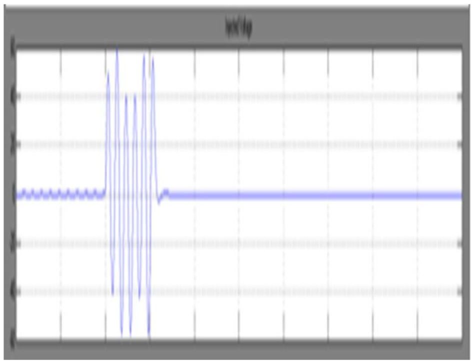

Figure 15 (b): Injected voltage at phase B

The Fig 15 (a). shows the voltage sag in phase B. The duration of voltage sag ranges between 0.2 to 0.3 seconds. To overcome this problem the injection transformers are used to inject the phase A voltage in Fig 15 (b).

From Fig 14 and Fig 15 it is evident that the injection of compensation voltage from the injection transformer neutralizes the voltage sag and produce a three phase clean and smooth waveform as shown in Fig 17.

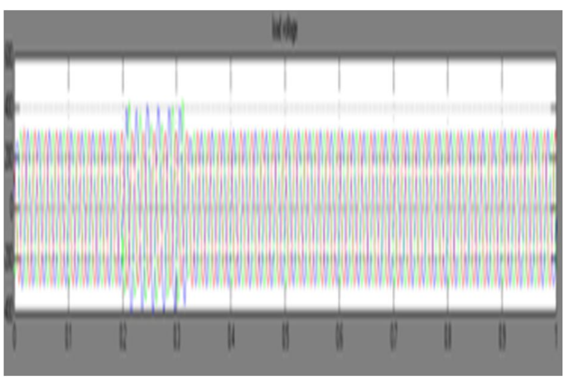

Figure 17: 3□ load waveform

5. CONCLUSION

A MATLAB/SIMULINK [20] model is designed for proposed 14 bus system. It is then simulated and analyzed without and with DVR and D-STATCOM placed at bus 11 and bus 14 for mitigating the voltage sag problem. It is found that the voltage sag caused by a double line to ground fault on phase A and phase B is compensated with voltage injected using DVR and D-STATCOM. The bus voltage increases with the increase in the magnitude of injected voltage and at the same time the reactive power compensation has been carried out successfully. Overall power quality can be improved by placing more DVR and D-STATCOM at various load buses.

In future work can be extended by connecting other types of custom power devices and also it is planned to consider the cost of installation for optimum allocation of these devices in the process of improving the quality of power.

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