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Improvement In Power Quality With D- Statcom Using Voltage Source Converters In Dg Systems

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ABSTRACT: Power quality issues have become more severe than in the past due to the dynamic and complex nature of modern power systems, largely as a result of increased reliability and cost effectiveness standards and the rapid intervention of power electronics in electrical Loads. This has led to the development of devices that offer greater flexibility and adaptability in their operation. This study presented a model based on the Voltage Source Converter (VSC) principle for improving voltage sags/swells, harmonic distortion, and poor power factor using a Distribution Static Compensator. TD-STATCOM (distribution static compensator) is represented as one from FACTS devices used in power system as power electronic shunt device that absorbs and provides reactive power to solve power quality problems in power distribution systems. This paper represents simulation of IEEE 15 bus test system with using the sensitivity index is the effective method for optimal location of D-STATCOM in the test system. D-STATCOM controller is achieved by PI controller and used to mitigate voltage sag under various conditions such as: load increasing, decreasing, line outage and single line to ground fault (SLG) using MATLAB R2014a simulink tool box.

Keywords: Power quality**,** Voltage Source Converter, MATLAB Simulink.

1.0 INTRODUCTION

Numerous undesired phenomena can be seen in the functioning of power systems as a result of the extensive usage of non-linear loads. We place special emphasis on the harmonic components of voltage and current waveforms. Traditionally, harmonics in line current have been filtered out using passive filters. [1]. However, they are typically cumbersome and can cause power system resonance. As a result, active power line conditioners have surpassed passive filters in popularity due to their ability to simultaneously adjust for harmonics and reactive power via a design that allows for connection in either a series or shunt configuration. Since current harmonic correction is necessary in many industrial applications, shunt active filters have surpassed their series-connected counterparts in popularity. Several active filter types have been proposed to improve the reliability of the grid. Following are the criteria used for the classification: Calculating the power rating and necessary response time in a compensated Adjustments that must be made to the system Method for calculating the nominal current and voltage [2]. Active filter capability may be achieved with a current-controlled voltage-source inverter by employing a suitable control technique. A huge number of micro-producers powered by solar panels and wind turbines will contribute to the electrical grid. [3].

In this algorithm, extracted reference source currents exactly follow the actual source currents during steady-state as well as dynamic conditions. As a result, load disturbances have negligible effect on the three-phase source currents. For compensating nonlinear and linear loads, the DSTATCOM uses this method [4]. For the purpose of extracting the weighted value of the load reactive power and active power current components in nonlinear loads, they utilize a back-propagation (BP) method in a 3-phase shunt-connected bespoke power device called as DSTATCOM [5]. The proposed control algorithm is used for load balancing and harmonics suppression with DC voltage regulation of DSTATCOM. In this BP algorithm, training of the weights has three stages. It includes feed forward of input signal training, calculation and back propagation of error signals and upgrading of the training weights. It may have one or more layers [6]. The main features of this algorithm are its stability, incessant monotony, and varied capabilities. Being based on mathematics, it can be taught with minimal effort and requires no specific hardware or software. Also, as the weights are updated in batches, there is little to no spikes or valleys in the correction's smoothness. This algorithm's learned output response is lightning fast, but the training procedure is expensive because of the large number of learning steps required [7]. Here, the nonlinear loads' compensation is accomplished with the assistance of a DSTATCOM and the proposed control method.

Power Quality in DG systems

The practice of providing safe power and grounding to delicate smart appliances. Though this may appear about right, limiting power quality concerns to "sensitive electronic equipment" may be debatable. The range of electrical devices that might be damaged by poor or insufficient power is effectively infinite [8]. All electrical equipment is prone to failure or malfunction when subjected to one or more power quality concerns in another sense, power quality is the range of electrical conditions within which a given piece of machinery can perform as designed without suffering any considerable performance or life - span degradation. Power distribution systems should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [9]. However, in power systems, especially the distribution systems have many nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the pure sinusoidal waveform is lost. This ends up producing many power quality problems.Power grids and electrical systems are very dynamic and intricate. Currents and voltages in these systems are particularly vulnerable to spikes and dips that occur suddenly. The linear and non-linear stresses they are subjected to cause these shifts. Moreover, the grid is vulnerable to a variety of incidents. Electric grids are being more contaminated with various harmonic currents and voltages due to the widespread adoption of power semiconductors in virtually all industrial and residential applications [10].

2.0 Proposed model and method

The performance of the proposed scheme is compared with the traditional voltage-controlled DSTATCOM. The proposed method provides power quality at nominal load and the compensatory injects reactive and harmonic components of load currents, resulting in UPF. The simulation and experimental results show that the proposed scheme provides DSTATCOM. A capability to improve several PQ problems (related to voltage and current).

To enhance the performance of distribution system, D-STATCOM was connected to the distribution system. D-STATCOM was designed using MATLAB simulink the test system shown in figure 6.1 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the DSTATCOM energy storage capabilities. Circuit Breaker is used to control the period of operation of the D-STATCOM.

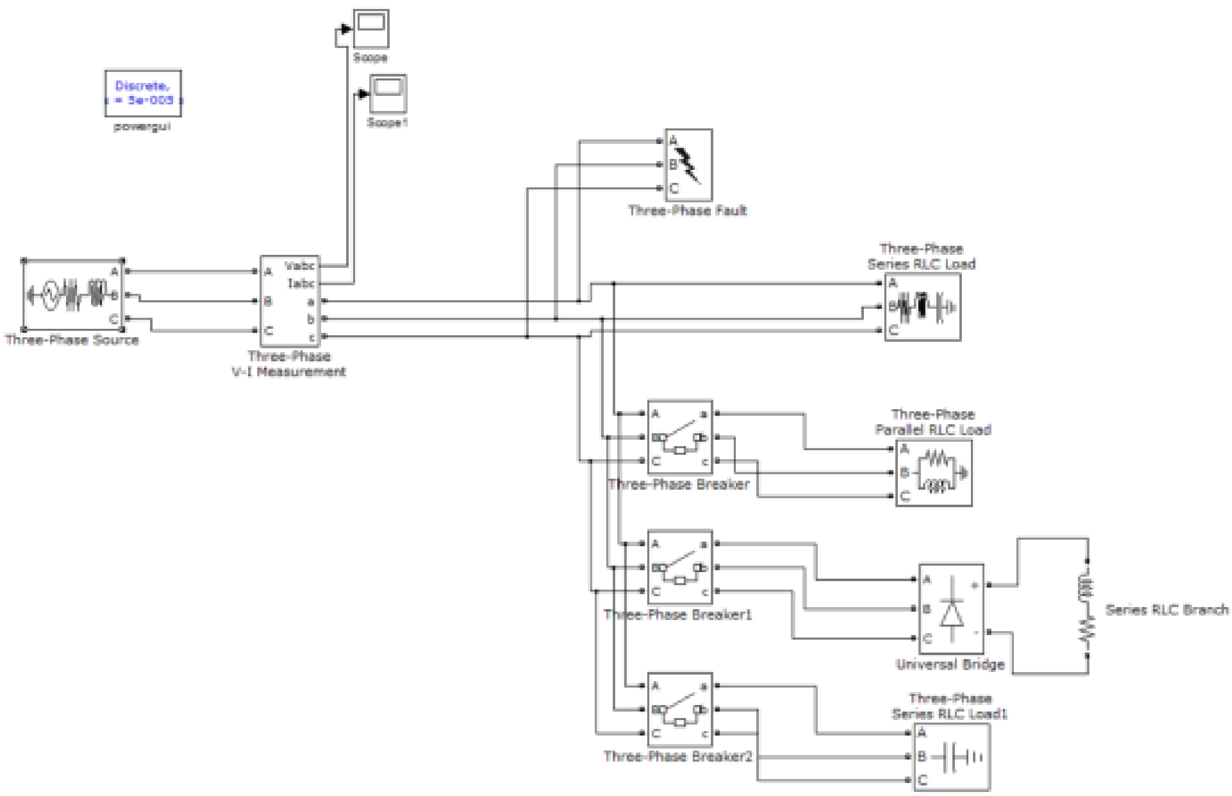

Figure 1: problem identification circuit

3.0 Design and configaration of DSTATCOM

The shunt active power filter is connected in parallel across the supply to offer current compensation and are designed in such a way that they generate equal and opposite reactive power and harmonic compensation by estimating the reference current signal and generating Pulse Width Modulation (PWM) pulses in accordance with them.

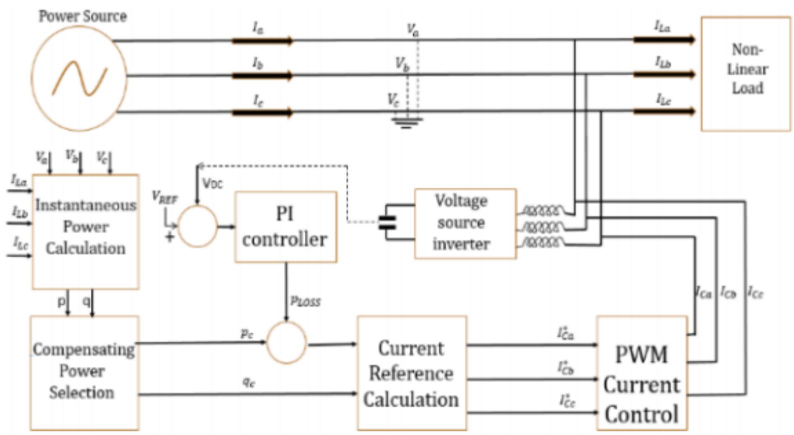

Fig 2. Schematic Diagram of a DSTATCOM

DSTATCOM refers to a shunt active power filter that was developed for the purpose of addressing power quality concerns in the distribution portion of the power grid. A DC capacitor, three-phase inverter (IGBT, thyristor) module, AC filter, coupling transformer, and control scheme make up the DSTATCOM. The Voltage Source Inverter (VSI) is the foundational electrical component of the DSTATCOM, in which a direct current (DC) voltage input is inverted into a three-phase voltage output at fundamental frequency, which is then added to the supply voltage waveform.

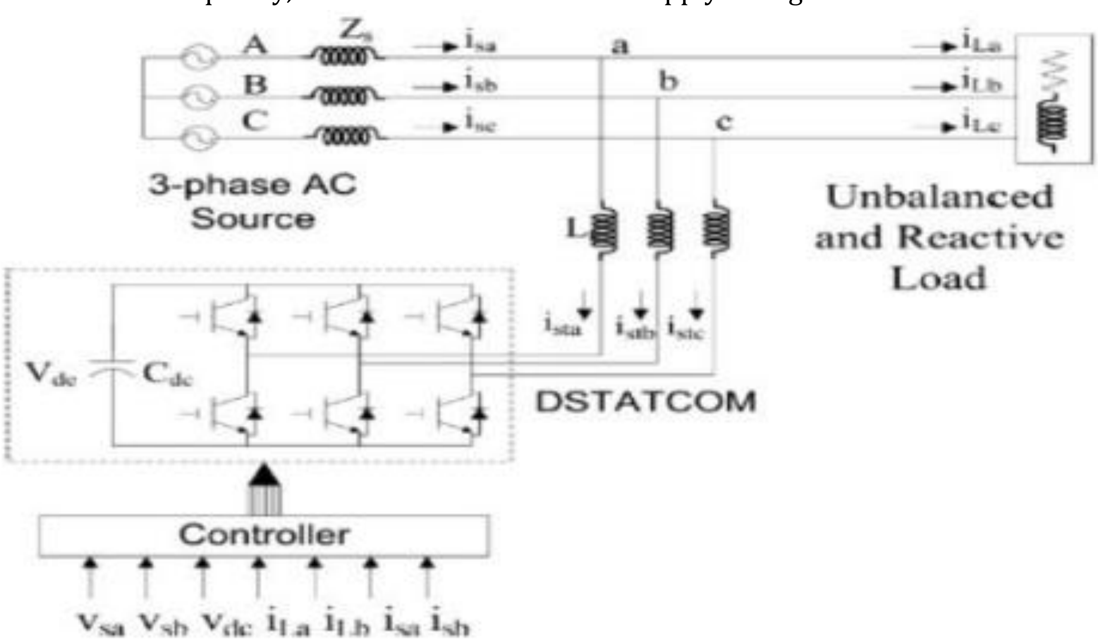

Fig 3: Main Components of DSTATCOM

DSTATCOM's design for reducing harmonics under ideal AC Mains is grounded in a control strategy that involves three distinct phases: (1) the measurement of instantaneous current and voltage signals via power transformers (PT), current transformers (CT), Hall-effect sensors, and isolation amplifiers; (2) the derivation of reference current signals via the separation of the instantaneous power's mean and oscillating parts via control methods and AF configurations; and (3) the implementation of the resulting signals.

4.0 Proposed method with Mat-Lab Simulink

The Simulink software suite may model, simulate, and analyze dynamic systems. It works with linear and nonlinear systems' continuous-time, sample-based, and mixed-time models. Furthermore, we may experiment with "what if" scenarios by changing the parameters and observing the results in real-time with GUI models. In a block diagram, each individual block represents one particular instance of the block type being depicted. The outputs of a block are related to its inputs, states, and time in a certain way, which is determined by the block's type. One or more of each sort of block used to model a system can be included in a block diagram.

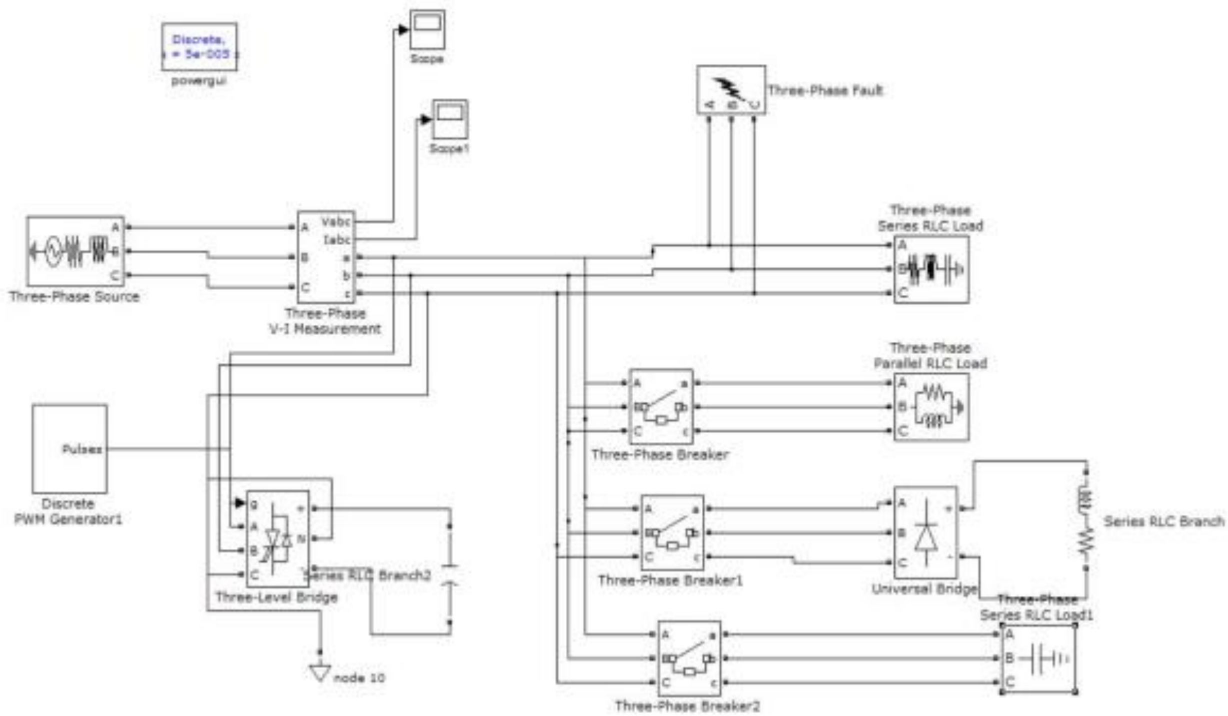

Fig 4: Simulation DSTATCOM Circuit Diagram

4.0 Results and Discussions

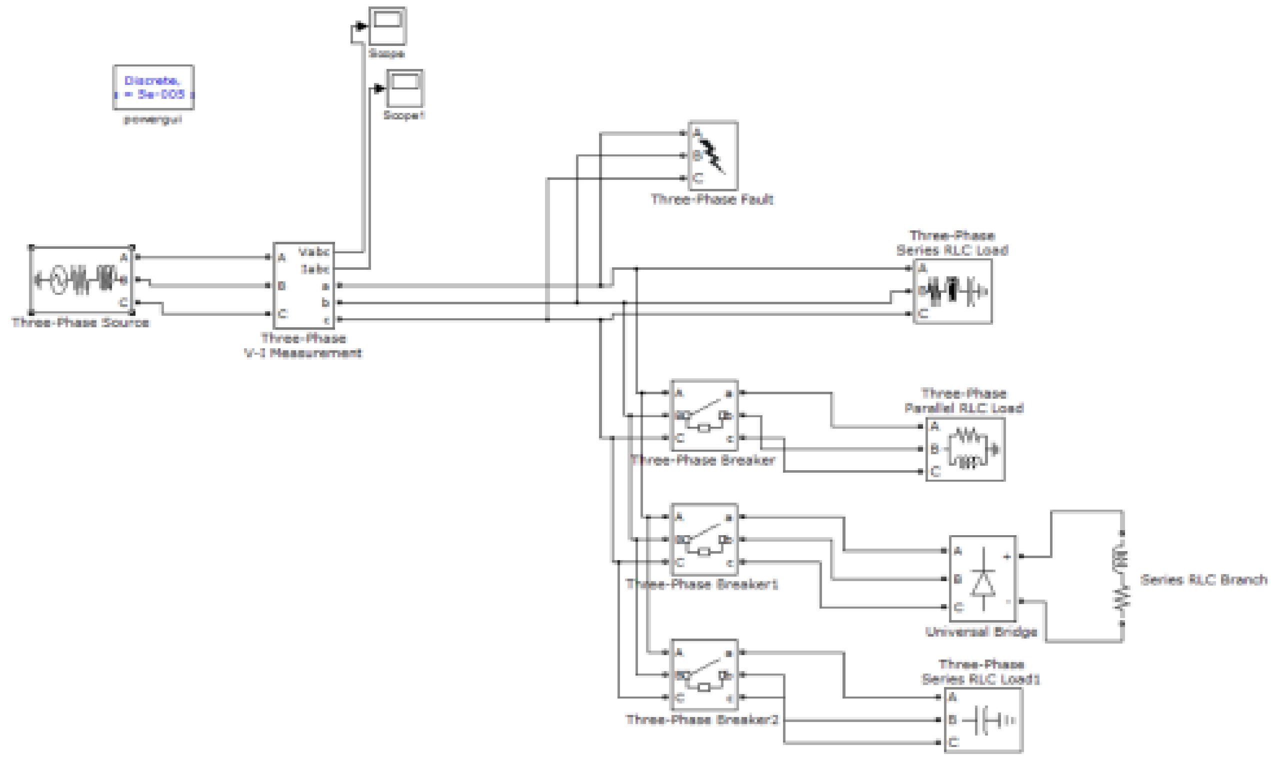

Fig 5: Simulation of Problem identification circuit of DSTATCOM

Common power quality problems are

- Voltage sag and swell
- Harmonic distortion and Low power factor

Voltage sag and swell

4.1 Simulation of power quality problems by adding a DSTATCOM

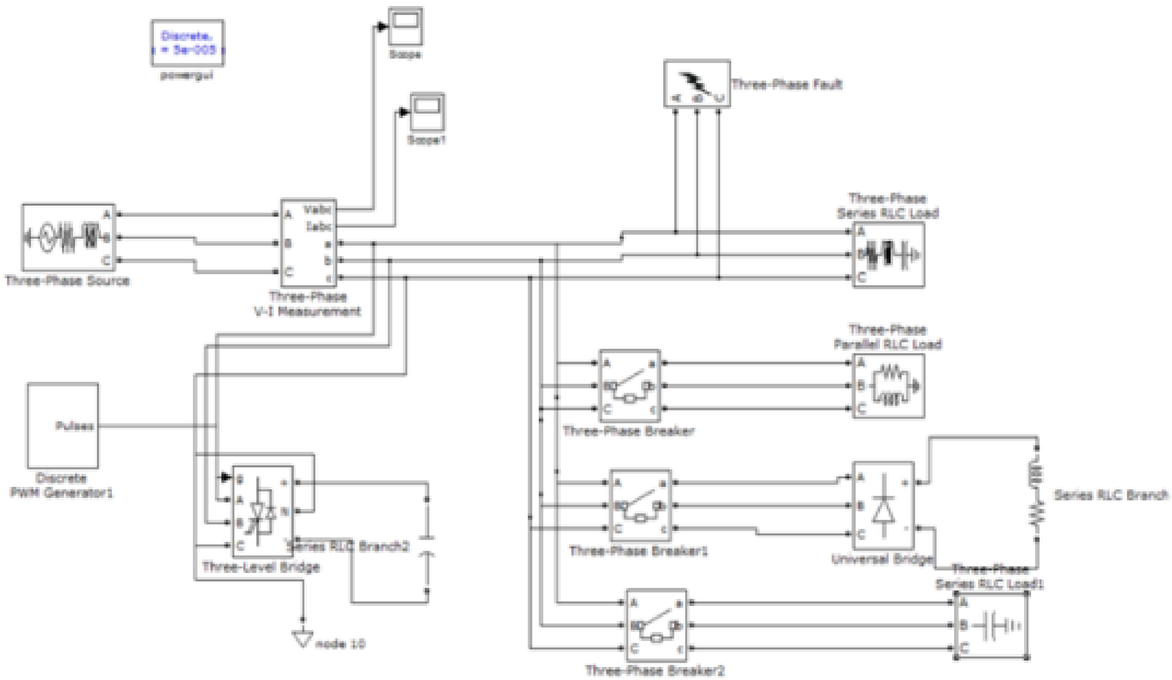

Fig 6: simulation of power quality problems by adding a DSTATCOM

4.2 The test system

The simulation applied on IEEE 15 bus test system, it, s line data and load data described in table 1:

Tabl-1. IEEE 15 bus test system line data and load data.

IEEE 15 Bus Line Data				IEEE 15 Bus Load Data		
from	To	R(fi)	X(fi)	Bus	PL(kw)	QL(kvar)
1	2	1.35309	1.32349	2	44.1	44.99
2	3	1.17024	1.14464	3	70	71.41
3	4	0.84111	0.82271	4	140	142.82
4	5	1.53248	1.0276	5	44.1	44.99
2	9	2.01317	1.3579	6	140	142.82
9	10	1.68671	1.1377	7	70	71.41
2	6	2.55727	1.7249	8	140	142.82
6	7	1.0882	0.734	9	70	71.41
6	8	1.25143	0.8441	10	44.1	44.99
3	11	1.79553	1.2111	11	70	71.41
11	12	2.44845	1.6516	12	44.1	77.99
12	13	2.01317	1.3579	13	140	142.82
4	14	2.23081	1.5047	14	140	142.82
4	15	1.19702	0.8074	15	70	71.41

The test system shown in the figure -5, contain 11 Kv, 50 Hz distribution system, 15 bus, Total generation: P= 1.26 MW, Q= 1.28 Mvar, D-statcom is connected to the bus no 6, three phase fault block connected at the line (1-2).

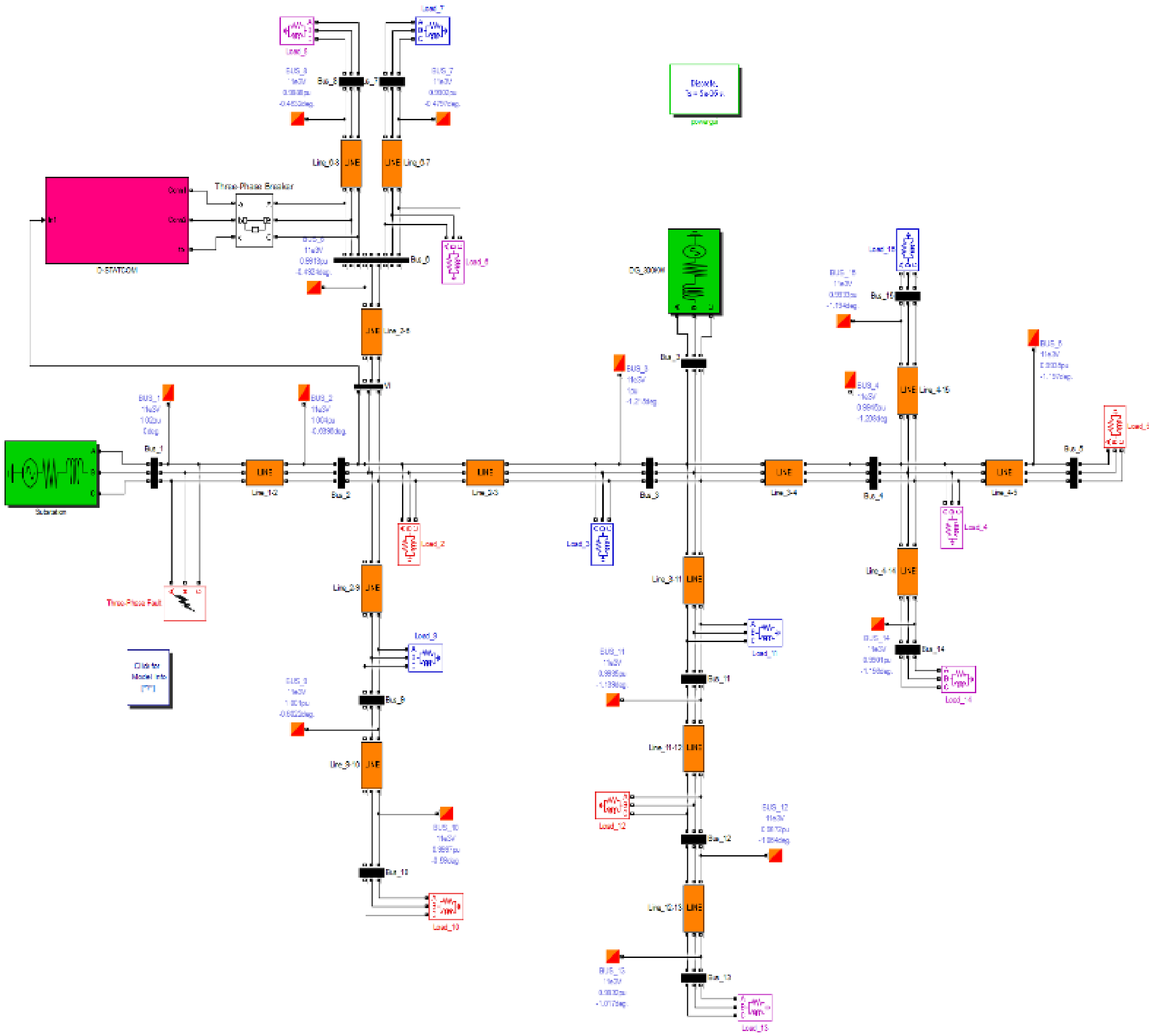

Figure-7. Single line diagram for the system with D-statcom connected at bus no 6

The D-statcom controller and components shown in figure 5.1

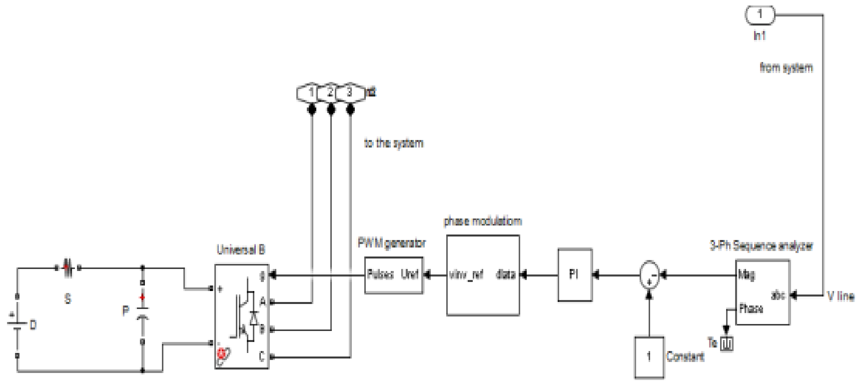

Figure 8- Model Simulink of D-statcom PI controller.

Optimal location of D-STATCOM is found by calculating the stability index of all the buses [7-9]. The bus with maximum value of stability index is selected as a candidate bus. Figure 5.2. shows single line diagram of a two bus distribution system where Vm & Vn are sending and receiving end voltages respectively, Im is thebranch current, Rm & Xm are branch resistance and reactance respectively.

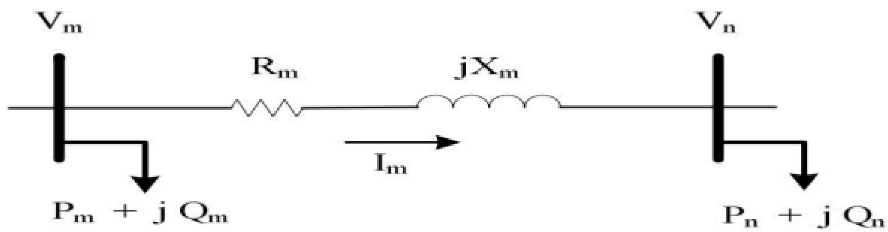

Figure 9- single line diagram of 2-bus distribution system.

After deriving an expression, the stability index is defined as

$$= \frac{4R_m(P_n^2 + Q_n^2)}{V_m^2 P_n}$$

The value of SI should be ≤ 1 for stability. The bus with highest value of SI is most unstable and is selected as candidate bus. [10]

The calculation of stability index (S.I.) for all buses of IEEE 15 bus test system using equation (1) described in table 2.

Table 2. Stability index (S.I.) for all buses of IEEE 15 bus system.

Bus No	Stability Index (S.I)
2	0.0039
3	0.0055
4	0.0079
5	0.0046
6	0.0239
7	0.0052
8	0.0120
9	0.0094

10	0.0050
11	0.0085
12	0.0074
13	0.0195
14	0.0213
15	0.0057

5. SIMULATION RESULTS

system description	11 kv, 50 Hz	PI controller	Kp 0.5,	Ki 500
Carrier frequency	1000 Hz	Sample time	50 μsec	
Energy storage system	18.9 Kv			

Case 1.A. (Additional load with different values at all buses without using D-statcom).

Table 3. The min and max bus voltages without using D-statcom

case	Without D-statcom		With D-statcom	
	Min voltage	Max voltage	Min voltage	Max voltage
Additional load 20% at all buses	0.8962	0.9388	0.9635	1.006
Additional load 30% at all buses	0.8678	0.9128	0.9596	1.005
Additional load 40% at all buses	0.841	0.8882	0.9519	0.9997
Additional load 50% at all buses	0.8157	0.865	0.9443	0.9947

Case 2.A. (load rejection at buses 11,12 and 13 without D-statcom).

Case	Without D-statcom	
	Min voltage	Max voltage
For load rejection at buses 11,12 and 13 after 0.5 sec	1.04	1.068

The voltage at buses 11,12 and 13 falls down to zero after load rejection from 0.5 sec of thesimulation starting. The voltage profile for 15 bus test system is shown in figure 6.1.

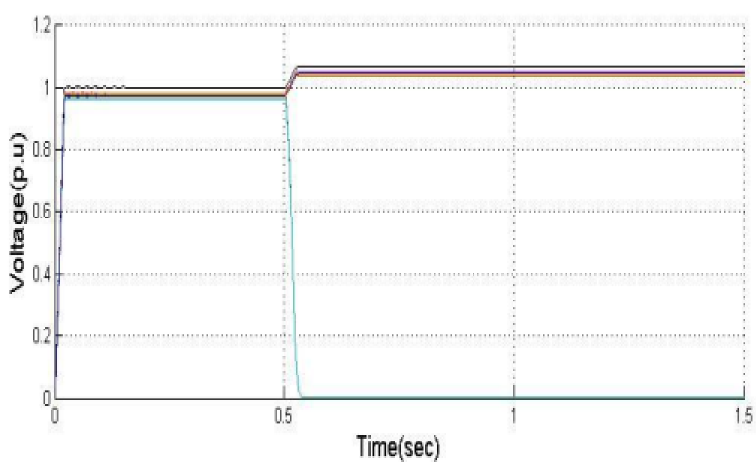

Figure 10 Voltage profile for 15 bus test system after load rejection without D-statcom.

Case 2.B. (load rejection at buses 11,12 and 13 with D-statcom connected at bus 6).

Case	With D-statcom	
	Min voltage	Max voltage
For load rejection at buses 11,12 and 13 after 0.5 sec	0.9926	1.024

The voltage at buses 11,12 and 13 falls down to zero after load rejection from 0.5 sec of the simulation starting. The voltage profile for 15 bus test system is shown in figure 6.2.

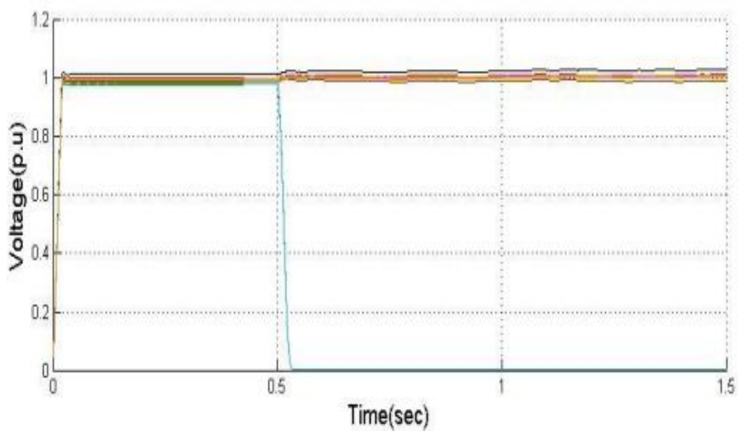

Figure 11 Voltage profile for 15 bus test system after load rejection with D-statcom

Case 3.A. (single line to ground fault occurs at line 1-2 from 0.5 sec to 1 sec without Dstatcom)

Case	Without D-statcom	
	Min voltage	Max voltage
During Single line to ground fault occurs from 0.5 sec to 1sec	0.6575	0.6727

The voltage profile for 15 bus test system is shown in the figure 11.

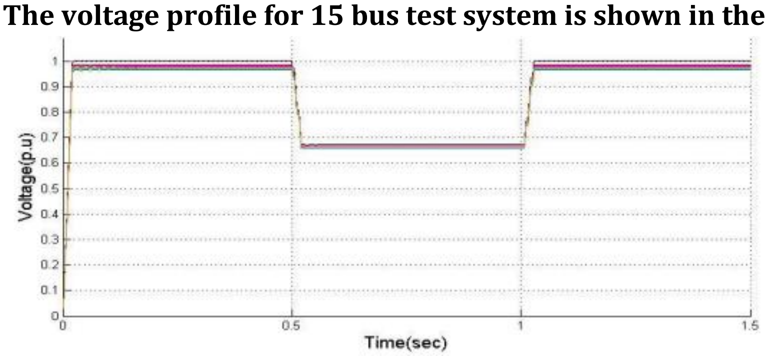

Figure 12:Voltage profile for 15 bus test system during fault without D-statcom.

case 3.B. (single line to ground fault occurs at line 1-2 from 0.5 sec to 1 sec with D-statcom connected at bus 6).

Case	With D-statcom	
	Min voltage	Max voltage
During Single line to ground fault occurs from 0.5 sec to 1sec	0.9131	1.015

The voltage profile for 15 bus test system is shown in figure 7.2.

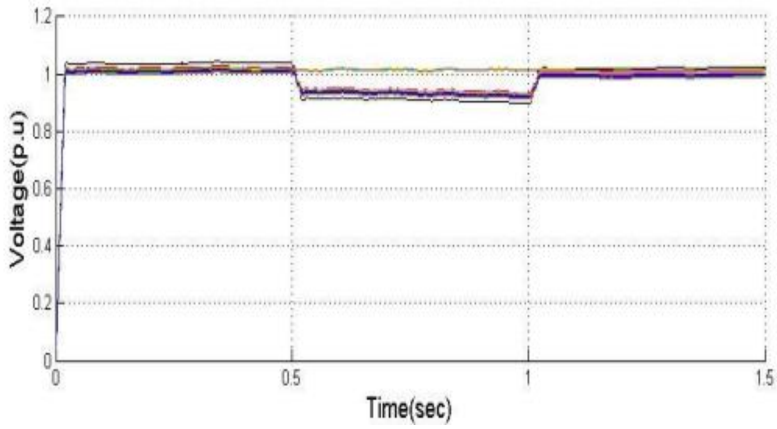

Figure13 Voltage profile for 15 bus test system during fault with D-statcom

case 4.A. (without D-statcom, additional load 20% is applied and disconnect the generator DG at bus 3 after 0.5 sec).

Case	Without D-statcom	
	Min voltage	Max voltage
After additional load 20% and disconnect the generator DG at bus 3 after 0.5 sec from the simulation time	0.7069	0.7546

The voltage profile for 15 bus test system is shown in figure 12.

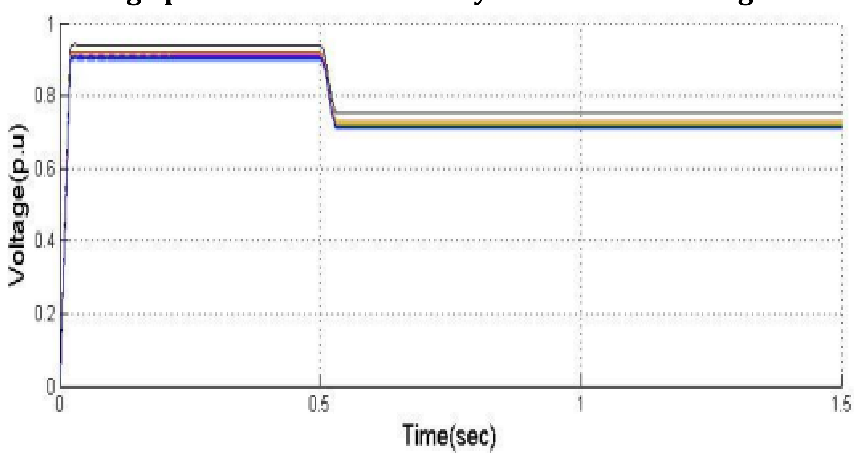

Figure 14 Voltage profile for 15 bus test system with additional load 20%, disconnect the generator at bus 3. simulation achieved without D-statcom

case 4.B. (with D-statcom, connected at bus 6, additional load 20% is applied and disconnect the generator DG at bus 3 after 0.5 sec)

Case	With D-statcom	
	Min voltage	Max voltage
After additional load 20% and disconnect the generator DG at bus 3after 0.5 sec from the simultation time	0.9475	0.9965

The voltage profile for 15 bus test system is shown in figure 14.

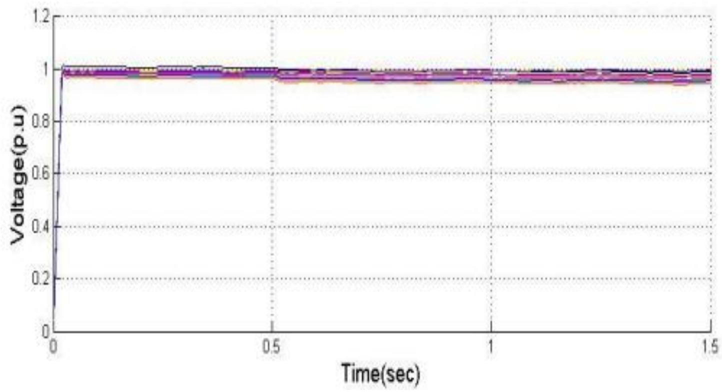

Figure 15. Voltage profile for 15 bus test system with additional load 20% and disconnect the generator at bus 3. simulation achieved with D-statcom

Case 5. (A comparison between D-statcom location at bus 6 and bus 14 when single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec).

Case	With D-statcom	
	Min voltage	Max voltage
D-statcom connected at bus 6 and single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec	0.9131	1.015
D-statcom connected at bus 14 and single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec	0.8709	1.013

The next figures 9,10 describe the results of the Simulation when D-statcom is connected at bus 6 and bus 14 respectively.

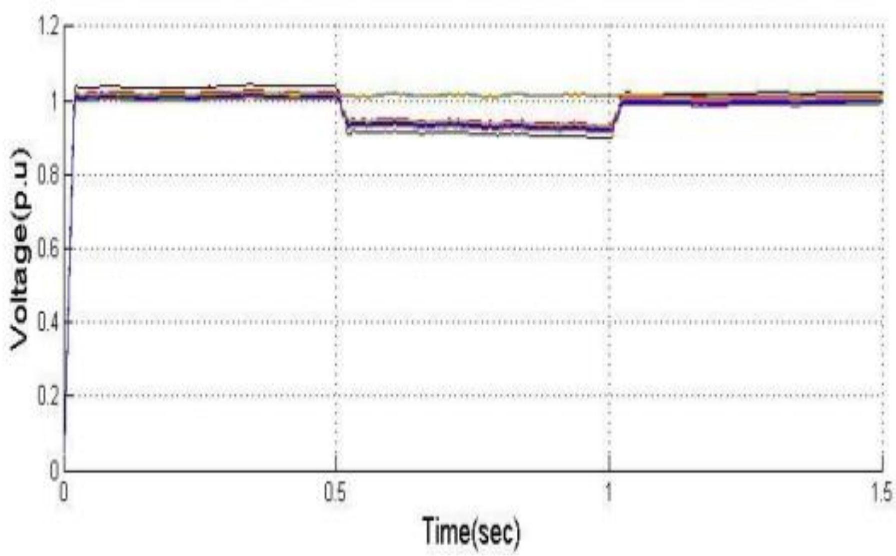

Figure 16. Voltage profile for 15 bus test system when D-statcom is connected at bus 6 and single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec

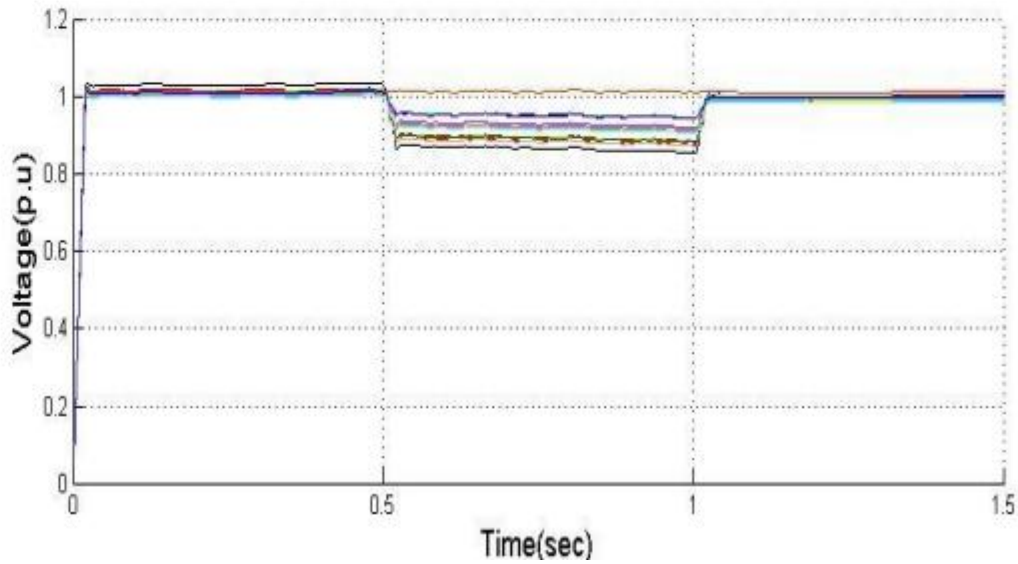

Figure 17. Voltage profile for 15 bus test system when D-statcom is connected at bus 14 and single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec

case 6.A. (An additional nonlinear load is applied at bus 5 without D-statcom).

Case	Without D-statcom	
	Min voltage	Max voltage
The test system steady state voltage at 1 sec After applying nonlinear load at bus 5 from 0.5 sec of the simulation	0.594	0.6957
Duration from transient at 0.5 sec after applying nonlinear load to the steady state	0.5 sec	

The voltage profile for 15 bus test system is shown in figure 11.1

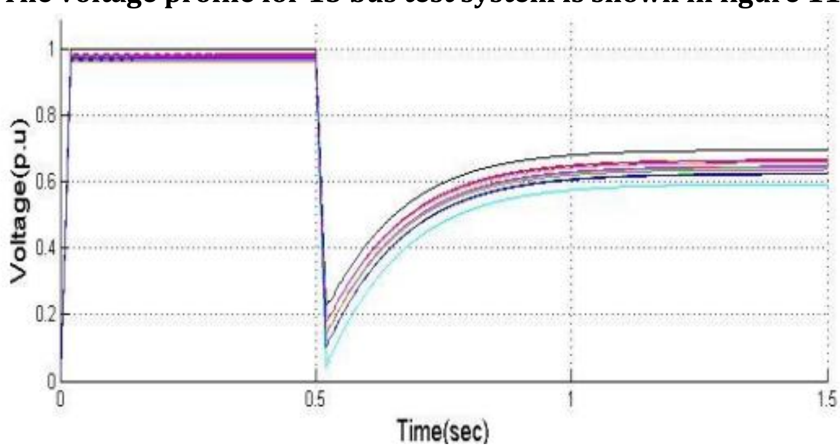

Figure 18 Voltage profile for 15 bus test system after additional nonlinear load at 0.5 sec and without Dstatcom

case 6.B. (An additional nonlinear load is applied at bus 5 with D-statcom).

Case	With D-statcom	
	Min voltage	Max voltage
The test system steady state voltage at 1 sec After applying nonlinear load at bus 5 from 0.5 sec of the simulation	0.858	1.058
Duration from transient at 0.5 sec after applying nonlinear load to the steady state	0.183 msec	

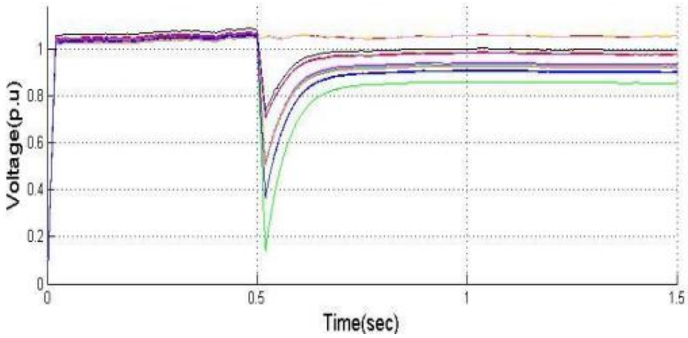

Figure 19 Voltage profile for 15 bus test system after additional nonlinear load and with D-statcom

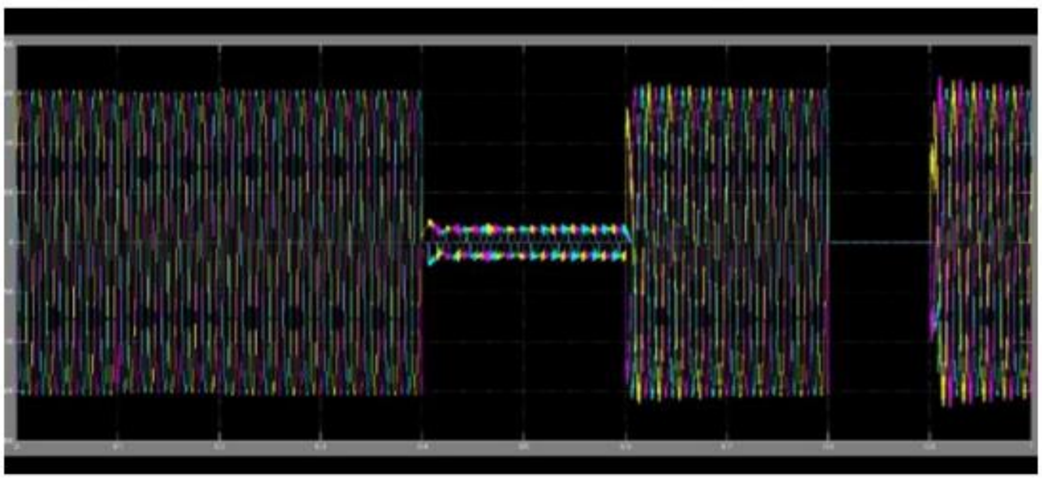

Figure 20: Simulation results of problem identification circuit of DSTATCOM

Common power quality problems are

• Voltage sag and swell

• Harmonic distortion and Low power factor

Voltage sag and swell

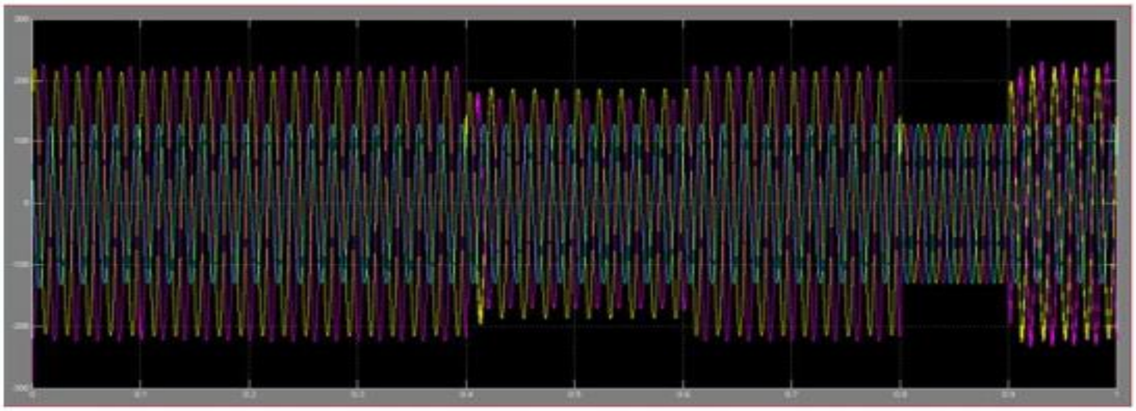

Figure 21: simulation results of voltage sag and swell

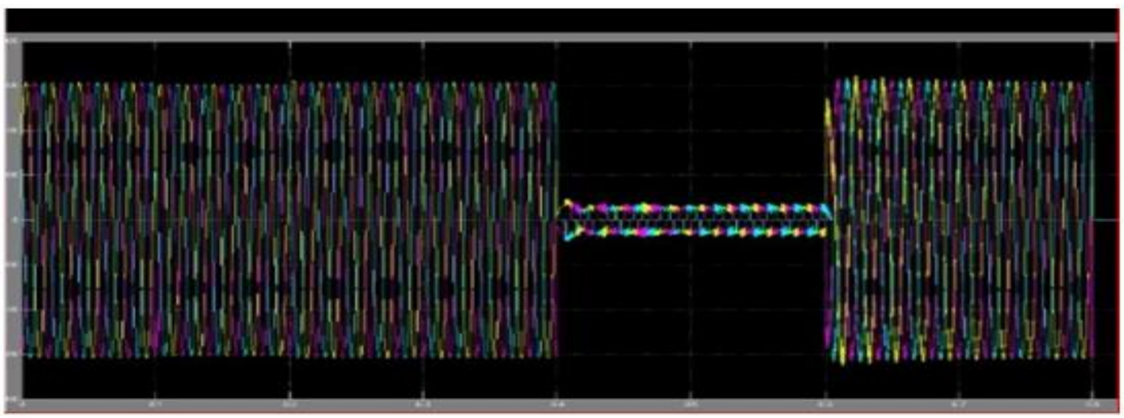

Figure 22: simulation results of harmonic distortion

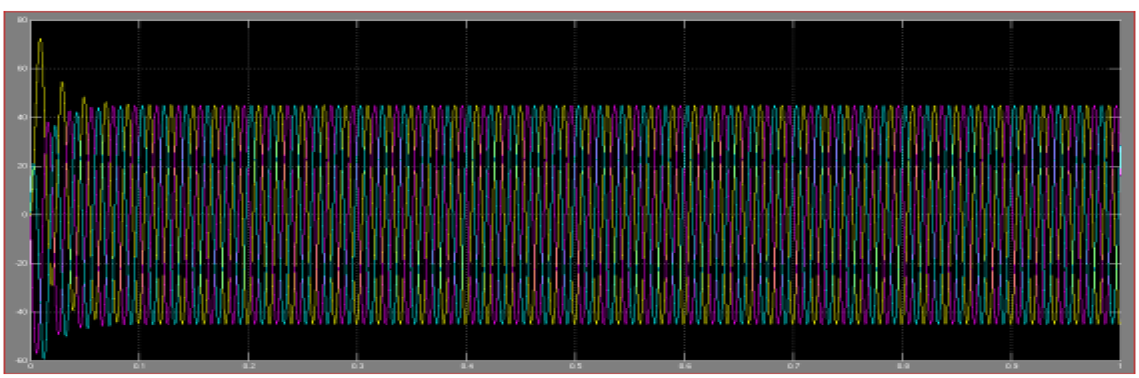

Figure 23: simulation results of DSTATCOM voltage and current wave forms

The sensitivity index is the effective mothod for optimal location of D-STATCOM. It is seen that bus no 6 is the best location of the device. The simulation result of the test system indicates that the fast voltage recovery for distribution systems is one of the major advantages of using D-statcom. Also, the change of D-statcom location to another bus such as bus no 14 which is considered a second selection in the table list with the same condition (single line to ground fault at line(1-2), do not give better results comparing to the location of the device at bus no 6.

According to the analysis of the test sytem effectiveness of a proposed system mainly depends upon the percentage of voltage sag or voltage swell, fault type, location of the fault and Dc storage system rating.

6.0 CONCLUSION

The simulation results demonstrate that voltage sags may be reduced by incorporating D-STATCOM into the distribution system; the power factors also rise to near unity. To sum up, we can say that the power quality is enhanced by the incorporation of D-STATCOM with an LCL filter. Designing filters to mitigate power quality issues, such as harmonic distortion from non-linear loads and power loss owing to reactive power, is a common approach. Radial distribution systems with several non-linear loads like as fluorescent bulb loads, rectifier loads, unbalanced loads, and asynchronous machine loads have also been used to successfully illustrate DSTATCOM's effectiveness. With the above demonstrated technique to mitigate harmonics it is observable that the system response is fast and active. The system keeps the THD of the source current below 5% which is the limit specified by the IEEE- 519-1992 modified standards. A control algorithm has been proposed for the generation of reference load voltage for a voltage-controlled DSTATCOM. The performance of the proposed scheme is compared with the traditional voltage-controlled DSTATCOM. This Simulink can be applied in different bus systems with the development of the D-statcom device performance at nonlinear loads. As it can study the improvement of harmonics and power factor with the voltage sag and swell in one time to reach the best level of the network systems

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