ISSN 2056-5860

POWER QUALITY IMPROVEMENT IN POWER DISTRIBUTION SYSTEMS USING D-STATCOM

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ABSTRACT

The quality of electric power is one of the main branches in power system study. There are various power quality problems faced by the utilities like: voltage sag, flicker, electrical noise, harmonic distortion and different disturbances. So, it is very important to use the devices that can solve the power quality problems. D-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: D-statcom, FACTS, MATLAB Simulink, power quality, PWM, Voltage sag, Sensitivity index.

INTRODUCTION

The sources of poor power quality can be categorized into two groups: (1) actual loads, equipment and components and (2) subsystems of transmission and distribution systems. Poor quality is normally caused by power line disturbances such as impulses, notches, voltage sag and swell, voltage and current unbalances, momentary interruption and harmonic distortions. The International Electro-Technical Commission (IEC) classification of power quality includes loss-of-balance as a source of disturbance. IEEE standard also includes this feature as a source of quality deterioration of electric power. The other major contributors to poor power quality are harmonics and reactive power. Solid state control of ac power using high speed switches are the main source of harmonics whereas different non-linear loads contribute to excessive drawn of reactive power from supply. It leads to catastrophic consequences such as long production downtimes, mal-function of devices and shortened equipment life [1]. IEEE standards determined power quality problems into seven problems according to wave form:

- Transients
- Interruptions
- Sag (dips) /under voltage
- Swell/overvoltage
- Waveform distortion
- Voltage fluctuation
- Frequency variations

One of the most common power quality problems today is voltage sag (dips). A voltage dip is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with a duration from half a cycle to 1 min. In a three-phase system a voltage dip is by nature a three phase phenomenon, which affects both the phase-to ground and phase-to-phase voltages. A voltage dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which lead to high currents. The high current results in a voltage drop over the network impedance. At the fault location, the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged [2,3].
The Flexible AC Transmission System devices (FACTS) offer a fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. On the other hand, the custom power is for low voltage distribution, and improving the poor quality and reliability of supply affecting sensitive loads. Custom power devices are very similar to the FACTS. Most widely known custom power devices are D-STATCOM, UPQC, DVR among them D-STATCOM is very well known and can provide cost effective solution for the compensation of reactive power and unbalance loading in distribution system [4].
D-STATCOM is a fast response solid-state power electronic device provides shunt injected current at the point of connection for the distribution system to correct voltage sag. This value of the shunt injected current can be controlled by adjusting the output voltage of the converter to improve power quality.
D-STATCOM can exchange both active and reactive power with the distribution system by changing the amplitude and phase angle of the converter with respect to the terminal voltage of the line.it can be used to provide voltage regulation, power factor correction, compensation of harmonics and during transient condition provides leading or lagging reactive power to active system stability.

2 – D-STATCOM CONFIGURATION AND OPERATION

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in Figure 1. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, and a control strategy [5].

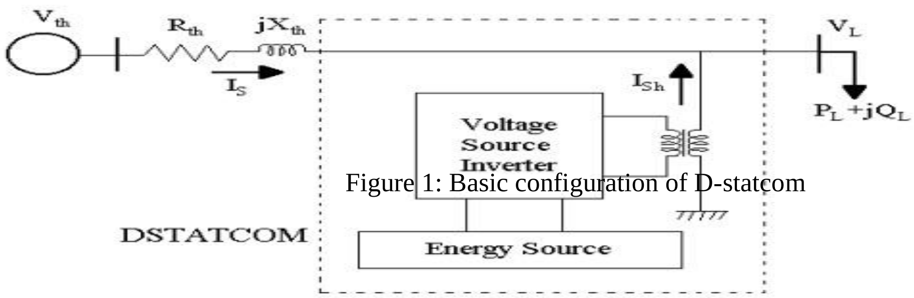

Figure 1: Basic configuration of D-statcom

The main component block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage with desired magnitude and frequency.

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2-1 VOLTAGE Source Converter (VSC)

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the ‘missing voltage’. The ‘missing voltage’ is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter are then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics [6]. Figure 2. shows the Simulink model of D-statcom Controller.

2-2 Controller

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m. s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Hence, custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. [6].

Figure 3 describes Phase-Modulation of the control angle δ.

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller and the output is the angle δ. which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage. [6].

The PI controller process described in figure 4.

The modulated signal Vinverter is compared against a triangular signal in order to generate the switching signals for the VSC valves.

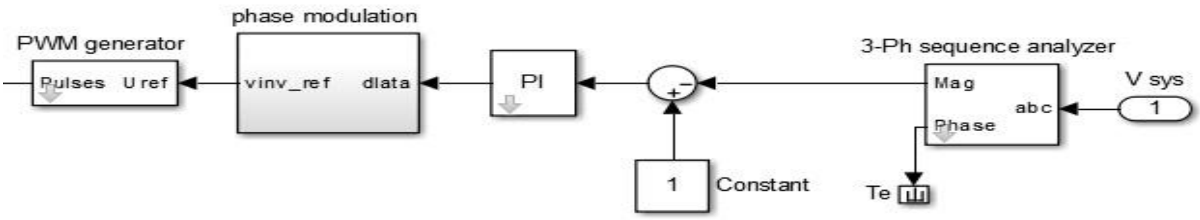

Figure-2. Simulink model of D-statcom Controller.

The sinusoidal voltage control signal (Vinverter) is phase-modulated by means of the angle δ.

$VA = \sin(\omega t + \delta)$

$VB = \sin(\omega t + \delta - 2\pi/3)$

$VC = \sin(\omega t + \delta + 2\pi/3)$

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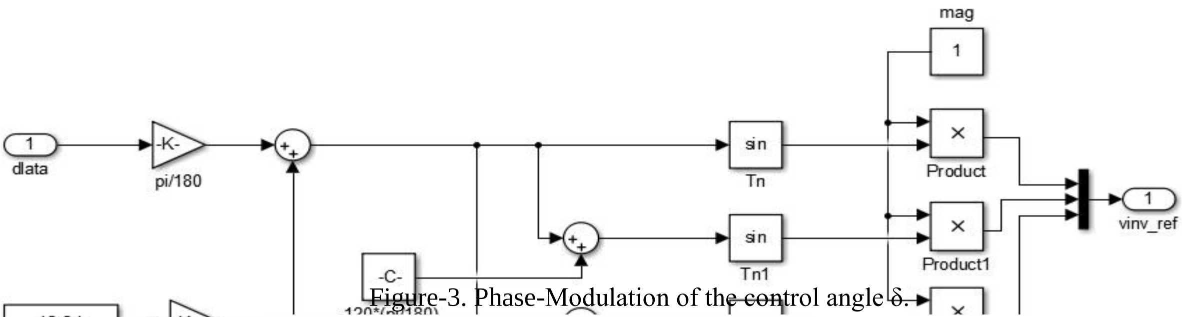

Figure-3. Phase-Modulation of the control angle δ.

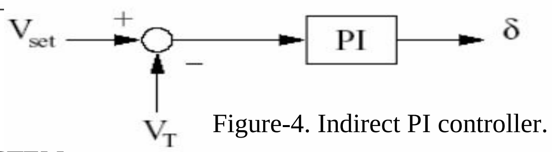

Figure-4. Indirect PI controller.

3 – 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(Ω)	X(Ω)	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).

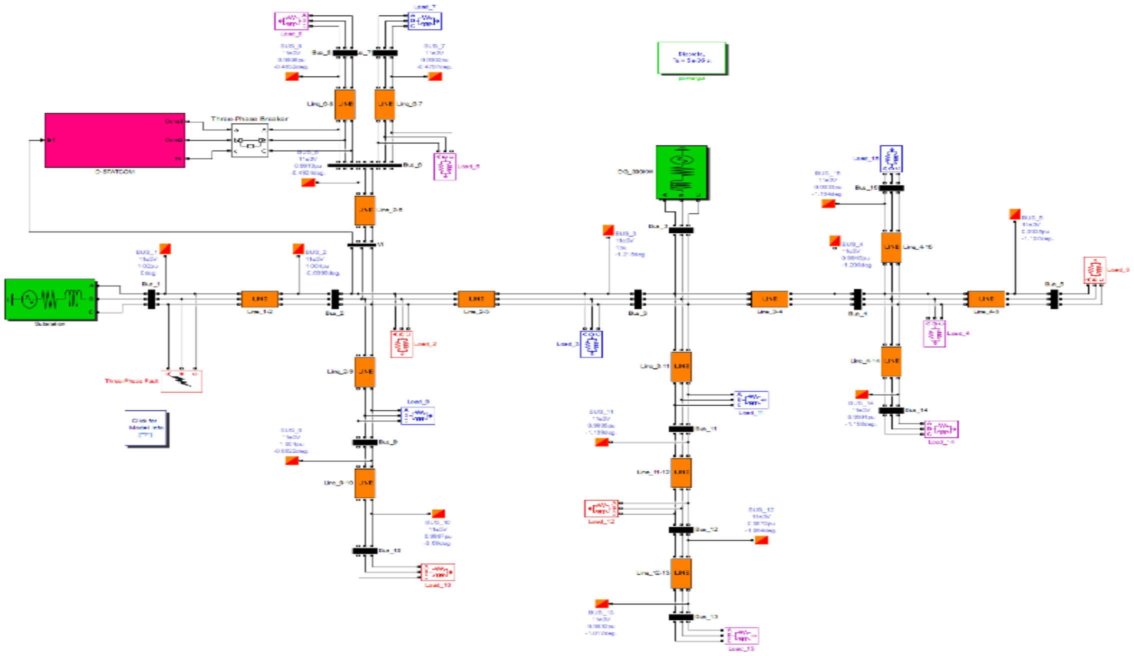

Figure-5. Single line diagram for the system with D-statcom connected at bus no 6.

The D-statcom controller and components shown in figure 5.1

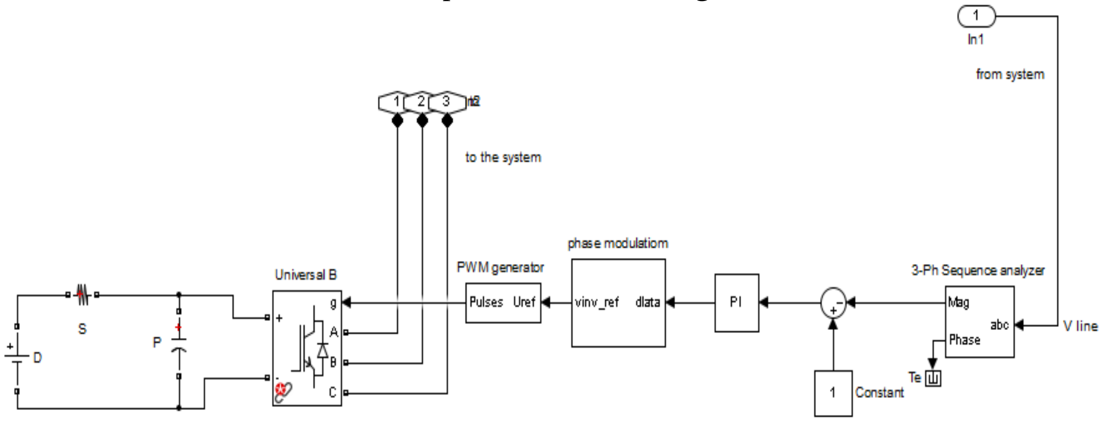

Figure 5.1- Model Simulink of D-statcom PI controller.

4– OPTIMAL LOCATION OF D-STATCOM

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.

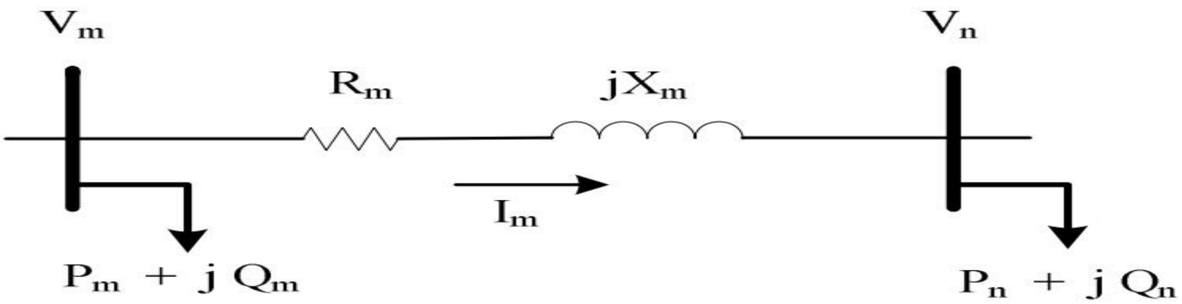

Figure 5.2- single line diagram of 2-bus distribution system.

After deriving an expression, the stability index is defined as

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$$SI = \frac{4R_m(P_n^2 + Q_n^2)}{V_m^2 P_n} \quad (1)$$

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 the simulation starting. The voltage profile for 15 bus test system is shown in figure 6.1.

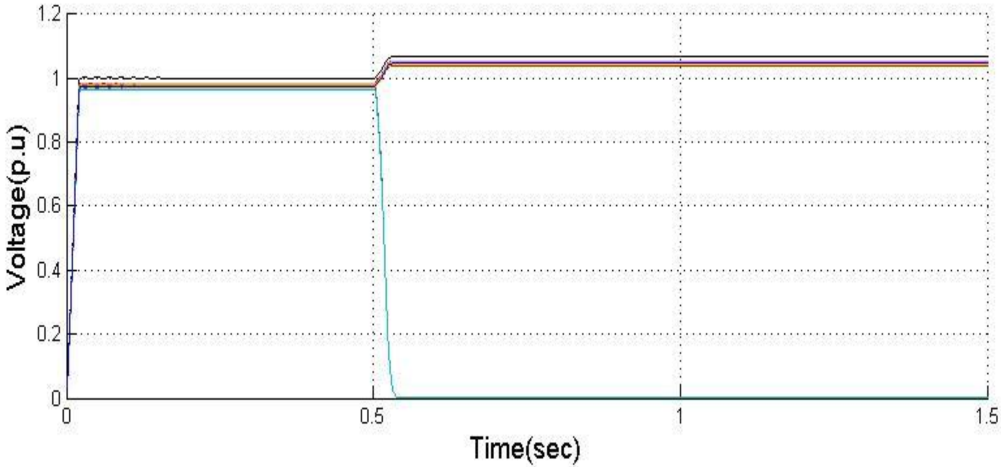

Figure 6.1 Voltage profile for 15 bus test system after load rejection without D-statcom.

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.

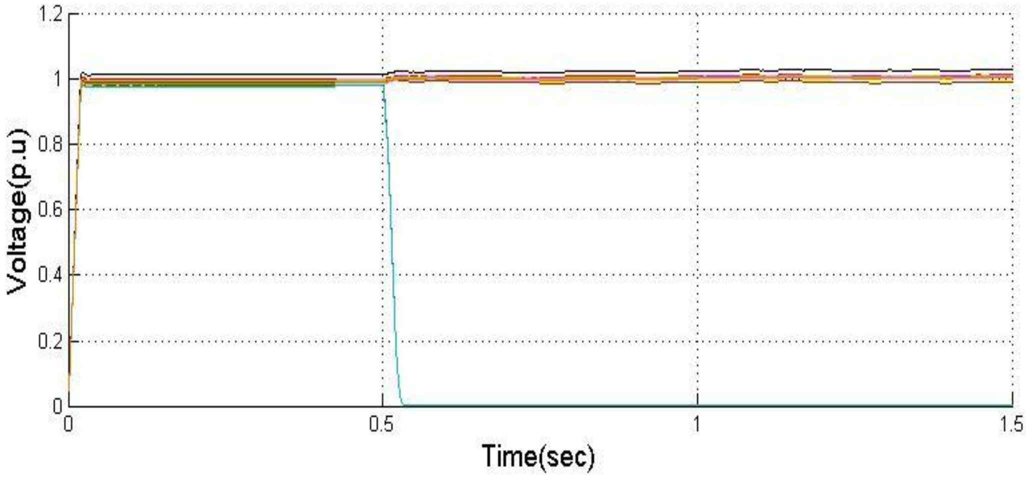

Figure 6.2 Voltage profile for 15 bus test system after load rejection with D-statcom

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

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

The voltage profile for 15 bus test system is shown in the figure 7.1.

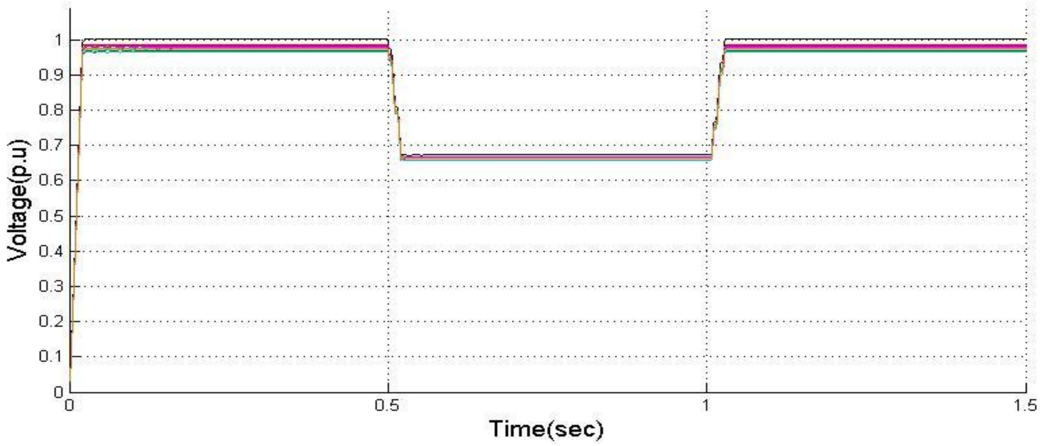

Figure 7.1 Voltage profile for 15 bus test system during fault without D-statcom.

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 1 sec	0.9131	1.015

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

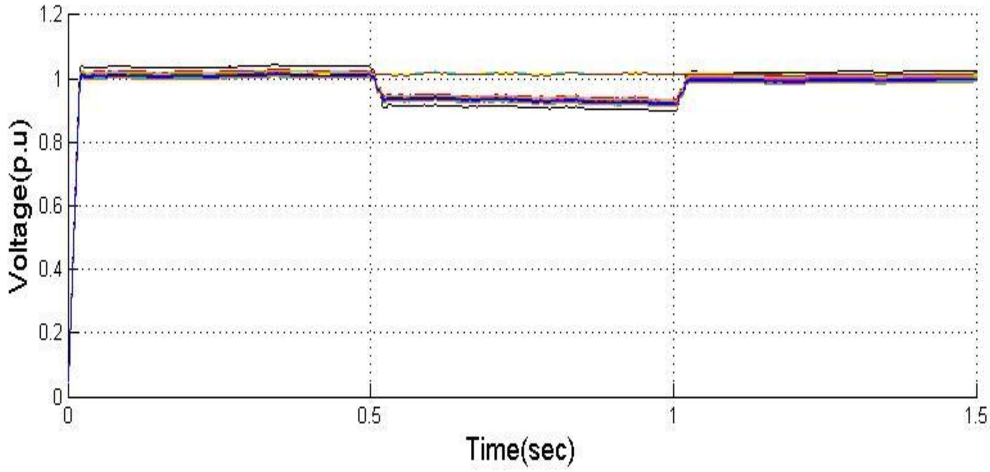

Figure 7.2 Voltage profile for 15 bus test system during fault with D-statcom.

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 8.1.

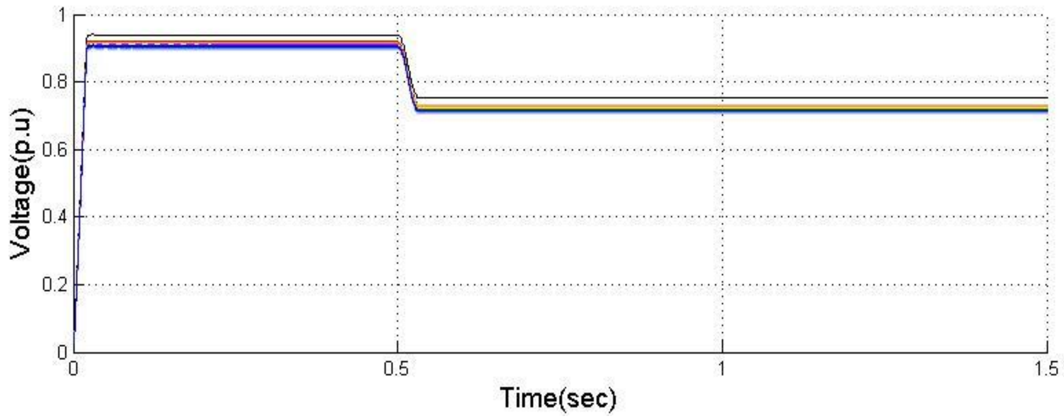

Figure 8.1 Voltage profile for 15 bus test system with additional load 20%, disconnect the generator at bus 3. simulation achieved without D-statcom

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 3 after 0.5 sec from the simultation time	0.9475	0.9965

The voltage profile for 15 bus test system is shown in figure 8.2.

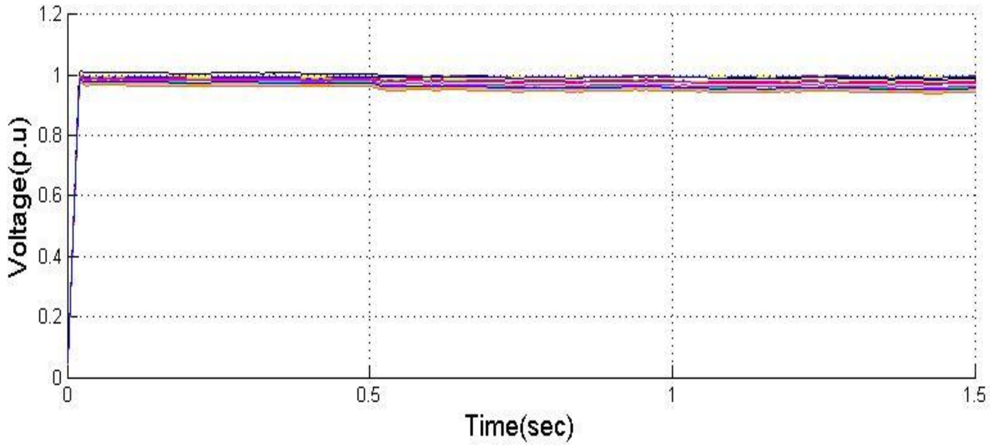

Figure 8.2. Voltage profile for 15 bus test system with additional load 20% and disconnect the generator at bus 3. simulation achieved with D-statcom

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.

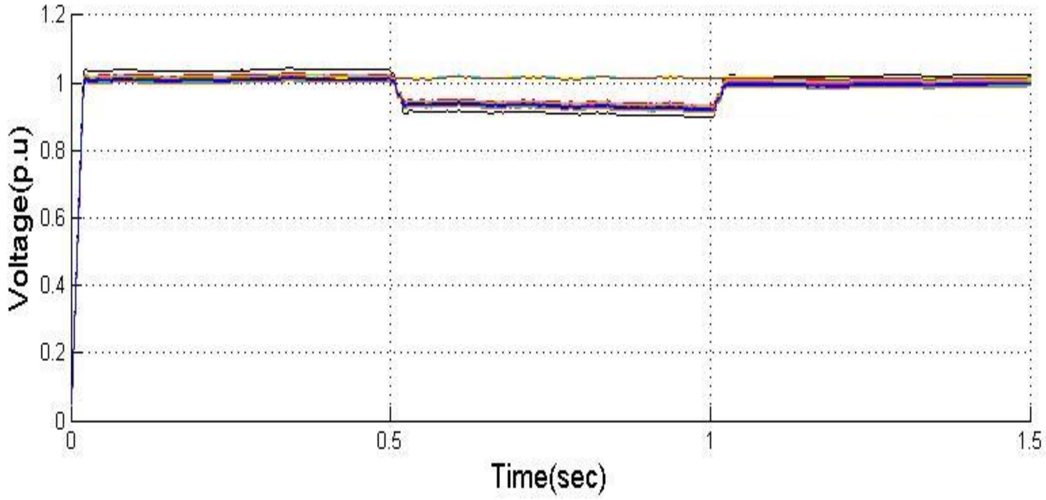

Figure 9. Voltage profile for 15 bus test system when D-statcom is connected at bus 6 and single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec

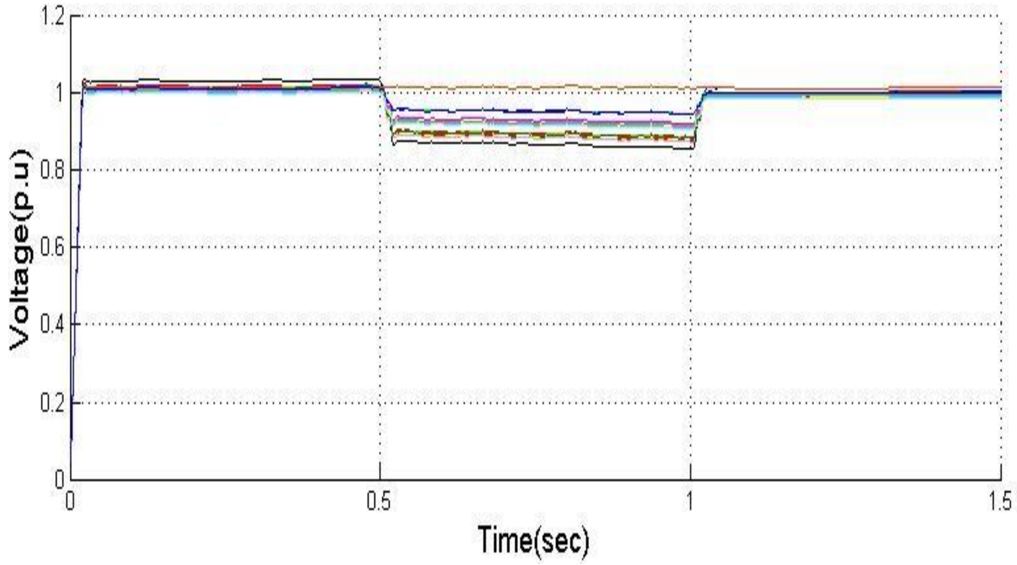

Figure 10. Voltage profile for 15 bus test system when D-statcom is connected at bus 14 and single line to ground fault is applied at Line 1-2 from 0.5 sec to 1 sec

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

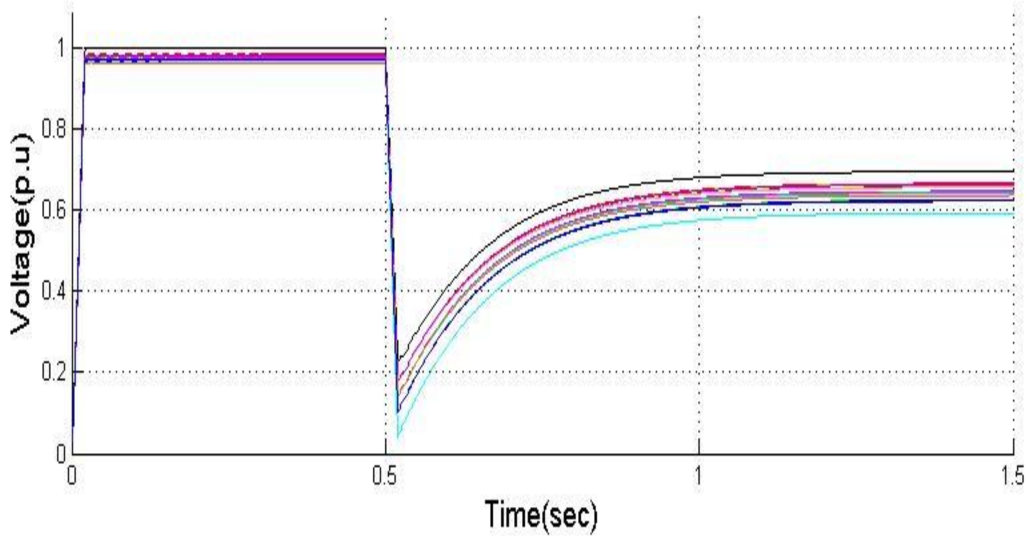

Figure 11.1 Voltage profile for 15 bus test system after additional nonlinear load at 0.5 sec and without D-statcom

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	

The voltage profile for 15 bus test system is shown in figure 11.2

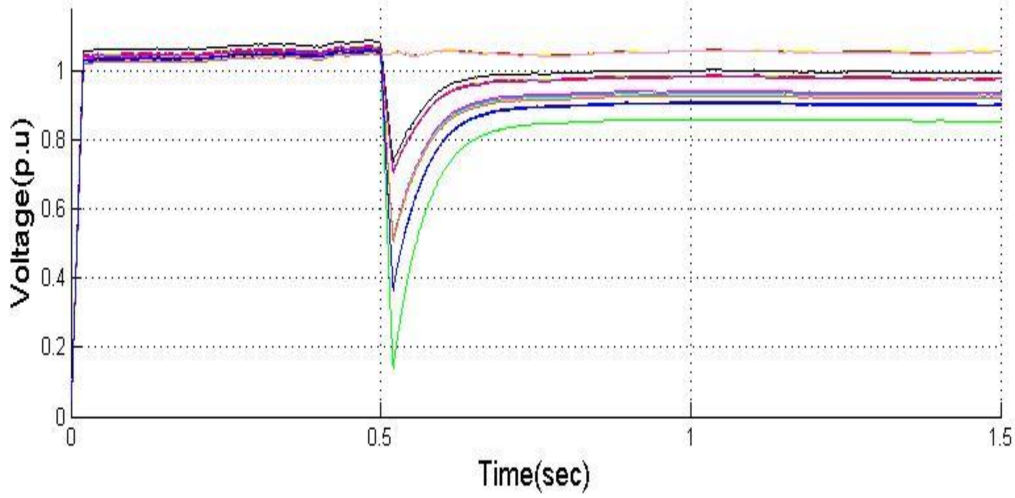

Figure 11.2 Voltage profile for 15 bus test system after additional nonlinear load and with D-statcom.

6– Conclusion

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.

7– Future work

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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