Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 5, Issue 18, pages 11-18, 2019

Performance Analysis of Power Quality Improvement for Standard IEEE 14-Bus based FACTS Controller

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Abstract **- FACTS systems can quickly influence the transmission line parameters like impedance, phase & voltage to supply fast controller of transmission or distribution response. This category of FACTS can be inserted to the transmission line in shunt, like static compensator or STATCOM, series like series compensator or SSSC and common such as, unified power controller or UPFC, and use the accessible energy from the system. FACTS have been inspected in power system area. There are numerous advantages in applied FACTS family such as system stability increase, loading ability of transmission systems, power quality enhancement and increase usage of low generation cost. When the fault occurs, more reactive power is demand from the system to achieve the fault and return the system to the stable condition.**

Simulation results and discussion of the IEEE 14-bus system with/without STATCOM unit during a single line fault & three lines fault are investigated in this paper. 14-bus system is modeled using the blocks of Simulink. The purpose of this study is to promote a STATCOM model for power quality improvement.

Keywords: component; System power quality improvement; STATCOM; FACTS devices; IEEE 14-bus system; System stability; Power system simulator.

OBJECTIVE

The study of the existing research in the present paper has been undertaken with the following objectives:

1-To study the IEEE-14 bus system of power system.

2-To study of a STATCOM system to improve the power system quality.

3-To make the model of IEEE-14 bus and STATCOM systems analysis in MATLAB simulation.

I. INTRODUCTION

Power quality (PQ) has become an important rule for the fulfillment of numerous applications such as production & information technology, and has an impact on high control & automation of technology systems. So, PQ has achieved increased attention by two industrial/commercial consumers [1]. Power system has to be preserved from the climate conditions, owing to increase electricity overloading. Power electronics known as FACTS has been inserted in order to control various parameters of transmission line [2].

FACTS give features for enhancing transmission line in terms of best application of existing property, increase line reliability, transient stability of the grid and increase supply quality for sensitive manufactures [3, 4]. Application of several FACTS can help in reducing the different PQ issues. The efficient applied of power system resources for a connotation FACTS was inserted lately. The basic connotation of FACTS is depend on the applied of high power electronics in order to dominate active power, reactive power and also voltage in transmission line [5, 6].

STATCOM unit is a reactive compensation which is a parallel inserted to the transmission & distribution systems that based on VSCs which composed of self-commutated switching units whereas, modern devices of STATCOMs comprise commutated switches like thyristors which is able on to injecting or absorbing reactive power to recompense the transmission system that is situated among the load and generators [7]. The working of STATCOM unit makes it to work as source/load for transmission system and considered as a member of the FACTS family. Moreover, in distribution systems, STATCOM unit can replace a var compensators or SVC [8].

This article is coordinated after introduction, section II describes basic configuration, operating principle and the mathematical equations of a STATCOM connected to a network, section III presents the modeling analysis of IEEE-14 bus applied in this work, section IV presents the results & discussion and finally, section V concludes this paper.

II. STATCOM, BASIC CONFIGURATION AND OPERATING PRINCIPLE

STATCOM model composed of VSC, storage unit; a magnetic transformer inserted in parallel and control loops. VSC transforms voltage dc through the storage unit to a collection of 3-phase voltages which are in phase, connected with the system across the magnetic transformer reactance. VSC inserted in parallel with the system gives a multifunctional topology that can be applied for distinct purposes like: regulation of the voltage and reactive power compensation, power factor improvement and removal of current harmonics [9, 10].

In STATCOM several technologies applied each depends on the power ratings. For higher power STATCOMs Gate Turn-of Thyristors (GTO) are applied whereas for lower power STATCOMs Insulated Gate Bipolar Transistors (IGBT) based technologies are used [11]. System of STATCOM has been known as IEEE based on the following three elements. A functional model of STATCOM is shown in Figure (1).

First element is Static: depend on the solid-state switching units without rotating components; the next element is Synchronous: identical to synchronous machine based on three sinusoidal voltages and final element which is Compensator: that presented with compensation of reactive power [12].

The relation among fundamental component for output voltage of the converter and the voltage through capacitor is expressed by equation (1):

$$V_{out} = K * V_{dc} \qquad (1)$$

Where,

K, is the coefficient that based on converter model, No. of switching pulses & converter controls.

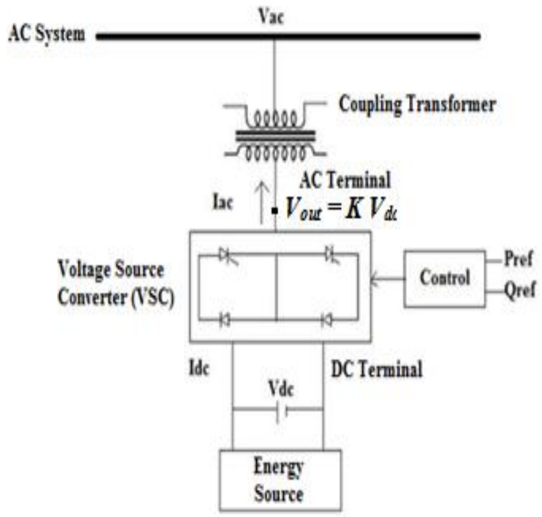


Figure 1: Basic circuit arrangement of STATCOM [13].

The flow value from inverter to the line can be given as follows:

$$I_{ac} = \frac{V_{out} - V_{ac}}{X} \qquad (2)$$

Where, X is magnetic transformer leakage reactance. So, exchange of reactive power can be declared based on the equation (3):

$$Q = \frac{V_{out}^2 - V_{out}\,V_{ac}\,\cos\alpha}{X} \qquad (3)$$

The real power exchange among inverter voltage and system can be computed as follows:

$$P = \frac{V_{out}\;V_{ac}\,\sin\alpha}{X} \qquad (4)$$

The STATCOM V-I characteristics are depicted in Figure (2). STATCOM losses are ignored & $I_{STATCOM}$ is supposed in order to be purely reactive. The negative current point to capacitive case whereas positive current point to inductive case. The limits on both cases are symmetrical ($\pm I_{max}$). The BC slope is presented for the characteristic of V-I to prohibit the STATCOM limits and to permit shunt operation of both/more units. Figure (3) show the principle operation of a STATCOM. The characteristics of V-I are illustrated by the following equation:

$$V = V_{ref} + X_s\, I \qquad (5)$$

Where,

V, Positive sequence voltage

I, Reactive current (I>0 point to an inductive case & I<0 point to capacitive case)

X_s, Slope/droop reactance (generally among 1% and 5%)

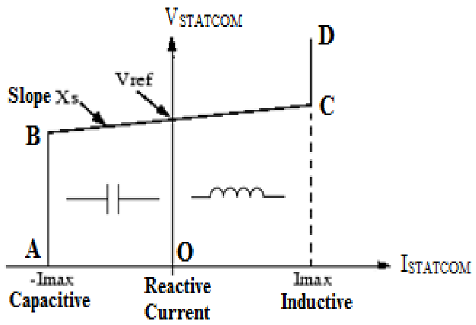


Figure 2: Representation of STATCOM V-I characteristics

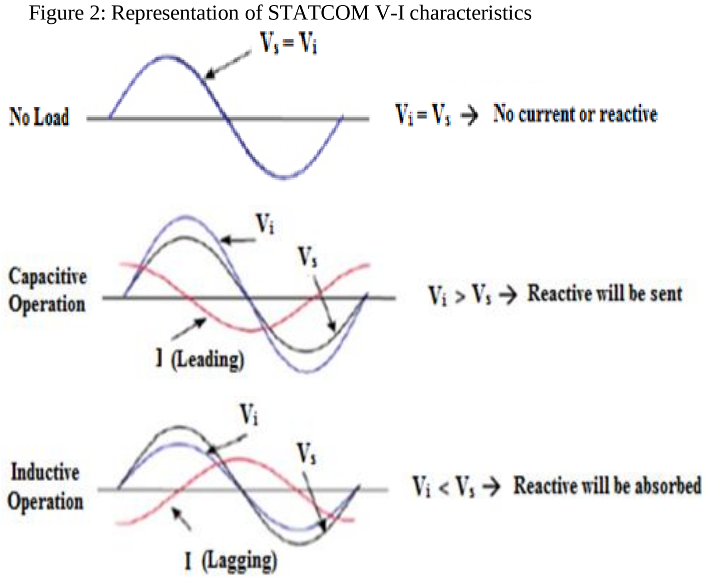


Figure 3: STATCOM system operation

Figure (4) depicts the block diagram of STATCOM based on control of pulse width modulation (PWM); it composed of, a phase-locked control (PLL) that synchronizes on the positive-sequence component of the voltage (V_1). The PLL output is applied to calculate the d-q components of the 3-phase voltage & currents (named as V_d, V_q or I_d, I_q). Measurement systems sensing the d-q components of positive-sequence voltage & currents to be controlled and the voltage (V_{dc}). The main hypotheses taken in the modeling step are: The supply voltages are stable, resistance & capacitance of the line are ignored, unity power factor, free ripple of DC output and switches are ideal/linear.

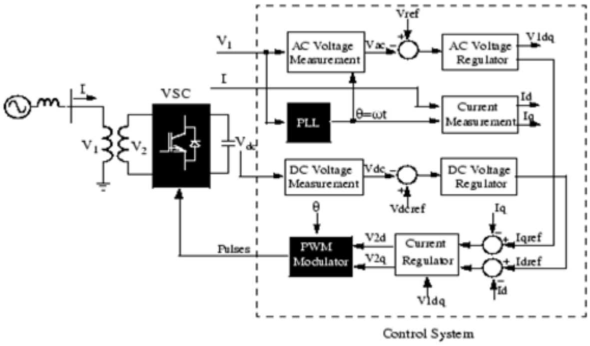


Figure 4: STATCOM block diagram based PWM control

Figure (5) shows some applications of STATCOM such as, improvements of PQ, control of reactive power, regulation of the voltage, power swings or oscillations damping, capacity enhancement of the transmission line, stability of transient and voltage, and application at system faults [14].

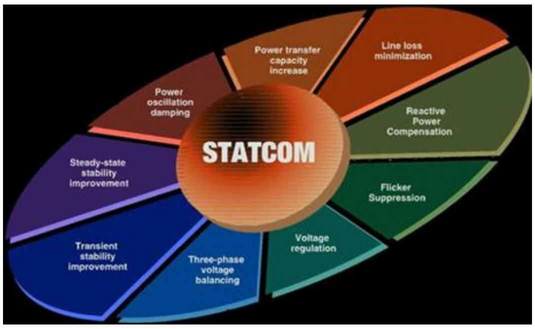


Figure 5: Various applications of STATCOM

III. Power System for IEEE 14-Bus Model Under Study

This paper produces the FACTS device in IEEE 14-bus system to power quality improvement. The system performance with and without STATCOM during single line fault and three lines fault conditions are studied. Matlab/Simulink program is utilized for simulation the system with and without STATCOM. The standard of IEEE 14-bus is illustrated in Figure (6). It contains of 5 synchronous machines, three of that are synchronous compensator (STATCOM) only applied for support of reactive power. There are 11 loads totaling 259MW & 73.5Mvar. The dynamic & static system data can be created in Appendix A. This system is vastly applied for voltage stability and low frequency stability analysis. The IEEE 14-bus was studied based Matlab/Simulink as in Figure (7).

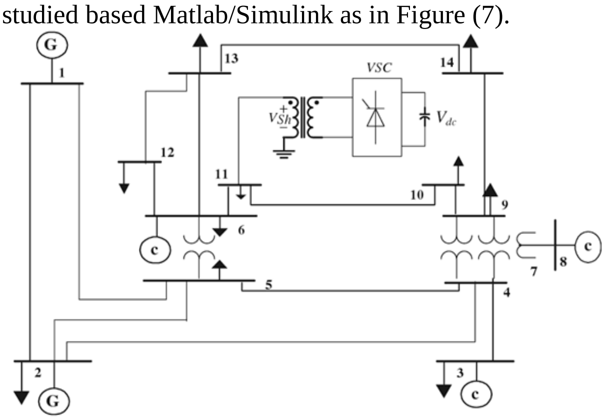


Figure 6: Standard of IEEE 14-bus system with STATCOM [15].

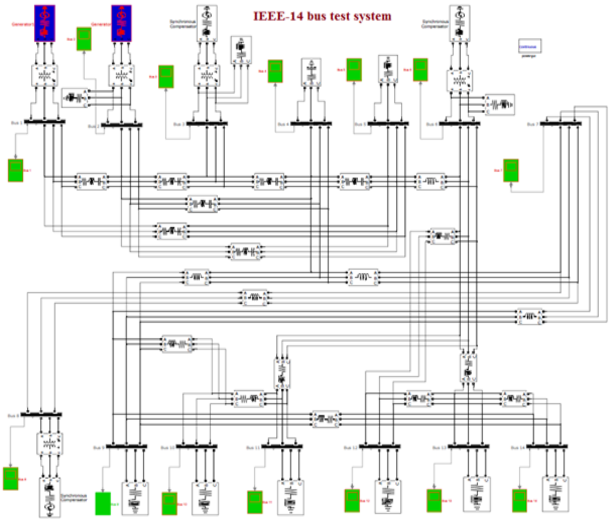


Figure 7: MATLAB simulation model of IEEE 14-bus system

IV. Results and Discussions

When the system running with & without STATCOM a single-line fault & three-line fault are applied, with fault resistance is 0.001Ω.

Study Case (1): Single-line fault

System performances with and without STATCOM are shown in Figure (8) in terms of voltage response through single-line fault at bus 1, 2, 3, 4, 5, 8, 9, 13 and 14. It is noticed that with STATCOM, the overshoot of the voltage response is better than the system without STATCOM. Table (I) summarizes the performance specification with and without STATCOM through a single-line fault disturbance in sense of overshoot.

Table I: Performance specification due to single-line fault disturbance

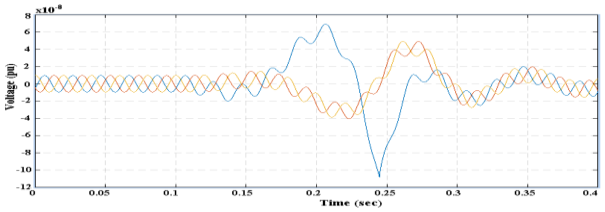
Under overshoot									
Bus number	(1)	(2)	(3)	(4)	(5)	(8)	(9)	(13)	(14)
Without STATCOM	$6.91*10^{4}$	6.35	2.5	1.44	3.25	1.28	1.32	1.9	1.48
With STATCOM	$5.26*10^{3}$	5.4	1.75	1.23	2.9	1.03	1.22	1.77	1.44

Study Case 2: Three-lines fault

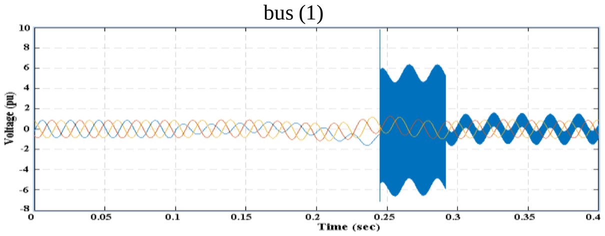
System performances with and without STATCOM are shown in Figure (9) in terms of voltage response through three-lines fault at bus 1, 2, 3, 4, 5, 8, 9, 13 and 14. It is noticed that with STATCOM, the response of the system in terms of voltage, the system with STATCOM is better than without STATCOM in sense of overshoot. Table (II) summarizes the performance specification with and without STATCOM during three lines fault disturbance.

Table II: Performance specification under three-line fault disturbance

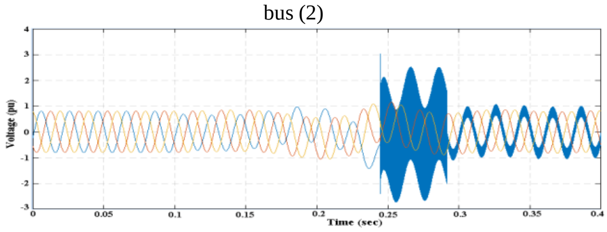
Under overshoot									
Bus number	(1)	(2)	(3)	(4)	(5)	(8)	(9)	(13)	(14)
Without STATCOM	$1.04*10^{7}$	1.8	1.4	1.6	1.3	1.2	1.2	1.3	1.5
With STATCOM	$1.26*10^{7}$	1.4	1.1	1.5	1.1	1.5	1.1	1.2	1.49



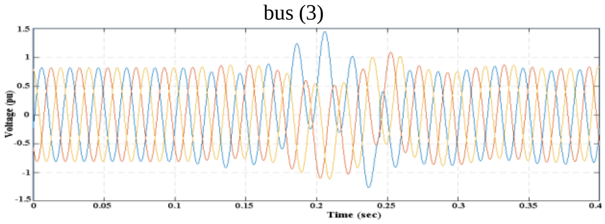
bus (1)



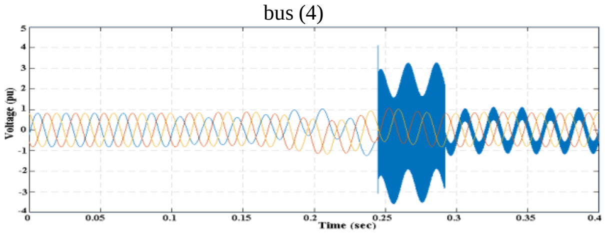
bus (2)



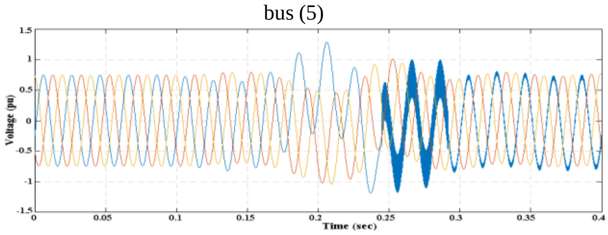
bus (3)



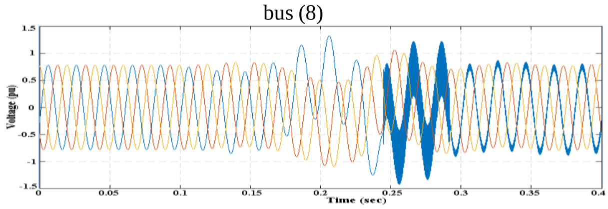
bus (4)



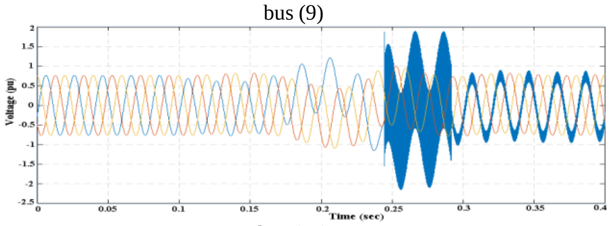
bus (5)



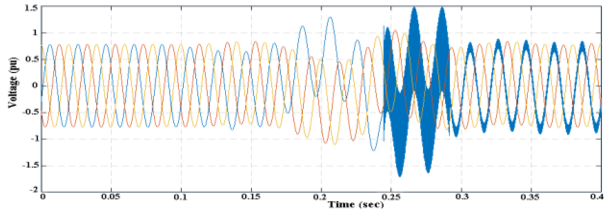
bus (8)



bus (9)

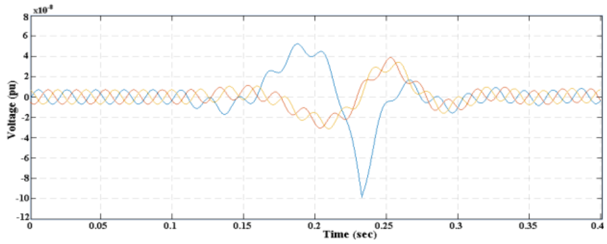


bus (13)

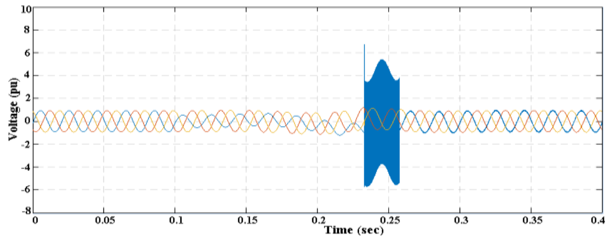


bus (14)

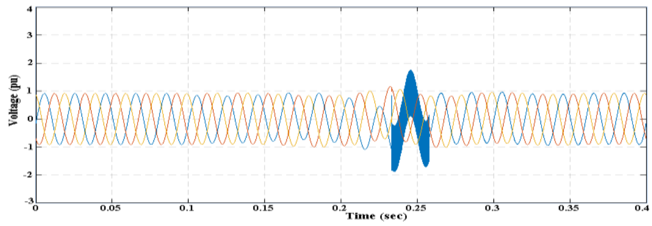
(a)Waveform of voltage response without STATCOM



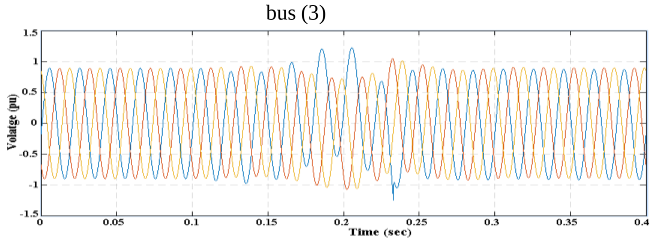
bus (1)



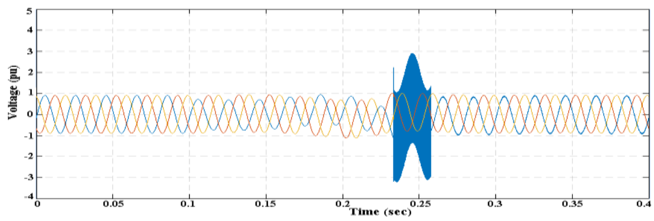
bus (2)



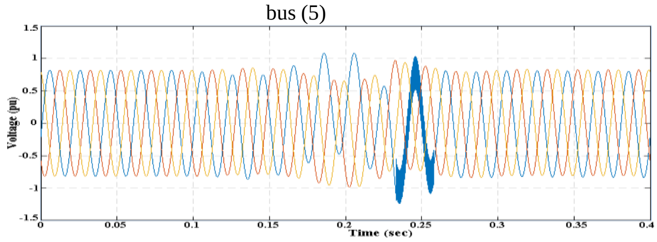
bus (3)



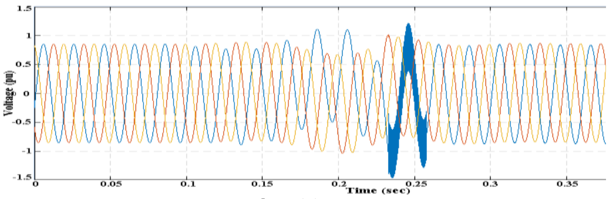
bus (4)



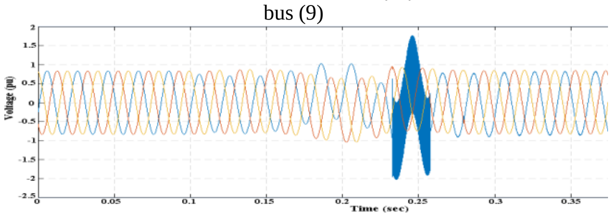
bus (5)



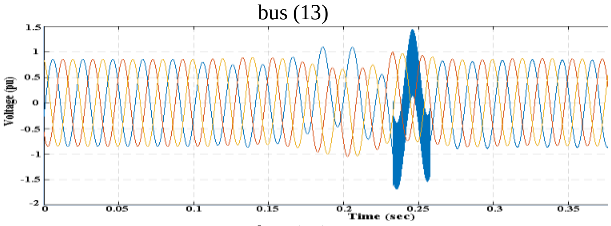
bus (8)



bus (9)



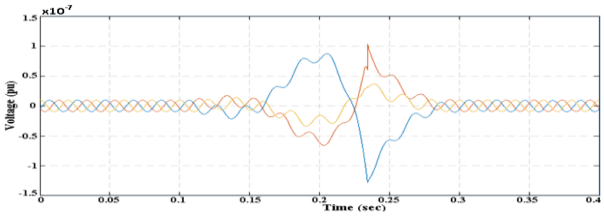
bus (13)



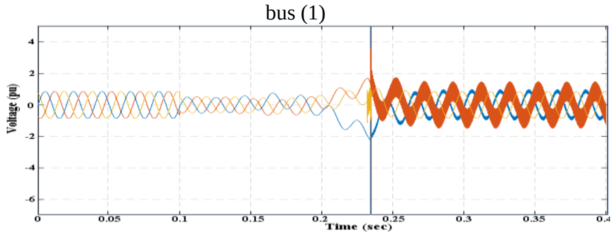
bus (14)

(b) Waveform of voltage response with STATCOM

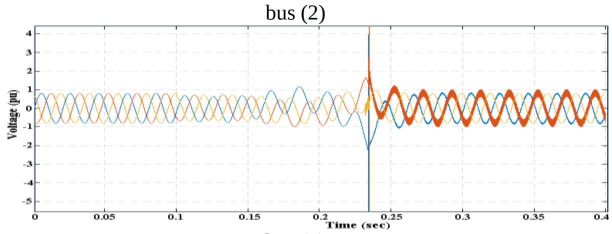
Figure 8: Waveform of voltage response for the system with and without STATCOM during single-line fault.



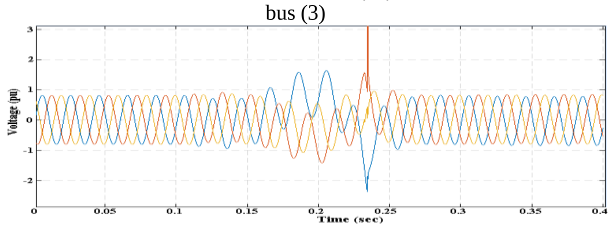
bus (1)



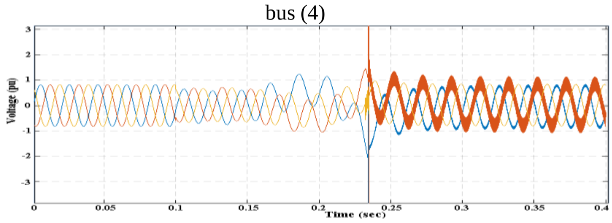
bus (2)



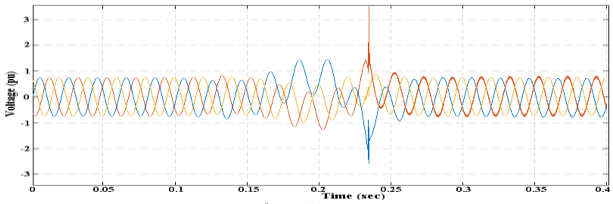
bus (3)



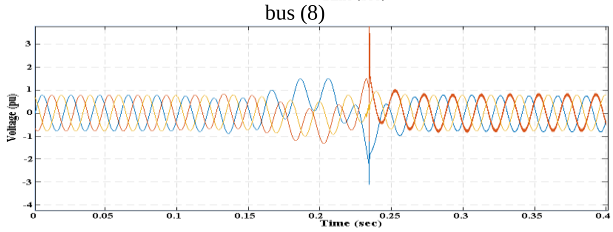
bus (4)



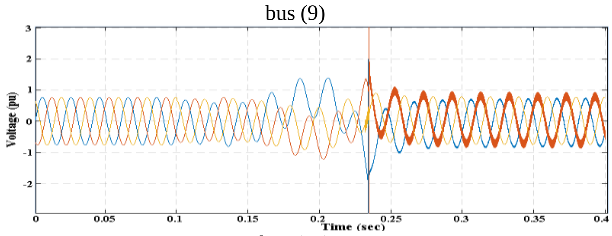
bus (5)



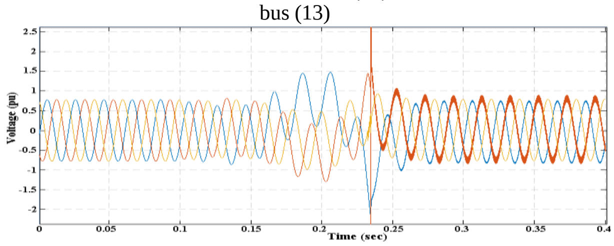
bus (8)



bus (9)

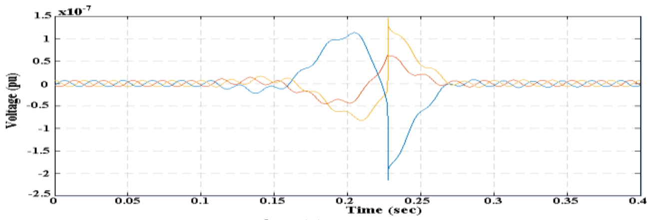


bus (13)

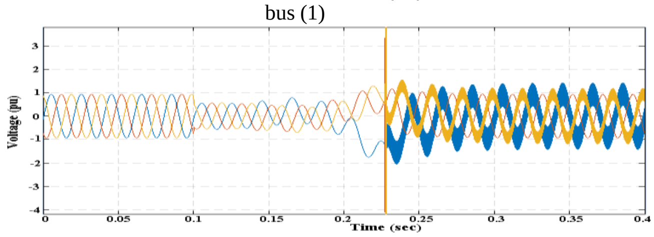


bus (14)

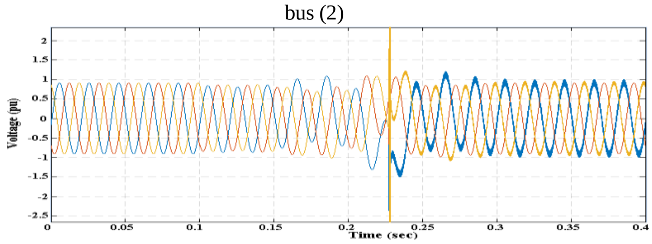
(a) Waveform of voltage response without STATCOM



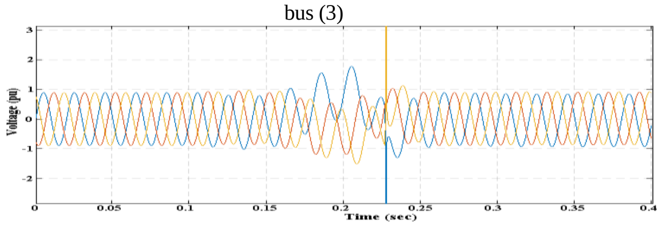
bus (1)



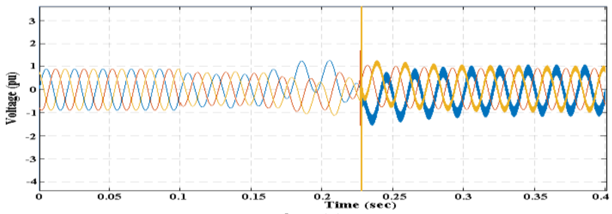
bus (2)



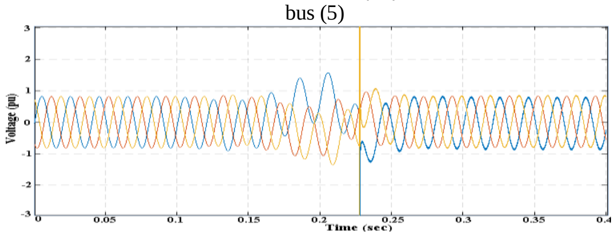
bus (3)



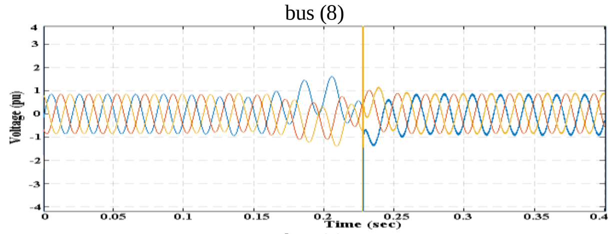
bus (4)



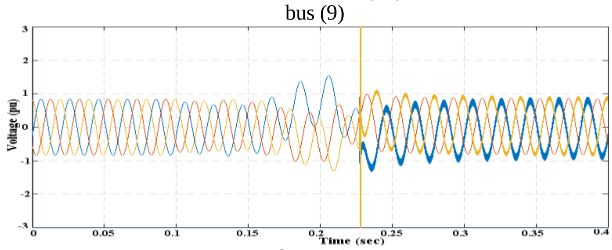
bus (5)



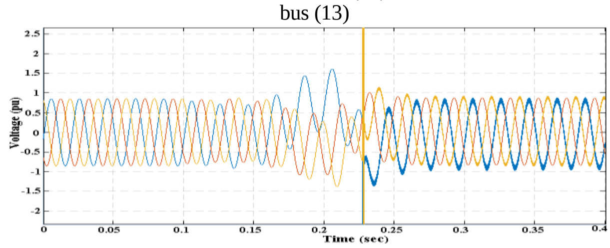
bus (8)



bus (9)



bus (13)



bus (14)

(b) Waveform of voltage response with STATCOM

Figure 9: Waveform of voltage response for the system with and without STATCOM during three-lines fault.

V. CONCLUSION

The results indicate that, the system with STATCOM device improve effectively power quality and reduce overshoot as compared to system without STATCOM. Therefore, the results show that, system with STATCOM is strong for variation of parameters. Simulation and modeling of IEEE 14-bus system with STATCOM device is employed for PQ improvement. The system model is studied and tested based on Matlab program and the numerical simulation results owing to fault conditions such as, single-line fault & three-line fault in terms of voltage response with/without STATCOM are presented. The system power with STATCOM is preferred and is fast, chive the fault and returns the system to the stable condition compared to system without FACTS devices.

APPENDIX-A

The system details for IEEE 14-bus is specified in Tables A.1-A.3

Table A.1: Loads details

Bus number	Load P (MW)	Load Q (Mvar)	Bus number	Load P (MW)	Load Q (Mvar)
(1)	0	0	(8)	0	0
(2)	21.7	12.7	(9)	29.5	16.6
(3)	94.2	19	(10)	9	5.8
(4)	47.8	-3.9	(11)	3.5	1.8
(5)	7.6	1.6	(12)	6.1	1.6
(6)	11.2	7.5	(13)	13.5	5.8
(7)	0	0	(14)	14.9	5

Total load = 259 MW, 73.50 MVAR

Table A.2: transmission Line characteristics

Buses	Resistance (pu)	Reactance (pu)	Line charging (pu)	Rating (pu)	Tap Ratio
1-2	0.0194	0.059	0.053	200	1
1-5	0.054	0.223	0.049	100	1
2-3	0.047	0.198	0.044	100	1
2-4	0.058	0.176	0.0374	100	1
2-5	0.057	0.174	0.034	100	1
3-4	0.067	0.171	0.0346	100	1
4-5	0.013	0.042	0.0128	100	1
4-7	0.00	0.209	0.00	100	0.978
4-9	0.00	0.5562	0.00	100	0.969
5-6	0.00	0.252	0.00	100	0.932
6-11	0.095	0.199	0.00	100	1
6-12	0.0123	0.256	0.00	100	1
6-13	0.0662	0.1303	0.00	100	1
7-8	0.00	0.1762	0.00	100	1
7-9	0.00	0.11001	0.00	100	1
9-10	0.032	0.085	0.00	100	1
9-14	0.127	0.2704	0.00	100	1
10-11	0.0821	0.1921	0.00	100	1
12-13	0.221	0.1999	0.00	100	1
13-14	0.171	0.348	0.00	100	1

Table A.3: Cost Coefficients and Generation Limits

Bus No.	P_G, min MW	P_G, max MW	Q_G, min Mvar.	Q_G, max Mvar.	Cost Coefficients a	b	c
1	10	250	10	250	0.0032	2.00	0
2	20	140	-40	50	0.0175	1.75	0
3	15	100	0	40	0.0625	1.00	0
6	10	120	-6	24	0.0083	3.25	0
8	10	45	-6	24	0.0250	3.00	0

Generating Cost =

$$\sum_{i=1}^{N_G} a_i P_{Gi}^2 + b_i P_{Gi} + c_i \qquad \$/hr$$

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