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# PERFORMANCE ANALYSIS OF THE STATCOM WITH DIFFERENT CONTROLLER TECHQUIES IN IEEE14 BUS SYSTEM

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*Abstract:* **The static synchronous compensator (STATCOM) is one of the developed converter-based flexible AC transmission systems (FACTS) controller. The STATCOM injects a current into the system to improve harmonic distortion. PI and Fuzzy Controller has been used to control for STATCOM. The effectiveness of suggested approach has been tested on IEEE 14-bus system. The simulation of the STATCOM is performed in the MATLAB SIMULINK environment. Simulation results are presented, which shows the compensation effectiveness and reduction in harmonics of the STATCOM controller at the connected bus. And implementation of STATCOM also presented.**

*Keywords*— **STATCOM, Power Quality, Total Harmonic Distortion, Reactive power compensation, Voltage Source Converter(VSC), Fuzzy**

## I.INTRODUCTION

The power quality embraces issues such as voltage flicker, voltage dip, and voltage rise, as well as harmonic performance and high-frequency noise. Power electronic devices distort voltage and current waveforms in a power network, influencing power facilities and customer equipment in a diverse manner. Harmonic currents induce abnormal noise and parasitic losses, and harmonic voltages cause a loss of accuracy in measurement instruments and the faulty operation of relays and control systems. Electromagnetic noise, caused by the noise of the high-frequency electromagnetic waves emitted from power-electronic circuits, affects electronic devices used in business and industry and often induces interfering voltage in communication lines[10] The corrective measure generally recommended for mitigating harmonics and high-frequency noise is to limit their generation at the source. The quality of the power is effected by many factors like harmonic contamination, due to the increment of non-linear loads, such as large thyristor power converters, rectifiers, voltage and current flickering due to arc in arc furnaces, sag and swell due to the switching (on and off) of the loads etc. These problems are partially solved with the help of LC passive filters. However, this kind of filter cannot solve random variations in the load current waveform and voltage waveform. Most of these voltage sensitive critical loads are non-linear in nature due to application of fast acting semiconductor switches and their specific control strategy whose presence in a system pose some major concerns as they affect the distribution utility in some highly undesirable ways.Harmonics, arise within the

 

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customer's own installation and may or may not propagate onto the network and so affect other customers. Harmonic problems can be dealt with by a combination of good design practice and well proven reduction equipment[11]. In recent years, the use of non-linear loads in heavy industries leads to harmonics and wide variations in reactive power in power system. Normally the current drawn by this type of non linear loads are non sinusoidal and therefore contains harmonics [2]. Static Synchronous Compensator (STATCOM) is one of the FACTS device which play a vital role in controlling the reactive power in power system [3]. By proper control strategy we can also suppress the harmonics [5].

A flexible ac transmission system (FACTS) is used for generating or absorbing reactive power. Static synchronous Compensator (STATCOM) is a FACTS controller operated as a shunt connected static VAR compensator based on a voltage source or current source converter whose capacitive or inductive output current can be controlled independent of the ac system voltage. A lot of work has been accomplished in the field of reactive power compensation. The STATCOM has a special characteristic that it does not depend on the ac system voltage [1]-[4] and yet compensates for any deviation in system voltage. The STATCOM is composed of a voltage source inverter with a dc capacitor, coupling transformer, and signal generator and control circuit [5], [6]. Due to its versatile nature and speedy response, STATCOM finds a wide application in the field, both as a reactive power compensating device and harmonic absorber [7], [8]. The PI regulators used for control of FACTS devices [6] suffer from the inadequacies of providing suitable control and transient stability enhancement over a wide range of power system operating conditions. A radial-basis-function neural network control scheme has also been suggested for the STATCOM to damp the electromechanical oscillations of the power system [7]. Linearized power system models with STATCOM have been developed in [8] and [9] to generate control signals to damp out inter-area oscillations. Since these controllers are derived from a small-signal model at a given operating point, they are not globally optimal. Besides the nonlinear nature of the power system operation necessitates the development of a nonlinear controller.

In recent years increasing interest has been seen in applying fuzzy theory to controller design in many engineering fields. The fuzzy controller has very attractive features over conventional controllers. It is easy to be implemented in a large-scale nonlinear dynamic system and not so sensitive to the system models, parameters and operation conditions. In particular human knowledge can be included in control rules with ease. Therefore investigation of fuzzy theory applications in power system control grows rapidly.

Fuzzy logic applied to the various engineering problems has been demonstrated that it can be constructed more easily than conventional control scheme. Since it has a natural human interface, where the expertise can be transferred or represented into certain linguistic fuzzy sets and rules. The conceptual meaning of the linguistic fuzzy sets are manipulated through fuzzy membership functions and the collection of fuzzy rules internally. However there has been a notable lack of rigorous theory that can

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explain how the system generates appropriate responses while similar, unexpected input data is presented to the system [l]. Generally the performance of a fuzzy controller mostly depends on the descent rule base and membership functions, which are usually given by expertise. However, while the adaptivity is taken into account, the fuzzy controller should be adaptive to the changes of physical world by adjustment of its parameters, such as rule base and membership function, and modification of the remaining defect from human operator [3].

## II.WORKING PRINCIPLE OF STATCOM

Static Synchronous Compensator (STATCOM) is a primary shunt device of the FACTS family, which uses power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. The variation of reactive power is performed by means of a voltage source convertor (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced commuted power electronics devices (CTO's or IGBT's) to synthesize the voltage from a dc voltage source. The operating principle of STATACOM is explained in Fig. 1. It can be seen that if Es> Et then current Iq flows from the counter to ac system through reactance and converter generates capacitive reactive power for ac system. On the other hand, if Es< Et then current Iq flows from ac system to the converter and converter absorbs inductive reactive power from ac system. Finally, if Es= Et then there is no exchange of reactive power. For computation purposes, we assume that the active and reactive power is transferred between two sources V1 and V2. V1 represents the system voltage to be controlled and V2 is the voltage generated by the VSC. In steady state operation, the voltage V2 generated by the VSC is in phase with V1 (∂=0, angle of V1 w.r.t. V2) so that only the reactive power is flowing from V1 to V2; i.e. STATCOM is observing reactive power. In contrary, if V2 is higher than V1, reactive power is flowing from V1 to V2 i.e. STATCOM is generating the reactive power.

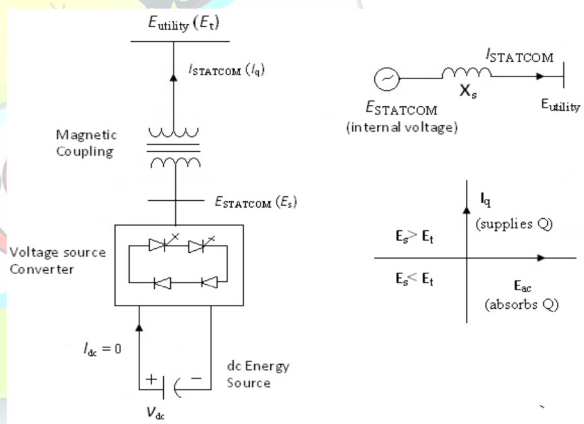


**Fig 1: STATCOM working concept**

## III PI CONTROLLER

This controller sets the manipulated variable in proportion to the difference between the setpoint and the measured variable. The bigger the difference, the greater the change in the manipulated variable. The proportional controller is a device that produces a

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control signal, $u(t)$ which is proportional to the input error signal $e(t)$. $u(t) \propto e(t)$

$$u(t) = K_p e(t) \quad \text{------- (8.1)}$$

$K_p$ - Proportional gain .Proportional controllers amplify the error signal by an amount $K_p$. The increase in loop gain improves the steady state tracking accuracy, disturbance signal rejection and relative stability and less sensitivity to parameter variations. But to increasing the gain to large values may lead to instability of the system. The drawback of the controllers is to lead the constant steady state error. The **advantage** of proportional control is that it is relatively easy to implement. However the **disadvantage** is that when implementing a proportional only controller there will be an *offset* in the output. Thus there is always a difference between the setpoint and the actual ouput.

Proportional + Integral (PI) controllers were developed because of the desirable property that systems with open loop transfer functions of type 1 or above have zero steady state error with respect to a step input.

The PI regulator is: $\dfrac{U(s)}{E(s)} = K_p + \dfrac{K_I}{s}$

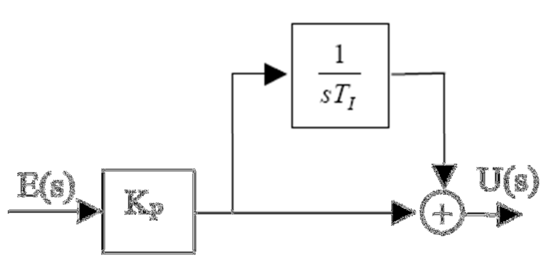


**Fig 2: PI Controller**

Tuning PI Controllers

General approach to tuning:

1. Initially have no integral gain (TI large)
2. Increase KP until get satisfactory response
3. Start to add in integral (decreasing TI) until the steady state error
is removed in satisfactory time
(may need to reduce KP if the combination becomes oscillatory)

## IV FUZZY CONTROLLER

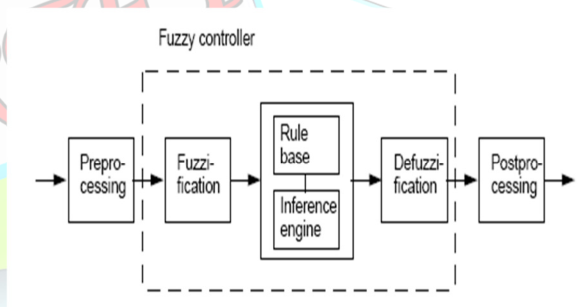


**Fig 3: Block diagram of Fuzzy Controller**

Expert's knowledge has been the essential information available for the design of the controllers of complex systems with unknown dynamics **[I].** Fuzzy logic techniques[9] provide a method for representing and implementing the expert's experience and knowledge [SI. The linguistic information from experts is then described by the fuzzy if-then rules with linguistic predicates **[4,** 5, 71.

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In order to handle all the cases conditioned by the input variables, fuzzy logic controllers are usually constructed based on a complete set of fuzzy if-then rules *[a,* 81. If the antecedents of all the fuzzy if-then rules in a complete fuzzy rule base contain the conditions for every element of the set of input variables, the entire input space is fully partitioned with **respect** to **the input** variables. Let the integral fuzzy rule base be defined to be the complete fuzzy rule base with the input space fully partitioned. With the integral fuzzy rule base, it is easy to find that more than one (desired) fuzzy regions will be partitioned when one specific fuzzy region of the input space is necessary to be further partitioned to improve the system performances. And the redundant rules for the control of the regions from the partition of the regions (not desired) are generated.

| Error rate /error | NS | NM | NB | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NS | NM | NB | NB | NS | ZE | PS | PM |
| NM | NB | NB | NB | NM | NS | ZE | PS |
| NB | NB | NB | NB | NB | NM | NS | ZE |
| ZE | NS | NM | NB | ZE | PS | PM | PB |
| PS | ZE | NS | NM | PS | PM | PB | PB |
| PM | PS | ZE | NS | NM | PB | PB | PB |
| PB | PM | PS | ZE | PB | PB | PB | PB |

Therefore, in this paper the partial fuzzy if-then rule base is adopted which allows the antecedents of fuzzy if-then rules to have conditions for different subsets of input variables. Since each fuzzy region of the input space can be partitioned all by itself into fuzzy sub-regions with the partial fuzzy rule base. no redundant rules occur. In many real complex situations, the nested design approach of fuzzy rules follows the expert's thinking process more naturally. That is, like an expert, the nested fuzzy if-then rules implement the hierarchy analysis and the design procedures for the censtruction of fuzzy controllers in the complicated systems. In our study, the nested design approach of fuzzy controllers with partial fuzzy if-then rule base is proposed to reduce the complexity of the fuzzy controller. The fuzzy controllers are first constructed with basic fuzzy if-then rules. And the parameters of the fuzzy controller are determined by the learning algorithm. Then the performances of the control system are evaluated with certain performance indexes. Based on the nested design of the partial fuzzy rule base, the fuzzy rule base of a fuzzy controller is modified by replacing the unsatisfactory

fuzzy rules with additional efficient fuzzy rules when the performance requirements of the fuzzy control system are not satisfied. And the nested structure of the partial fuzzy rule base can be further simpiified to be non-nested. Finally, simulations are carried out to show the effectiveness of the fuzzy controllers with nested fuzzy if-then rules.

## V CASE STUDY

**IEEE14 Bus System:** A single line diagram of the IEEE 14-bus standard system extracted from[13] is shown in Figure 9.1. It consists of five synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support. There are 11 loads in the system. Totaling 259 MW real load and 81.3 Mvar reactive load. Real generator load is 40 MW.

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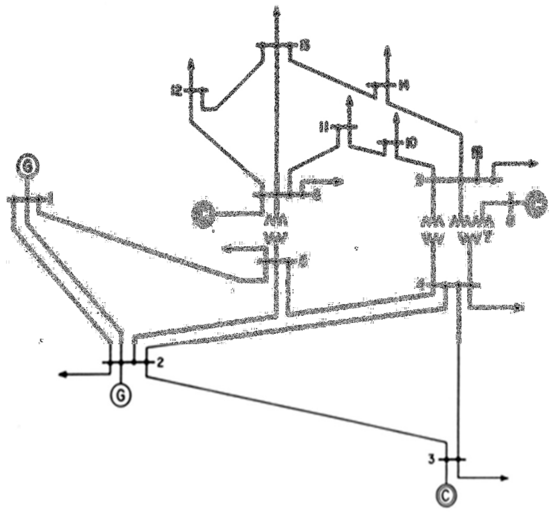


**Fig 4 : IEEE14 Bus System**

Under pre-fault condition , power flow analysis is taken for IEEE14 bus and observed the voltage and current harmonics. Then by inserting the STATCOM in the load bus ($4^{th}$ bus chosen). Power flow analysis is done with STATCOM and observed the voltage and current harmonics.

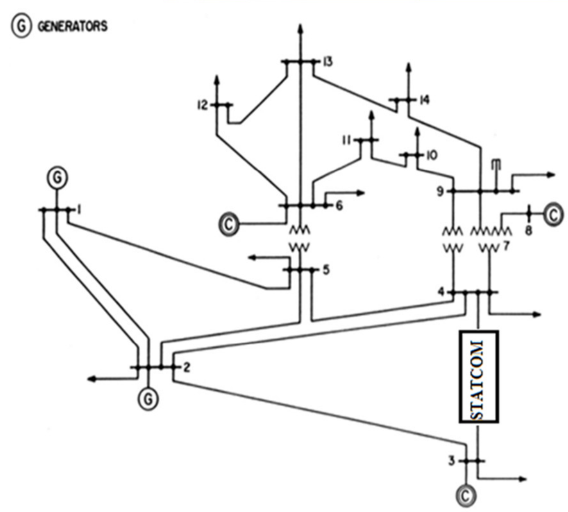
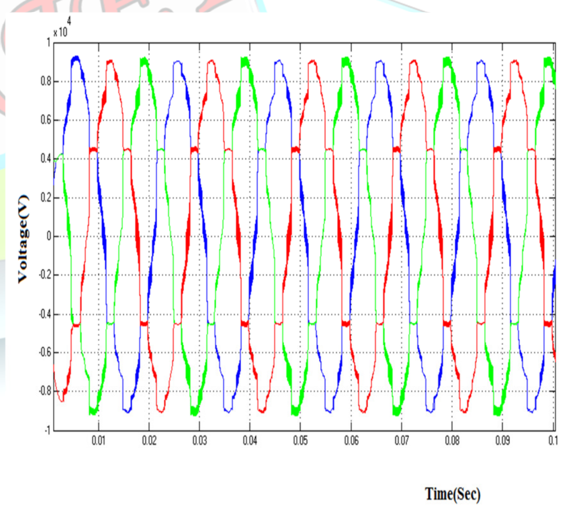



**Fig 5: IEEE14 bus with STATCOM**

## VI SIMULATION RESULTS

In order to analyse the performance of the STATCOM , suitable simulation is performed using MATLAB/Simulink. The system has two generator buses each of 11KV, 50Hz and twelve load buses of nominal voltage , active power. A STATCOM is connected to load bus. A 5 micro Farad capacitor provides the STATCOM energy storage capabilities. A three phase non linear load (a rectifier with resistor) is connected in load bus. Where Rp represents the 'ON' state resistance the switches which are in Voltage Source Inverter including coupling transformer leakage resistance, Lp represents the coupling transformer leakage inductance. A Voltage Source Inverter is the core element of the STATCOM.it generates a balanced and controlled three phase voltage Vp.

**WITHOUT STATCOM:** At Pre-fault condition, Without STATCOM the voltage and current waveform at $4^{th}$ bus is shown in fig 6.



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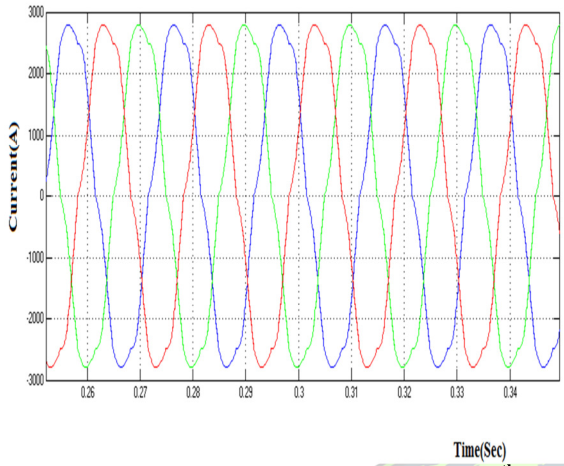



**Fig 6 : Voltage and Current waveforms at 4$^{th}$ bus without STATCOM**

To determine the Voltage and Current harmonics, FFT analysis is taken. In FFT analysis, 50Hz frequency and for 5 cycles the voltage and current harmonics are noted and the results are shown in fig 7 and 8 without STATCOM at 4$^{th}$ bus in the system.

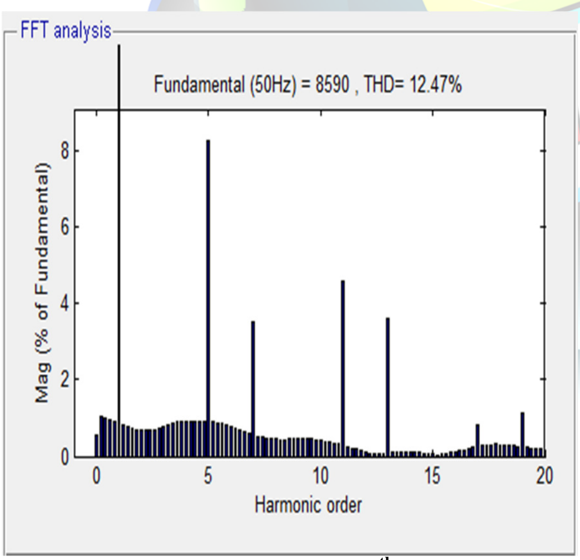



**Fig 7 : Voltage harmonics at 4$^{th}$ bus without STATCOM**

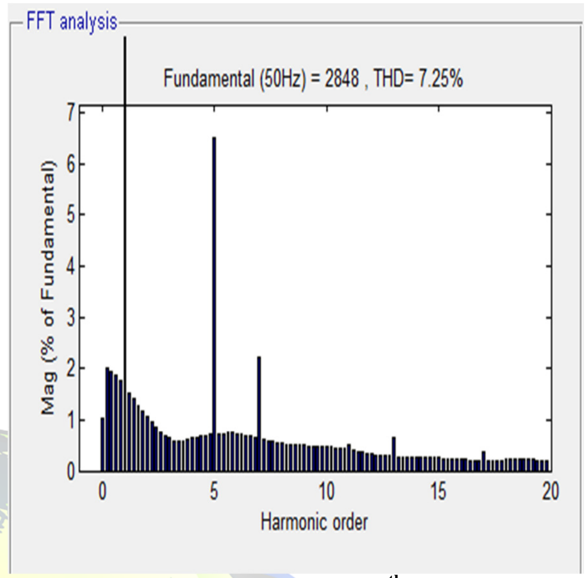
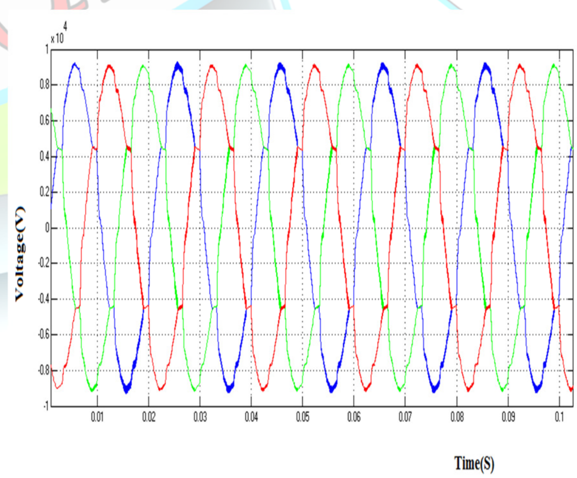



**Fig 8 : Current harmonics at 4$^{th}$ bus without STATCOM**

**WITH STATCOM:** At Pre-fault condition, STATCOM is connected in the 4$^{th}$ bus. By Connecting the STATCOM bus voltage get increased and current is decreased compared with STATCOM is disconnected from syatem. The voltage and current waveform at 4$^{th}$ bus With STATCOM is shown in fig 7.



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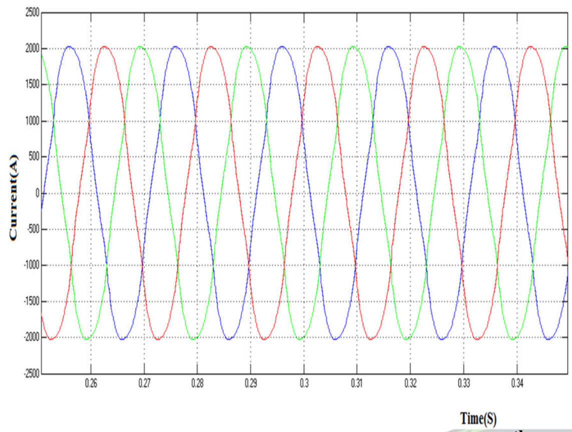


**Fig 10 : Voltage and Current waveforms at 4th bus with STATCOM(PI Controller)**

To determine the Voltage and Current harmonics, FFT analysis is taken and the results are shown in fig 11 and 12 with STATCOM at 4th bus in the system.

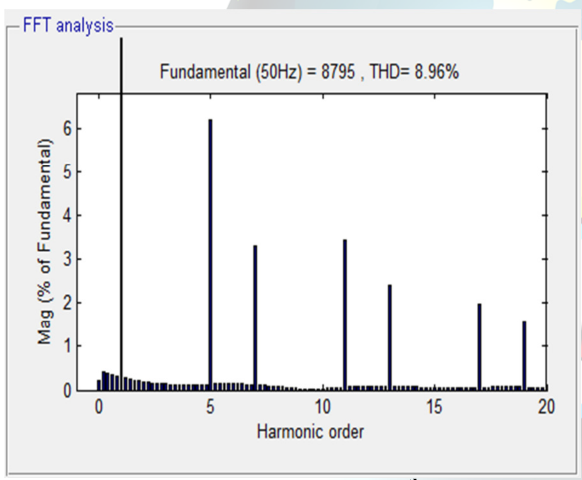


**Fig 11 : Voltage harmonics at 4th bus with STATCOM(PI Controller)**

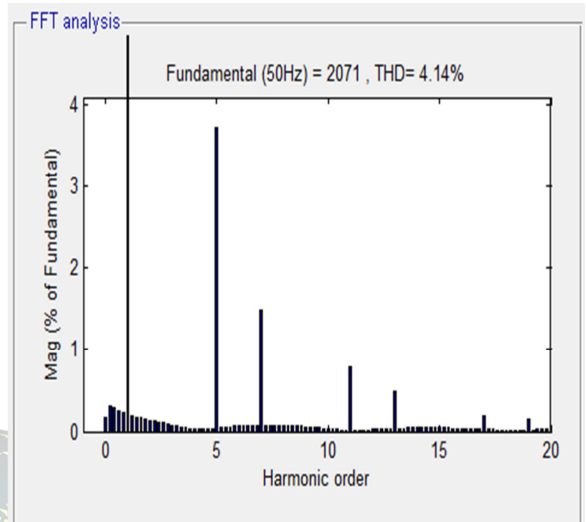


**Fig 12 : Current harmonics at 4th bus without STATCOM(PI Controller)**

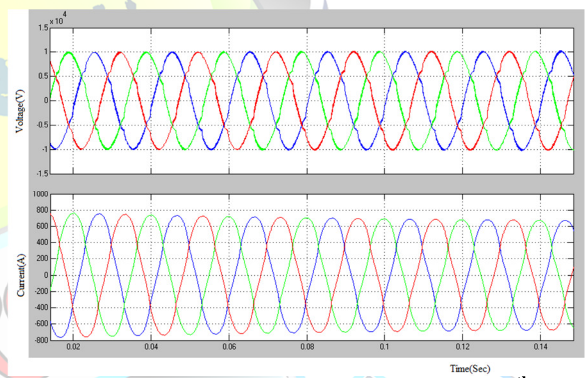


**Fig 13 : Voltage and Current waveforms at 4th bus with STATCOM(Fuzzy Controller)**

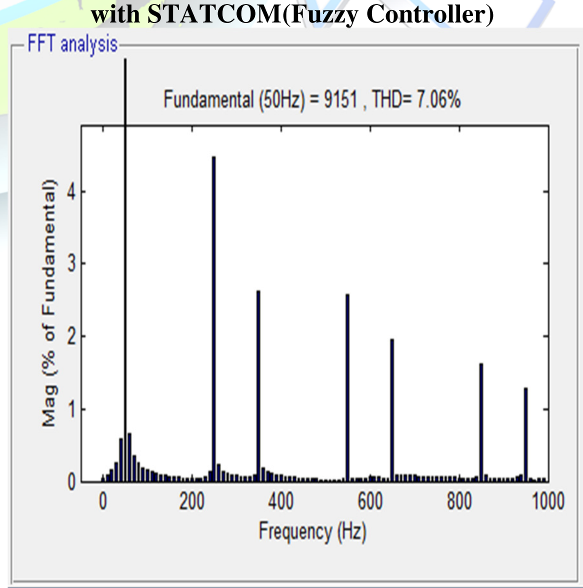

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**Fig 14 : Voltage harmonics at 4th bus with STATCOM(Fuzzy Controller)**

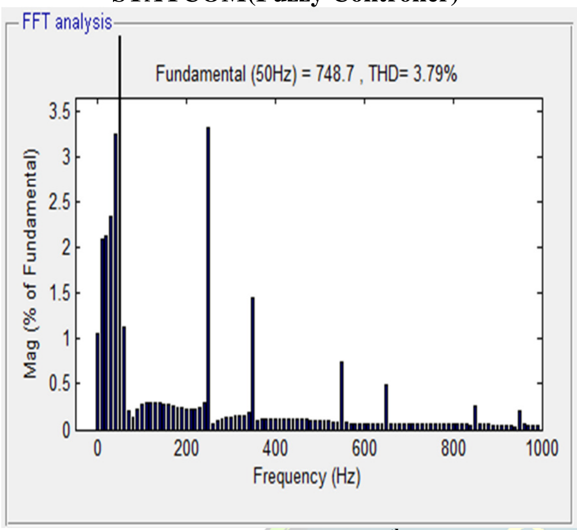


**Fig 15 : Current harmonics at 4th bus without STATCOM(Fuzzy Controller)**

| Parameters at 4th bus | Without STATCOM | With STATCOM (PI Controller) | With STATCOM (Fuzzy Controller) |
|---|---|---|---|
| Voltage in Volts | 9200 | 9300 | 9500 |
| Voltage Harmonics | 12.47 | 8.96 | 7.09 |
| Current in Amps | 2800 | 2100 | 1200 |
| Current Harmonics | 7.25 | 4.14 | 3.79 |

## VII CONCLUSION

STATCOM system has been modeled using MATLAB toolbox. The novelty of this paper lies in the application of PI and Fuzzy controller to generate switching signals for the shunt compensator of the STATCOM system. The performance of the system for application harmonic elimination has been successfully examined and analyzed.

## APPENDIX

Slack bus - 1
PV bus - 2
Load bus - 3,4, 5,6, 7,8 , 9,10,11,12,13 and 14
No.of Transmission line – 20
1-2, 1-5, 2-3, 2-4, 2-5, 3-4, 4-5, 4-9, 5-6, 6-7, 6-11, 6-12, 6-13, 7-8, 7-9, 9-10, 9-14, 10-11, 12-13, 13-14.

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