VOL. 13, NO. 2, JANUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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A FUZZY CONTROLLED STATCOM FOR COMPENSATION OF SEIG FEEDING SINGLE-PHASE HARMONIC LOAD

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ABSTRACT

This paper analyzes the harmonic content in source current and power factor at point of common coupling (PCC) when a single-phase non-linear load fed from wind generator with PI and fuzzy controlled STATCOM at PCC. Non-linear loads induce harmonics in the source components and deteriorate the system stability and reliability. This paper presents STATCOM for harmonic compensation connected at PCC when a two-phase non-linear load is connected at load side. Fuzzy controller yields precise response with quick action time. The paper examines the harmonic distortion in source parameter when STATCOM is connected controlled with PI and fuzzy controllers. The presented system was developed using MATLAB/SIMULINK software and results are presented. Results are presented showing harmonic distortion in source current with STATCOM controlled by PI controller and harmonic distortion in source current with STATCOM controlled by fuzzy controller.

Keywords: STATCOM, harmonics, non-linear, load, fuzzy, PI, controller.

INTRODUCTION

Due to enormous growth in industrialization, variety of loads are been used in electrical power system. Primary task of electrical system including generation, transmission and distribution is to deliver required quantity of power with good quality providing uninterrupted power without any outages. The diverse load conditions in power system may cause in-stability problem. Even though the power system meets the load requirements, this condition might cause power quality issues at the points before load connection. Loads are extensively categorized as linear loads and non-linear loads. Linear loads are the loads that do not create any warp in the waveforms but non-linear loads do not have one to one correspondence causing deviations in power system quality. Non-linear loads cause the source components to deviate from their original shape inducing harmonics. The distortion in source components affects the other sensitive loads connected at point of common coupling. Non-linear load draws non-linear currents from the source component and alters the source current waveform shape.

Filters are used to riddle out the unwanted components in power system. Passive filters and the active filters are the types of filters widely used in power system. Power system quality issues like harmonics can also be eliminated with the use of filters. Passive filters work with the use of inductors and capacitors and appropriate and proper tuning of these components can eliminate harmonics. Owing to disadvantages like tuning for fixed harmonic elimination and sizing for lower order harmonic elimination in passive filters gives a cut-in edge for active filters for harmonic elimination. Active filters are the compensating devices with power electronic switches and can eliminate complete harmonics in the system. Active filters are called FACTS devices used to eliminate power quality issues in power system.

The power quality at distribution level can be termed as maintaining sinusoidal voltage and current with proper magnitude and frequency as it should be. STATCOM is one of the FACTS device used to eliminate harmonics in source currents and is a shunt compensating device place in parallel to distribution line connected at point of common coupling. Figure-1 shows the schematic arrangement of STATCOM connected at point of common coupling when SEIG if feeding a single-phase non-linear load.

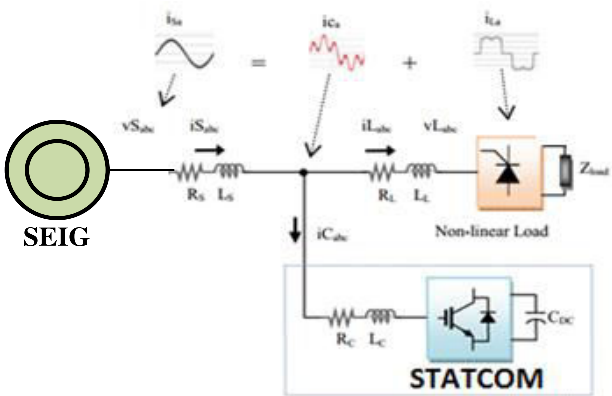

Figure-1. Block diagram of STATCOM.

This paper presents the analysis of harmonic content in source current when SEIG is feeding a single-phase non-linear load. Proposed system was developed using MATLAB/SIULINK software and results are presented. Results were shown with STATCOM operated with PI controller and STATCOM with fuzzy controller. Harmonic FFT windows of source current were shown for STATCOM connected at PCC and controlled with PI controller and is compared with STATCOM controlled with Fuzzy controller. Results justify that fuzzy controlled

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STATCOM gives better results while eliminating harmonics in source currents.

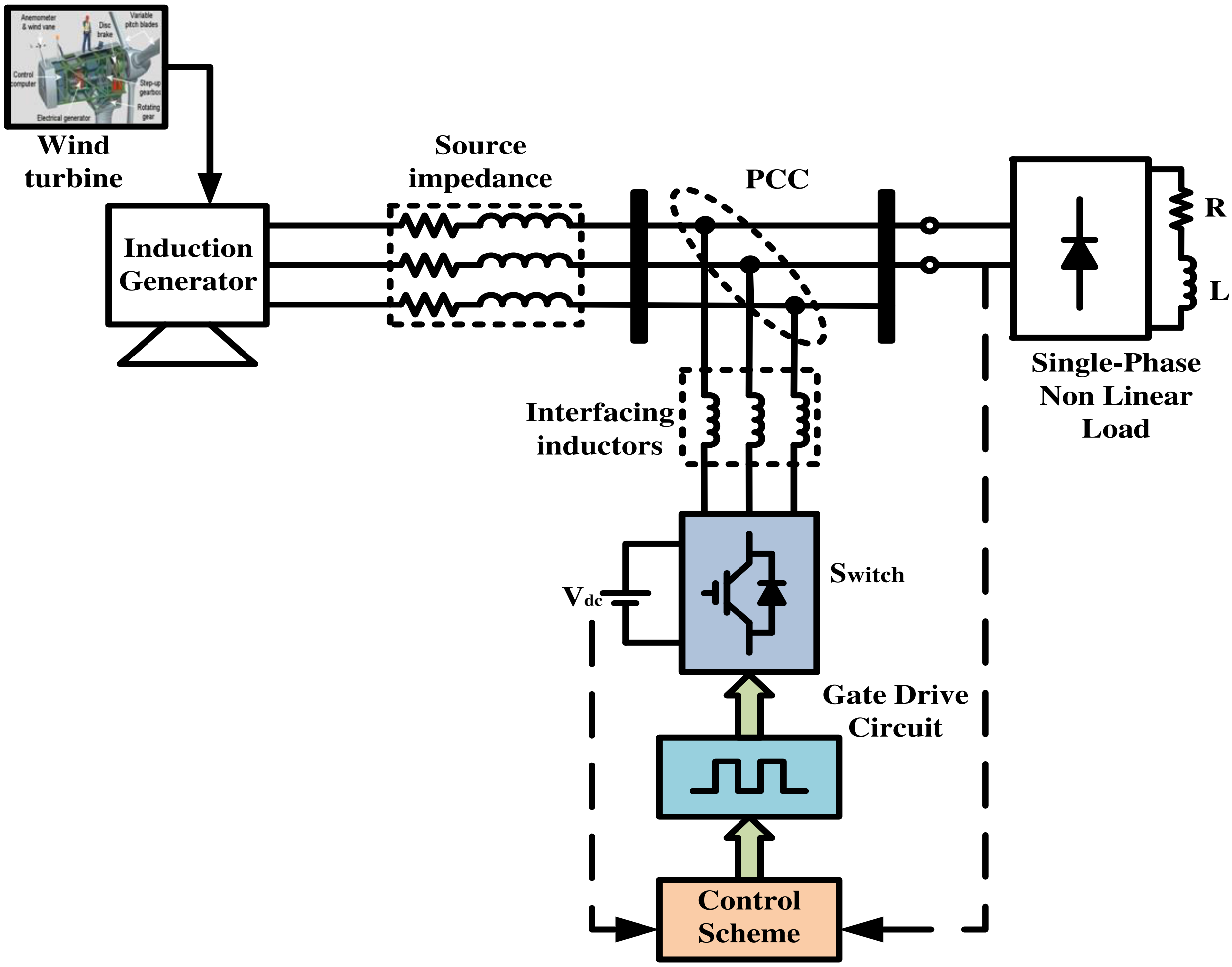

Figure-2. Schematic arrangement of STATCOM at PCC and SEIG feeding single-phase non-linear load.

SEIG FEEDING SINGLE-PHASE NON-LINEAR LOAD WITH STATCOM CONNECTED AT POINT OF COMMON COUPLING

Single phase non-linear load connected to distribution system induces harmonics into source components. Harmonics in source currents might cause mal-functioning of other sensitive loads connected to the same point. Even harmonics in currents can cause sensitive device to get damaged. A schematic arrangement of single-phase non-linear load connected in power system and with STATCOM at point of common coupling is represented in Figure-2. The source from which the non-linear load fed is singly excited induction generator (SEIG). The wind energy rotates the wind turbine which in-turn is coupled to an induction generator. The mechanical energy produced while rotation of wind turbine causes EMF to induce in stator windings and that electrical energy induced is tapped to feed a load. Set of capacitors are connected across induction generator to build up the initial voltage in induction generator. The source output of induction generator is fed to single phase non-linear load. STATCOM is connected at point of common coupling (PCC) which is to compensate harmonics in source currents caused due to non-linear load.

STATCOM is a simple voltage source converter (VSC) and consists of power electronic switches. Switches might be MOSFET's or IGBT's. Voltage source converter is fed from a stiff DC source and generally DC source can be a capacitor or small DC source. The pulses or the gate pulses to trigger power electronic switches to the STATCOM are obtained from gate drive circuit to which control signals are obtained from control circuit. The control circuit input signals are sensed from source voltage, source current and also from DC-link voltage across voltage source converter.

CONTROL STRATEGY TO STATCOM

In general, direct control is preferred where very fast voltage control is required (absence of capacitor dynamics) makes the response fast but THD of converter voltage varies with modulation index, thereby producing more harmonic distortion in the voltage at low modulation index. On the other hand, indirect control operation is slow as AC output voltage of STATCOM varies according to variation of DC capacitor voltages (presence of capacitor

VOL. 13, NO. 2, JANUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

dynamics make the response slow) but harmonic injection in the power system bus voltage can be kept at a very low level by operating the inverter at a high modulation index where THD of converter voltage is least. Out of different control strategies, more efficient method of controlling the STATCOM is by the synchronous reference frame strategy, which uses co-ordinate transformations to generate the current reference.

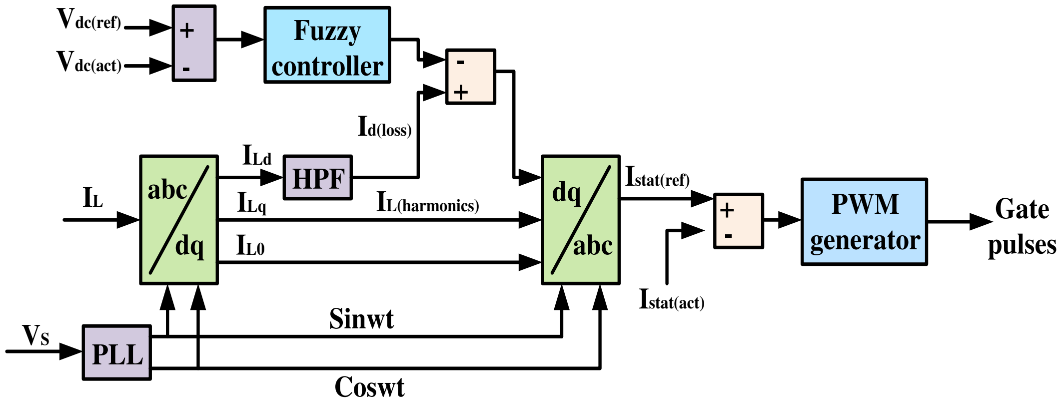

Figure-3. Control strategy for STATCOM with fuzzy logic controller.

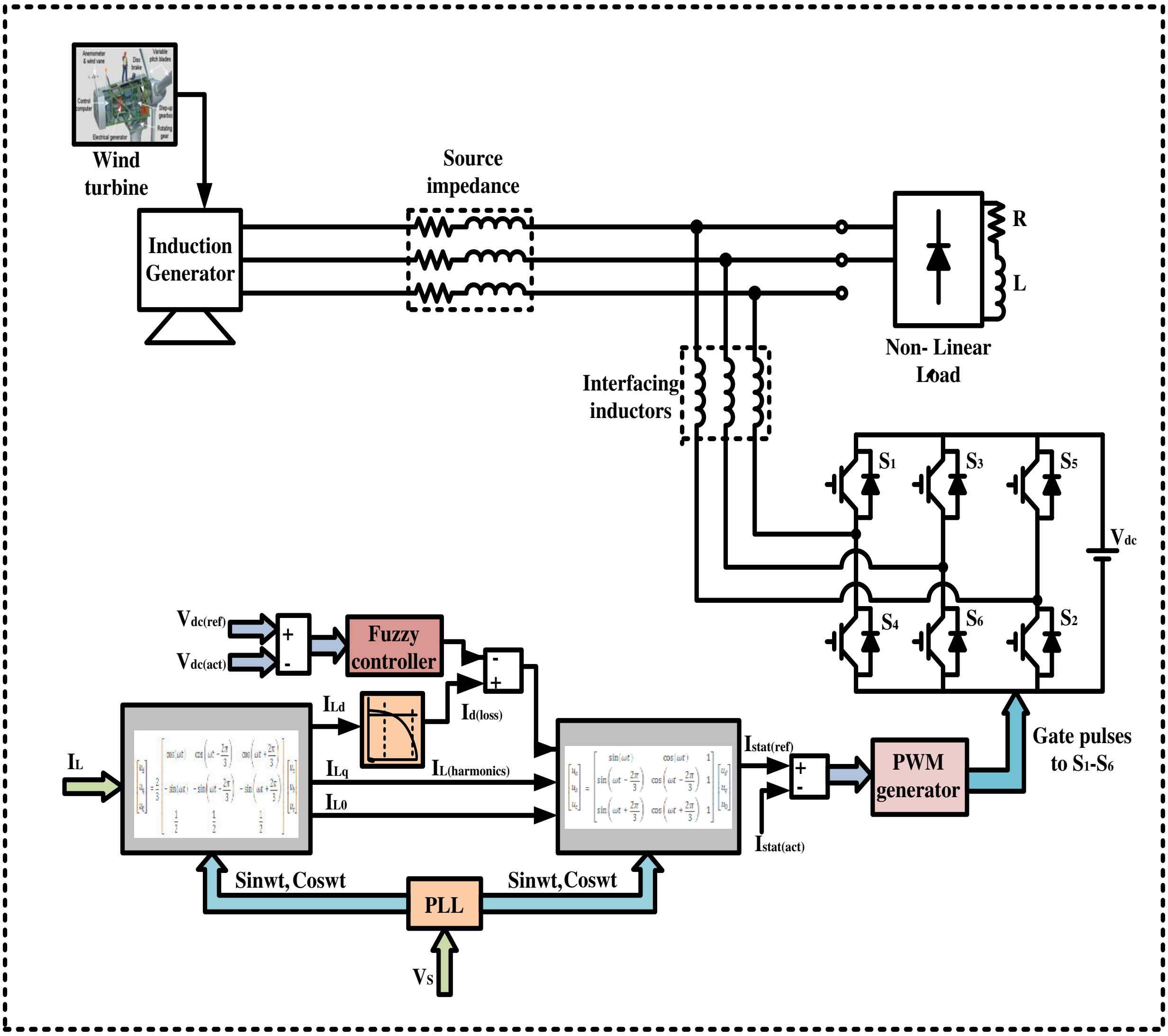

Figure-4. SEIG feeding 1-ϕ non-linear load and STATCOM at PCC with fuzzy logic controller.

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It employs the well known Clarkes Transformation and Parks Transformation for this purpose. Though, the transformations remind us of the primitive machine model concept, it may be noted that here there is no need to satisfy the condition of Power Invariance as the transformations are employed just to reduce the computations involved in generating the current reference and not to develop any equivalent system. Once the controller output is obtained, reverse transformations are employed to transform the quantities back to the actual three-phase system. Figure 3 shows the control strategy producing pulses to STATCOM and Figure-4 shows SEIG feeding 1-ϕ non-linear load and STATCOM at PCC with fuzzy logic controller (FLC).

Fuzzy logic controller (FLC)

Rules associate ideas and relate one event to another. Fuzzy machines, which always tend to mimic the behavior of man, work the same way. However, the decision and the means of choosing that decision are replaced by fuzzy sets and the rules are replaced by fuzzy rules. Fuzzy rules operate using a series of if-then statements. Fuzzy control, which directly uses fuzzy rules, is the most important application in fuzzy theory. Table-1 indicates fuzzy rule set.

Table-1. Fuzzy rule set.

		Error (E)				
Change in Error (ΔE)		NB	NS	Z	PS	PB
	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

Based on the above considerations, and after selecting the rule base, the shape of the membership function, the cross-point level and the de-fuzzification procedure, it is necessary to map the physical values of the linguistic variables into a normalized domain.

Actual DC-link voltage is measured with reference value of DC-link voltage across STATCOM and the error is fed to fuzzy controller. The fuzzy controller first converts the input to fuzzy based data and compares with fuzzy rule set similar to data shown in Table-1. The error is rectified and is sent for process after de-fuzzification. The de-fuzzified output is compared with the signal obtained from band pass filter to obtain reference current signal. The reference current signal is then sent for inverse Clarke's transformation to get three-phase reference currents which are then sent to gate drive circuit for generation of pulses.

SIMULATION RESULTS AND DISCUSSIONS

Table-2. System parameters.

Parameters	Value
Fundamental Frequency	50 Hz
Source Impedance	(0.1 +j0.9) Ω
Load Impedance	(0.5 +j12.56) Ω
DC Link Capacitor	1500 µF

The simulation analysis is carried under the effectiveness of the Total Harmonic Power Scheme with active compensation scheme for harmonic mitigation in SEIG fed 1-ϕ non-linear load with STATCOM for harmonic compensation. Table-2 indicates the system parameters considered for system design.

Case 1: STATCOM operated with PI controller

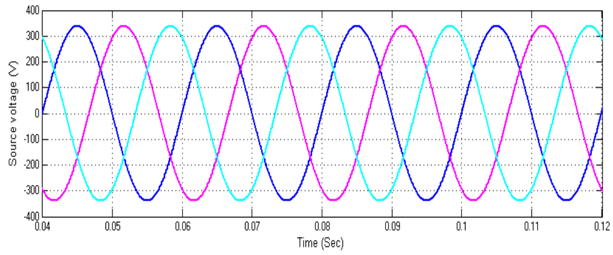

Figure-5. Three-phase source voltage.

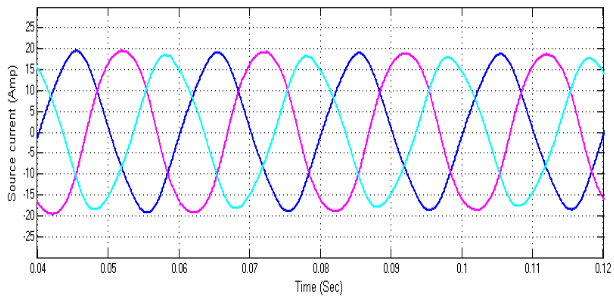

Figure-6. Three-phase source current.

Figure-5 shows the three-phase source voltages and Figure-6 shows the three-phase source currents from source SEIG. Source voltage is maintained at constant magnitude of 320 V in all the three phases and source current is at 20 A magnitudes in all the three phases. Both source voltage and source current are maintained sinusoidal in shape.

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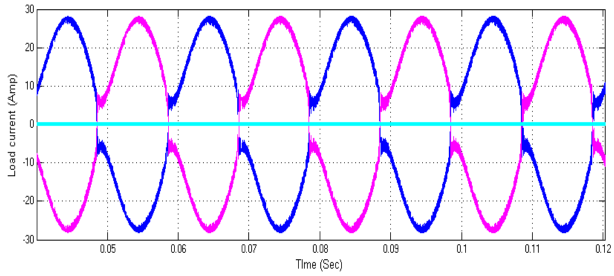

Figure-7. Load current.

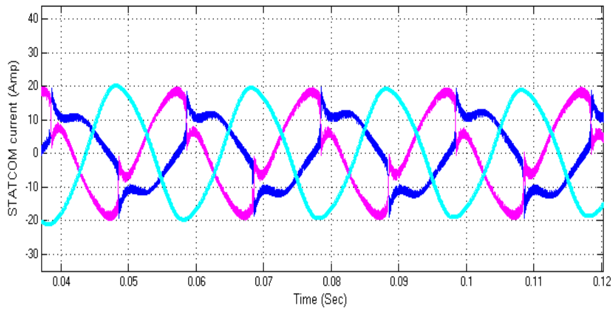

Figure-8. Compensating currents from STATCOM.

Figure-7 represents load current and Figure-8 represents the compensating currents fed to point of common coupling from STATCOM for harmonic elimination.

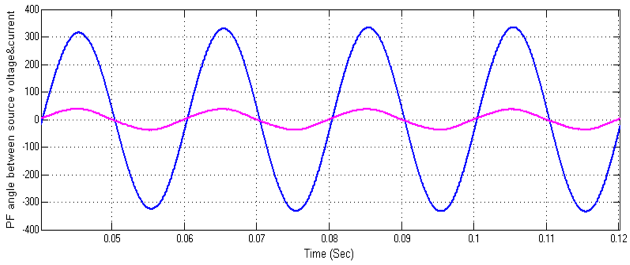

Figure-9. Power factor angle between source voltage and source current.

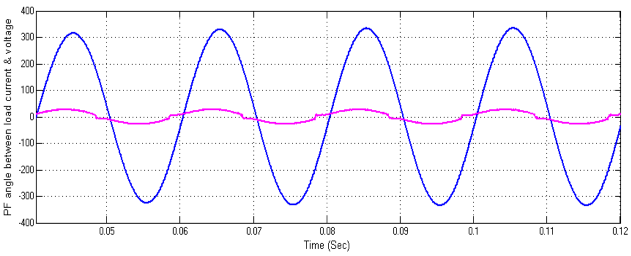

Figure-10. Power factor angle between load voltage and load current.

Figure-9 represents Power factor angle between source voltage and source current and as no phase angle difference is observed between source voltage and current, source power factor is maintained nearer unity. Figure 10 represents Power factor angle between load voltage and load current. Since load is of non-linear type, load current is distorted and load power factor is non-unity.

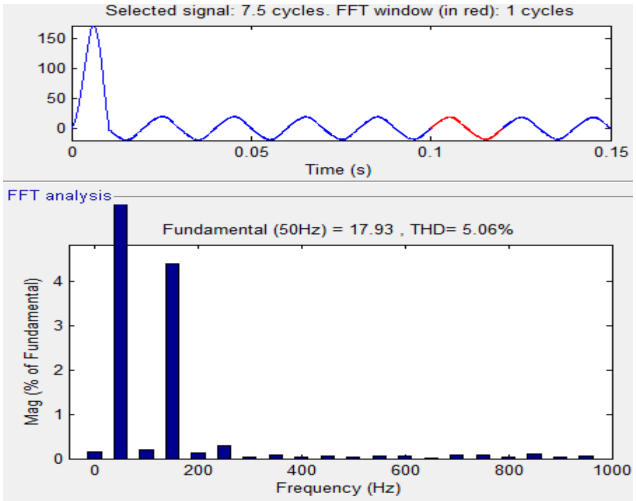

Figure-11. THD of source current with PI controller.

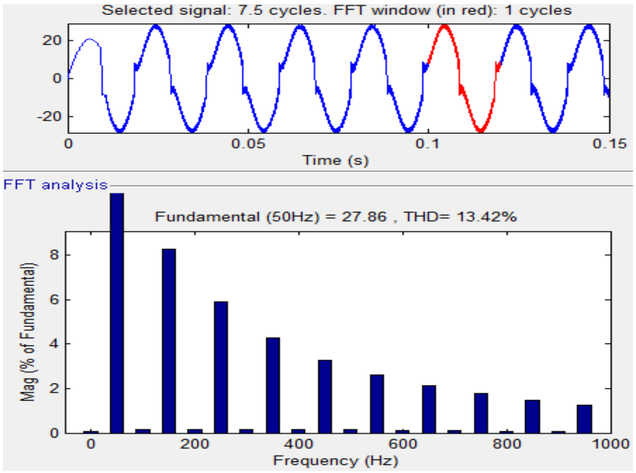

Figure-12. THD of load current with PI controller.

Figure-11 shows total harmonic distortion in source current with STATCOM controlled with PI controller indicating 5.06 % of harmonic distortion. Figure-12 shows harmonic distortion window of load current indicating 13.42 % of distortion in load current. With STATCOM controlled with PI controller the source current distortion is maintained at 5.06 %.

Case 2: STATCOM operated with fuzzy controller

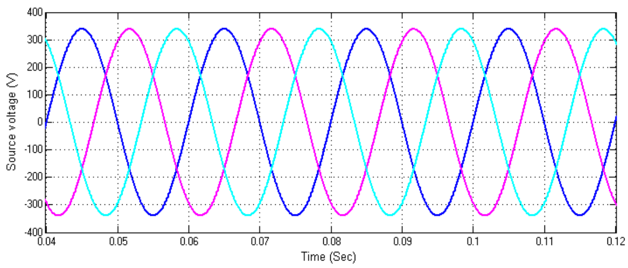

Figure-13. Three-phase source voltage.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

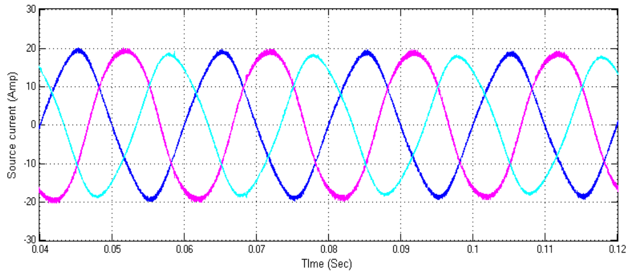

Figure-14. Three-phase source current.

Figure-13 shows the three-phase source voltages and Figure-14 shows the three-phase source currents from source SEIG. Source voltage is maintained at constant magnitude of 320 V in all the three phases and source current is at 20 A magnitudes in all the three phases. Both source voltage and source current are maintained sinusoidal in shape.

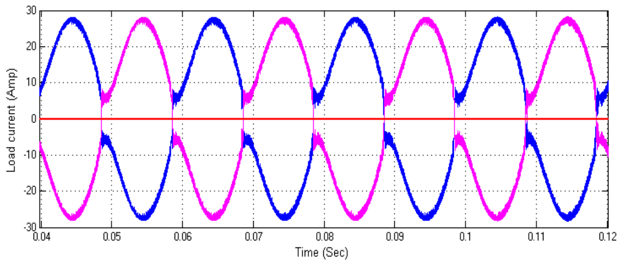

Figure-15. Load current.

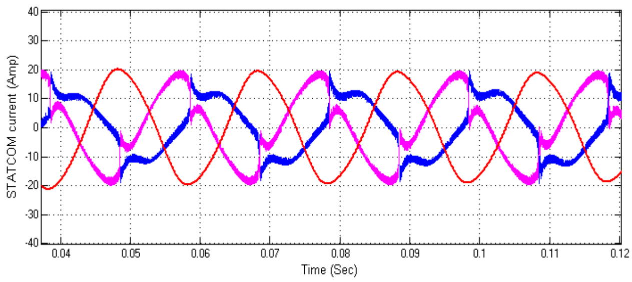

Figure-16. Compensating currents from STATCOM.

Figure-15 represents load current and Figure-16 represents the compensating currents fed to point of common coupling from STATCOM for harmonic elimination.

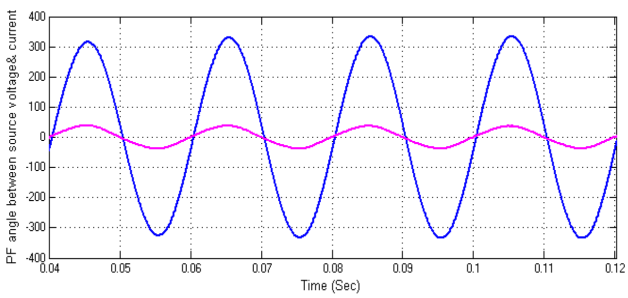

Figure-17. Power factor angle between source voltage and source current.

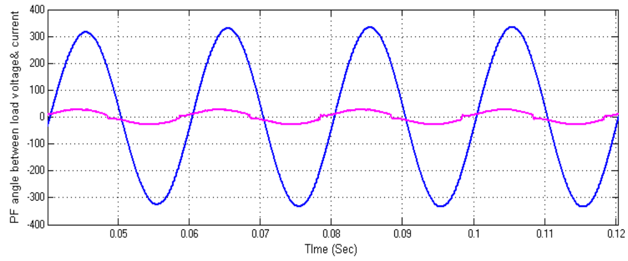

Figure-18. Power factor angle between load voltage and load current

Figure-17 represents Power factor angle between source voltage and source current and as no phase angle difference is observed between source voltage and current, source power factor is maintained nearer unity. Figure-18 represents Power factor angle between load voltage and load current. Since load is of non-linear type, load current is distorted and load power factor is non-unity.

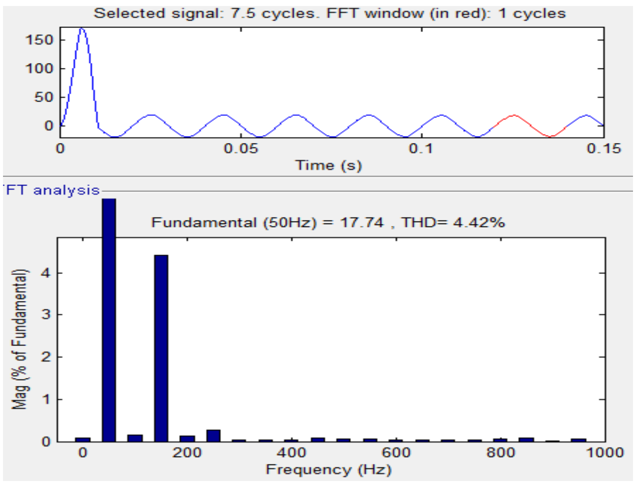

Figure-19. THD of source current with fuzzy controller.

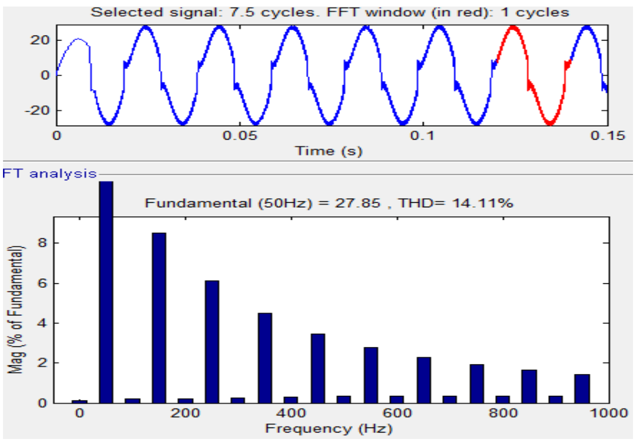

Figure-20. THD of load current with fuzzy controller.

Figure-19 shows total harmonic distortion in source current with STATCOM controlled with PI controller indicating 4.42 % of harmonic distortion. Figure-20 shows harmonic distortion window of load current indicating 14.11 % of distortion in load current.

With STATCOM controlled with fuzzy controller the source current distortion is maintained at 4.42 % which is well below the THD in source current with PI controlled STATCOM as shown in Table-3.

Table-3. THD comparison with PI and fuzzy controllers.

THD	Source current	Load current
PI	5.06 %	13.42 %
Fuzzy	4.42 %	14.11 %

CONCLUSIONS

Harmonics are major source of distortion in power system components and can cause serious damage to the components connected at load center. FACTS devices are developed to compensate power quality issues in power system and STACOM is one of the FACTS device used to compensate harmonics in source components. This paper refers the harmonic analysis of source current in power system with STATCOM connected at point of common coupling for the system SEIG feeding single-phase non-linear load. Results were shown indicating source components, load components and harmonic distortion window in source current and load current when STATCOM is controlled with conventional PI and with fuzzy controllers. THD in source current is reduced to 4.42 % in the case of STATCOM with fuzzy controller when compared to value of 5.06 % of THD in source current when STATCOM controlled with PI controller. Power factor is also shown in results. Results prove that the fuzzy controlled STATCOM can effectively reduce distortion in source current to low value when SEIG feeding single-phase non-linear load. THD comparison was also tabulated for better differentiation between conventional PI and fuzzy controllers.

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