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IJIEMR Transactions, online available on 15th Feb 2021. Link :http://www.ijiemr.org/downloads.php?vol=Volume-10&issue=ISSUE-02

DOI: 10.48047/IJIEMR/V10/I02/12

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Volume 10, Issue 02, Pages: 57-63.

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Enhancement of Power Quality by AI based Shunt Active DC Power Filter (SADPF) for Non Linear and Unbalanced Loads

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ABSTRACT
With the increasing use of non linear loads such as AC to DC and DC to AC converters, the source current gets deviated from its sinusoidal nature because of harmonic content in it and voltage across the load is not proportional to the current flowing through it. The source current must be sinusoidal to provide quality power to the load. An Artificial Intelligence based Shunt Active DC Power Filter (SADPF) proposed will eliminate the harmonic content in source current making it sinusoidal. SADPF is controlled by Fuzzy Logic Controller (FLC) which is a subset of Artificial Intelligence (AI).

Keywords: Shunt Active DC Power Filter, Fuzzy Logic Controllers, Artificial Intelligence, Non Linear Loads.

1. INTRODUCTION
Development of solid state devices like Diode, Silicon Controlled Rectifier (SCR), Insulated Gate Bipolar Transistors (IGBT), Metal Oxide Semi Conductor Field Effect Transistor (MOSFET) etc., has led to growth of power converters for ensuring satisfactory operation of various types of loads. Power Converters are used to convert the power from AC to DC (Rectifier) or DC to AC (Inverter) or AC voltage with fixed frequency to a variable frequency (Cycloconverter) or Fixed DC input to variable DC output (Chopper). These converters while doing conversion injects harmonics into the system due to the switching operation of the solid state devices used in the converters. These harmonics cause undesirable affects like power losses due to overheating in the equipment finally decreasing the power system performance and its reliability. Active Filter is an alternate solution for improving the power system performance and its reliability, since it behaves as either Current Source or Voltage Source by reducing current harmonics and voltage harmonics. In contrast, passive filters also can filter out the harmonics but due to their drawbacks like providing fixed compensation, possibility of resonance with the power system due to mistuning of frequency and due to their bulky size, Active Filters are being used now for improving the power quality of the system. Active Filters are of three types; Series, Shunt and Hybrid these can be connected in different topologies based on the requirement [1][2].

2. SHUNT ACTIVE DC POWER FILTER
Active Filter connected in parallel with the source and load is a Shunt Active Power Filter, as it uses the DC Voltage across the DC Capacitor for power conversion it is termed as Shunt Active DC Power Filter. SADPF injects harmonic current of same magnitude and 180^0 out of phase as that of load current in to the system there by cancelling the harmonic content in the load current and making the source current sinusoidal. SADPF basically consists of a DC Capacitor, Bidirectional Converter and a smoothing Inductor. Pulse

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Width Modulation (PWM) inverters using IGBT or GTOs were making SADPF to perform efficiently. Many number of control strategies were proposed in time domain and frequency domain for SADPFs.

The control strategy used in the proposed system is the Instantaneous Power Theory or P-Q theory which involves Clarke's Transformation [3][5][6]. Its operation includes measuring the load current, extracting the harmonic content from the load current by excluding fundamental component which becomes the reference current. This reference current is compared with phase of voltage and some amount of power loss is added to compensate for the power loss in the system to produce the reference compensating current. By processing the reference compensating current and filter current, necessary gate pulses are generated which are used to generate the compensating current which is finally injected into the system at the Point of Common Coupling (PCC) [7]. The DC Link voltage across the DC Capacitor has to be maintained at a steady state value, which is done by Proportional Integral (PI) Controller assisted by FLC. The reference DC Voltage and DC Link Voltage are compared with each other and error is processed by FLC and then the output of FLC is given PI to obtain the Power Loss.

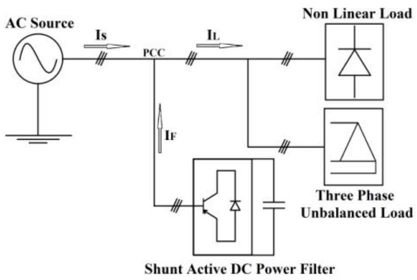

Figure 1. Schematic Diagram of Proposed System

3. FUZZY LOGIC CONTROLLER

Fuzzy Logic is a form of Artificial Intelligence software which can be considered as subset of AI as it performs a form of decision making. Fuzzy Logic Controllers (FLCs) used in this work to compute the values of kp and ki from the differ-ence between the reference voltage and DC Link Voltage [4]. The error and change of error are given as inputs to the Fuzzy Logic Controller. For conversion of error and change of error into linguistic variables seven fuzzy sets such as NH (Negative High), NM (Negative Medium), NL (Negative Low), ZE (Zero Error), PL (Positive Low), PM (Positive Medium) and PH (Positive High) were used. Fuzzy Controller in each phase uses seven Fuzzy Sets for each Input and output, Triangular Membership Functions for inputs and outputs, Implication of using the "min" operator, Fuzzy Rule Base with 49 Rules, Mamdani Fuzzy Inference Mechanism based on Fuzzy implication, Defuzzification using the "Centroid" Method.

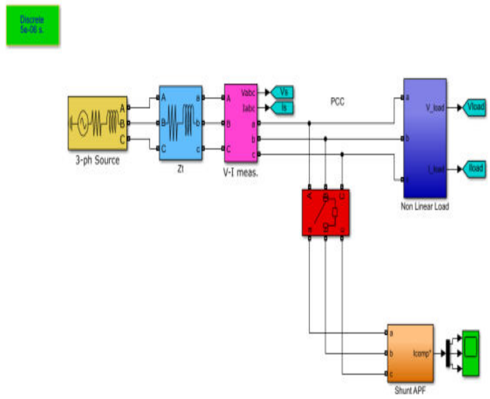

Figure 2. MATLAB/Simulink Model of Proposed System

4. DESIGN OF AI BASED SHUNT ACTIVE DC POWER FILTER (SADPF)

Shunt Active DC Power Filter controlled by AI based Fuzzy Logic Controller is designed in MATLAB/Simulink environment as shown in Figure 3. with the parameters mentioned in Table 1. The Design of Fuzzy Logic Controller is shown in Figure 4. Rectifier with a resistive load and unbalanced load is shown in Figure 5.

Table 1. Design Parameters of Proposed System

Design Parameters	
Source Voltage(Vrms) (ph-ph)	400 Volts
Frequency	50 Hertz
Sampling Time(Ts)	5e-6 Seconds
Source Resistance (Rs)	0.001 Ohms
Source Inductance (Ls)	1e-8 Henries
Base Voltage(Vrms) (ph-ph)	25e3 Volts
System Impedance	
System Resistance (R)	0.01 Ohms
System Inductance (L)	1e-6 Henries
System Impedance Before Rectifier	
System Resistance (R)	0.001 Ohms
System Inductance (L)	1e-3 Henries
Load	
Rectifier Load Resistance	10 Ohms
Three Phase Unbalanced Load	
Resistance of R-Phase (Rr)	10 Ohms
Resistance of Y-Phase (Ry)	20 Ohms
Resistance of B-Phase (Rb)	30 Ohms
Voltage Source Inverter	
DC Link Capacitance (Cdc)	570 Micro Farads
DC Voltage	850 Volts

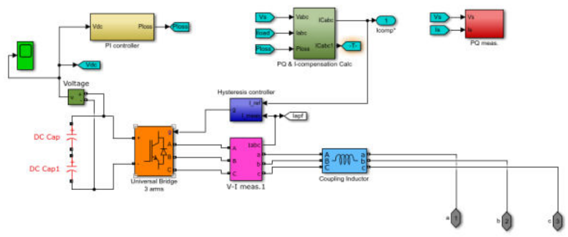

Figure 3. MATLAB/Simulink Model of Shunt Active DC Power Filter (SADPF)

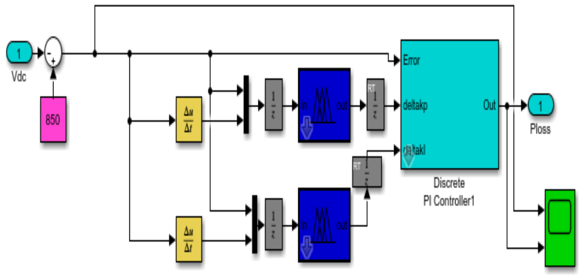

Figure 4. MATLAB/Simulink Model of Fuzzy Logic Controller

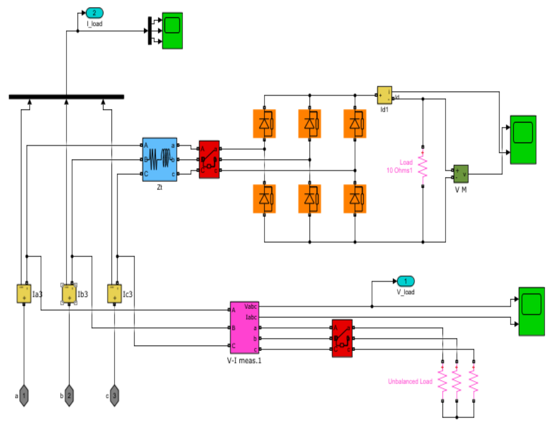

Figure 5. MATLAB/Simulink Model of Load

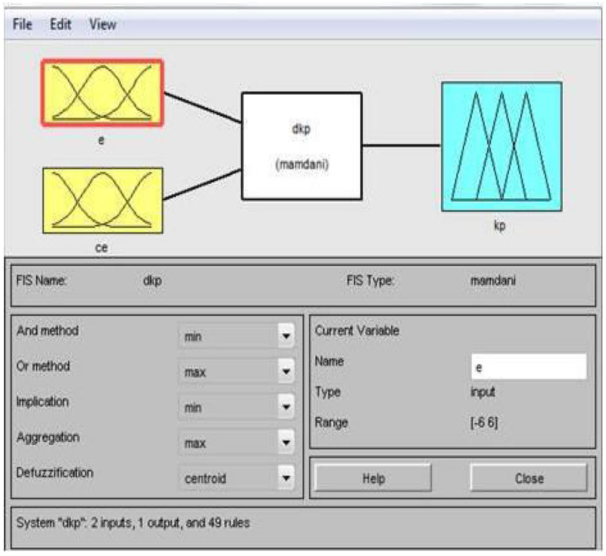

Figure 6. MATLAB/Simulink Fuzzy Inference System for Proportional Gain of PI Controller

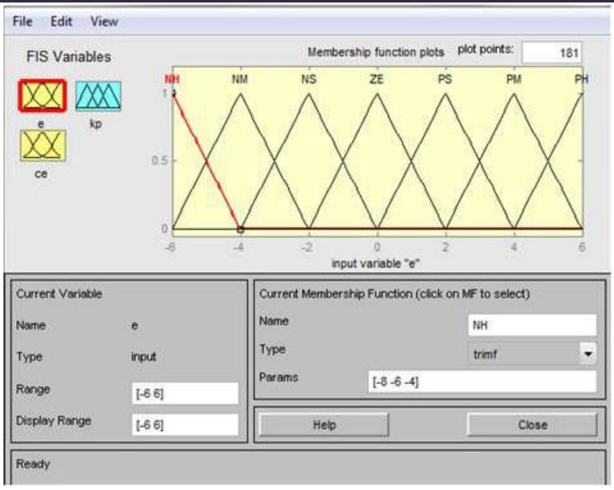

Figure 7. MATLAB/Simulink Fuzzy Membership Function for Proportional Gain of PI Controller

Table 2: Fuzzy Rule Base for proportional gain of PI Controller

Error	Change of Error (ce) for kp						
(e)	NH	NM	NL	ZE	PL	PM	PH
NH	PH	PH	NH	PM	PL	PL	ZE
NM	PH	PH	NM	PM	PL	ZE	ZE
NL	PM	PM	NL	PL	ZE	NL	NM
ZE	PM	PL	ZE	ZE	NL	NM	NM
PL	PL	PL	ZE	NL	NL	NM	NM
PM	ZE	ZE	NL	NM	NM	NM	NH
PH	ZE	NL	NL	NM	NM	NH	NH

5. SIMULATION

Shunt Active DC Power Filter (SADPF) is simulated in MATLAB/Simulink with a sampling time of 5e-6 seconds. Simulation of proposed system is done by considering two cases, which are as follows,

Case 1: Non Linear Load is connected from start of simulation ie: from T=0 seconds and the unbalanced load is connected at T=0.1 seconds without connecting the filter.

Case 2: Non Linear Load is connected from start of simulation ie: from T=0 seconds and the unbalanced load is connected at T=0.1 seconds by connecting the filter at T=0 seconds.

For the above two cases, the waveforms of Source Current, Load Current, Filter Current, DC Voltage across the Rectifier, phase relation between source voltage and source current were obtained. Total Harmonic Distortion of Source Current in % were also obtained for the above two cases.

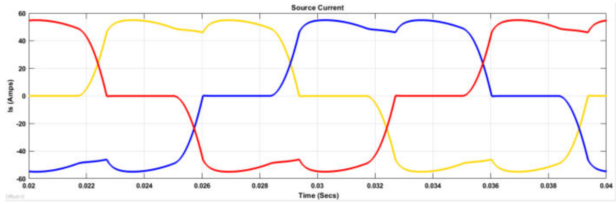

Figure 8. Source Current of Non Linear Load without Filter

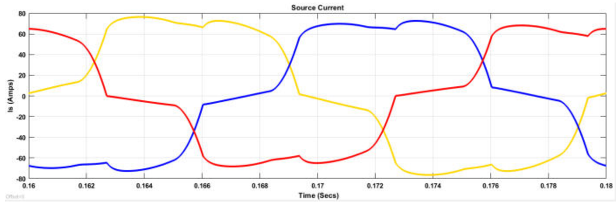

Figure 9. Source Current of Non Linear Load and Unbalanced Load without Filter

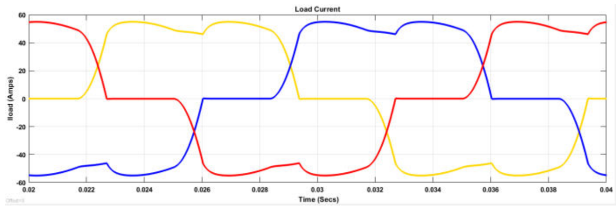

Figure 10. Load Current of Non Linear Load without Filter

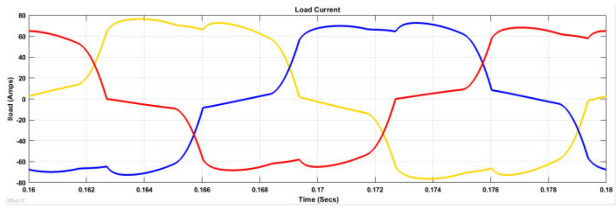

Figure 11. Load Current of Non Linear Load and Unbalanced Load without Filter

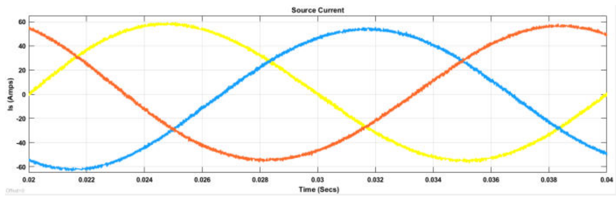

Figure 12. Source Current of Non Linear Load with Filter

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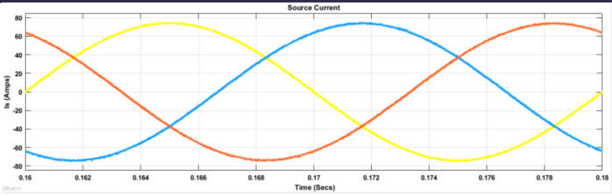

Figure 13. Source Current of Non Linear Load and Unbalanced Load with Filter

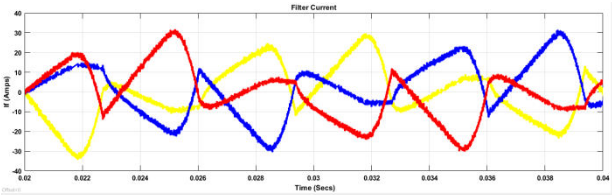

Figure 14. Filter Current

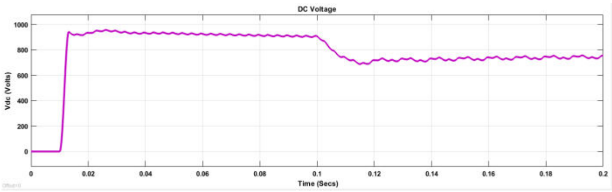

Figure 15. DC Voltage

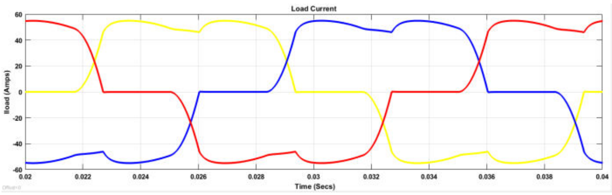

Figure 16. Load Current of Non Linear Load with Filter

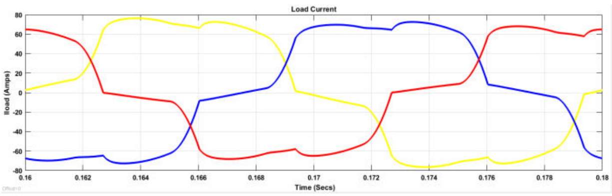

Figure 17. Load Current of Non Linear Load and Unbalanced Load with Filter

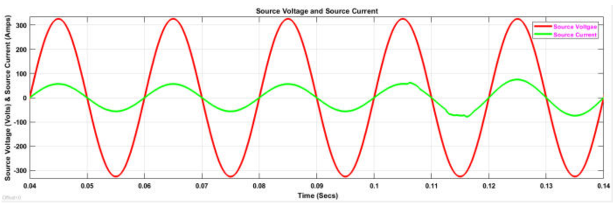

Figure 18. Source Voltage and Source Current with Filter

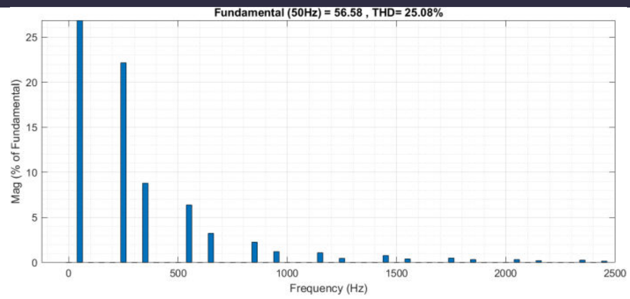

Figure 19. Total Harmonic Distortion of Source Current of Non Linear Load without Filter.

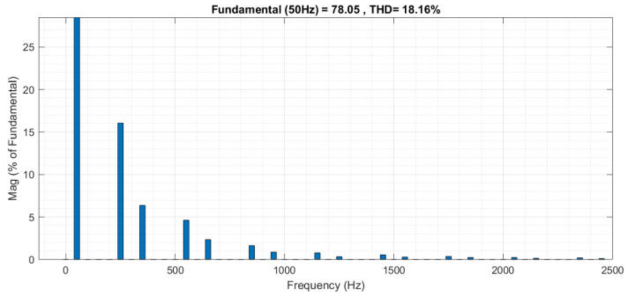

Figure 20. Total Harmonic Distortion of Source Current of Non Linear Load and Unbalanced Load without Filter.

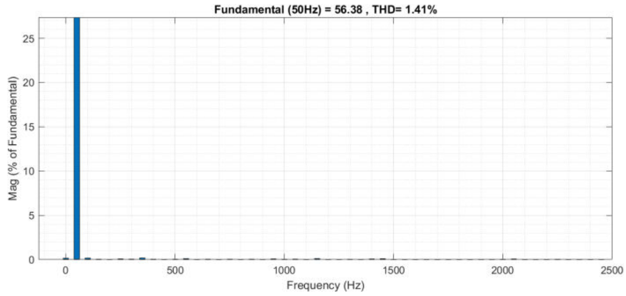

Figure 21. Total Harmonic Distortion of Source Current of Non Linear Load with Filter.

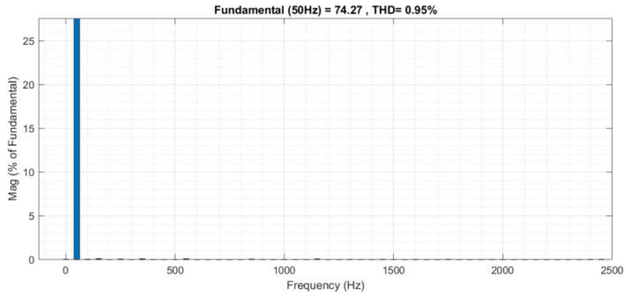

Figure 22. Total Harmonic Distortion of Source Current of Non Linear Load and Unbalanced Load with Filter.

6. RESULTS AND DISCUSSIONS

The analysis of Source Current for the two cases after simulation provides the following observations,

Case 1: Source Current for Non Linear Load is observed to be non sinusoidal as shown in Figure 8. as it contains harmonic content with THD of 25.08% as shown in Figure 19.

Source Current for Non Linear and Unbalanced Load is also non sinusoidal as shown in Figure 9. As it contains harmonic content with THD of 18.16% as shown in Figure 20. Due to connection of unbalanced load to the already connected Non Linear Load the THD is reduced from 25.08% to 18.16%.

Case 2: Source Current for Non Linear Load is found to be sinusoidal as the harmonics were reduced by the SADPF as shown in Figure 12, its THD is also reduced to 1.41% as shown in Figure 21.

Source Current for Non Linear and Unbalanced Load also found to be sinusoidal as the harmonics were mitigated by SADPF as shown in Figure 13. Its THD is reduced to 0.95% as shown in Figure 22.

It is also observed that with SADPF the source voltage and source current were found to be in phase with each other as shown in the Figure 18.

Table 3. Total Harmonic Distortion of Source Current With and Without Filter

Signal	Signal No	Total Harmonic Distortion without Filter(%)	Total Harmonic Distortion with Filter(%)
NON LINEAR LOAD			
Is	1	25.08	1.41
	2	25.08	1.45
	3	25.08	1.43
NON LINEAR LOAD & UNBALANCED LOAD			
Is	1	18.16	0.98
	2	18.90	0.95
	3	20.47	1.00

7. CONCLUSIONS

Simulation Results of proposed AI based Shunt Active DC Power Filter (SADPF) for Non Linear and Unbalanced Loads in MATLAB/Simulink makes it clear that the presence of Non Linear Load in the Power System injects harmonics into system, making the Source Current polluted with harmonics. Source Current must be sinusoidal to deliver quality power to the load. The connection of unbalanced load will not contribute to the harmonic content in the source current but its load current magnitude varies with respect to the load connected. Surprisingly after connection Unbalanced Load the THD in Source Current is reduced from 25.08% to 18.16%. The Proposed AI based SADPF compensated the harmonic content in the Load Current making the Source Current sinusoidal. The THD of Source Current is reduced from 25.08 to 1.41% for Non Linear Load and from 18.16 to 0.98%.It can be concluded that the proposed AI based SADPF improves the performance and reliability of Power System by mitigating the harmonics due to Non Linear Load, providing quality power to the load.

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