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Experimental Study of Fuzzy-SVPWM-Based Indirect Current Controlled Shunt Hybrid Active Power Filter

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***Abstract*:** In order to reduce harmonics and reactive power, the Shunt Hybrid Active Power Filter (SHAPF) is experimentally investigated in this study. A fuzzy logic controller (FLC) is used in the current work to generate the necessary harmonic reference currents and control the SHAPF's DC side voltage. Space Vector Pulse Width Modulation (SVPWM) is utilised to provide the necessary pulses needed for the Voltage Source Converter (VSC) in the shunt Active Power Filter (APF) in order to effectively use the DC side voltage. The suggested control mechanism has been subjected to experimental study to evaluate it. The Spartan 6 Field-Programmable Gate Array (FPGA) controller is used to implement the SHAPF's control algorithm in the digital realm. Careful selection and setup of SHAPF components are necessary to meet the core requirements for the application structure. The equipment This document presents the SHAPF component designs. The experiments conducted in this study using a 150V/1.5kVA experimental setup demonstrate the feasibility of SHAPF.

Keywords: Fuzzy logic controller; Indirect current control scheme; Space vector pulse width modulation; Shunt hybrid active power filter; Spartan 6 FPGA controller; Total harmonic distortion (THD).

1 INTRODUCTION

Power quality is a very important issue to all levels of electricity consumers. Widespread increase in renewable energy generation, power electronic equipment’s and commercial applications increases the harmonic distortion levels at the end use services and on the overall power system. Alternatively, the requirement for clean power supply is increasing for sensitive loads such as electronic equipment used in medical and automated applications. This demand has led to the advancement of various harmonic mitigation techniques [1]-[3].

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The most basic method of harmonic mitigation is to use passive inductor-capacitor (LC) filters. These tuned LC filters are connected in parallel to harmonic generating load/source. Passive filters are tuned such that at/near dominant harmonic component, resonance of passive filter occurs. So that the harmonic component choses to flow through passive filter instead of source, consequently, reduce the harmonic content in the source current. But passive filters are bulky in nature. Installing passive filter for every dominant

harmonic component is difficult and rigorous. Multiple

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passive filters connected to utility might cause series and parallel resonance in the power system [4]. In the literature, to overcome the aforementioned issues, active power filters are proposed. To mitigate the harmonic components, active power injects equal and opposite components there by cancelling original harmonics. For current harmonic mitigation, shunt active power filter (APF) which is connected in shunt with load is used. The shunt APF is operated in closed loop, such that to force the source current to be free of harmonics and to be at unity power factor (UPF). But they are restricted by high maintenance, high cost, low power to volume ratio and difficulty in operating under high voltage conditions [5].

Hybrid Active Power Filter (HAPF) is the better solution for mitigating harmonics. HAPF incorporates compensation characteristics of both passive and active filters. The control strategy of SHAPF is the key element for its successful performance in improving the power quality and is implemented in two stages. First stage is generation of reference compensation current signal, and the second stage is to track the current signal to generate switching signals to drive the converter [6]-[7]. In literature, numerous control techniques have been reported for active and HAPFs. Instantaneous reactive power theory-based reference current generation is one of the most used methods because it avoids park transformation. However, this method uses a high pass filter which creates delay in the reference current, and to nullify this delay a phase lead or phase lag compensator need to be used [8]-[9]. While the other method based on synchronous reference frame theory using park transformation, doesn't require low pass or high pass filters. These conventional reference current generation techniques use linear controllers which need accurate model of the system. These linear controllers fail to work satisfactorily in parameter deviations, nonlinearities etc. The above-mentioned problems can be effectively overcome by intelligent control methods like fuzzy logic controllers and artificial neural network controllers [10]-[12]. The second stage of control is current control. Among the various current

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control methods, two methods are often used. One is nonlinear current control and another one is linear current control. Nonlinear controllers such as hysteresis controllers are used to regulate the converter current through saturation limit for the current signal. Hysteresis controller doesn't need an additional pulse width modulator to drive the inverter and they are easy to implement. However, they operate at varying switching frequency [13]-[15]. Linear current controllers are designed using linear mathematical model of the plant. They are followed by a pulse width modulator, which can be sine based or space vector based. Linear current controllers are robust and have modularity. To make the SHAPF more dynamic and robust, a fuzzy tuned PI controller is used for reference current generation. A linear current controller is used for current control and to effectively utilize the DC side capacitor voltage, SVPWM is used to drive the converter. The complete control scheme operates in synchronous reference frame to simplify the design process.

Fig.1 shows the block diagram of fuzzy tuner used in controller. The fuzzification block converts the real-world crisp inputs to fuzzy sets. To convert the crisp inputs from the real world to linguistic variables and vice versa.

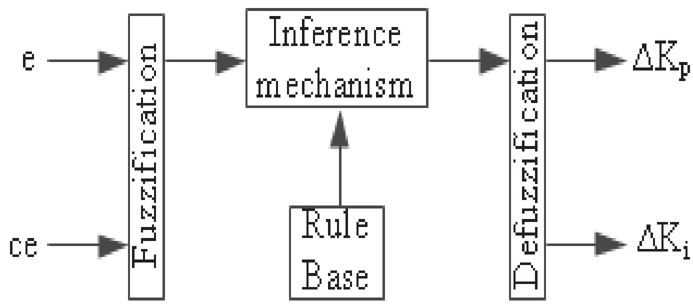

Fig.1 Block Diagram of Fuzzy Tuner

2 EXPERIMENTAL RESULTS AND DISCUSSION

A. Results without Compensation

The 3-Ɏ source currents (R, Y, B) without any compensation are shown in Fig. 2. It can be observed that the source currents are highly distorted and have dominant lower order harmonics due to nonlinear load. Fig.7 depicts the numerical data of the test system before compensation. It is found that, due to lower order harmonics in the source current and finite impendence of source, lower order harmonic components appear in the supply voltage.

As the source and load are balanced, 3rd harmonic and its multiples are absent in the source current. The Fourier transformation of supply current waveform depicts that source current has lower order

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harmonics namely 5th, 7th, 11th, and 13th. The 5th harmonic is the most dominating with a current magnitude of 1.18A (21.3%). The THD of source current and voltage are reported as 24.69% and 4.4% respectively.

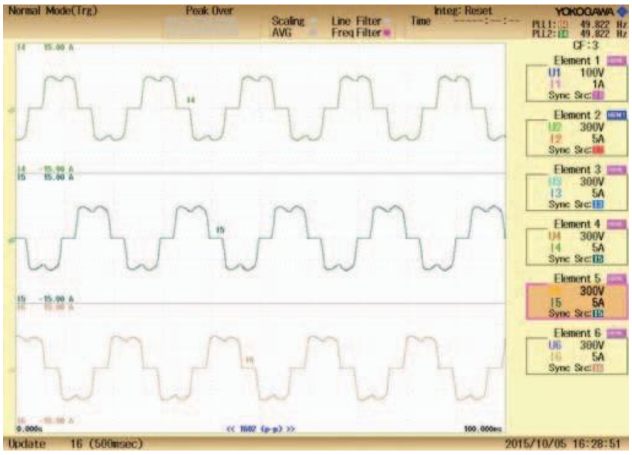

Fig.2 Three phase source currents before compensation

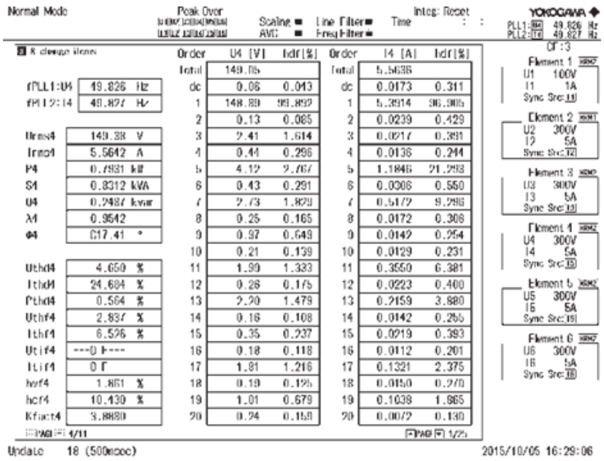

Fig.3 Numerical data obtained before compensation

B. Results with Passive Filter

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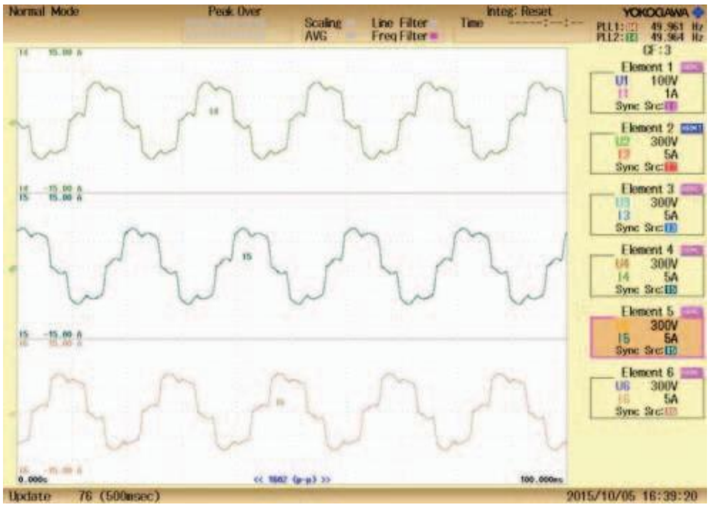
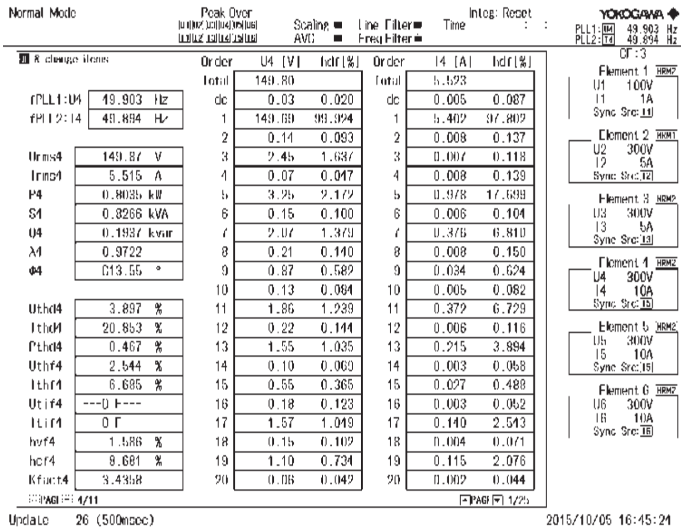


Fig. 4 Three phase source currents with passive filter

As the 5th harmonic component is dominant in the source current, a shunt passive filter fine-tuned for 5th harmonic frequency is used in the system. The 3- Ɏ source current with the inclusion of passive filter to the test system is shows in Fig.4. The flat shaped current during zero crossing, which appeared before compensation is now smoothened. Fig.5 shows the numerical data of the test system with passive filter. From the Fourier analysis of source current, the 5th harmonic component is significantly attenuated.

The 5th harmonic content is reduced from 21.29% to 17.7% and the THD is reduced to 20.85% from 24.68%. The distortion factor is also improved to 0.97 with the 5th harmonic compensation. To increase the power factor of the system, at the fundamental frequency, the passive filter supplies reactive power to the PCC.



Normal Mode — Peak Over — Scaling — AVG — Line Filter — Freq Filter — Integ: Reset — Time — YOKOGAWA — PLL1: 49.903 Hz — PLL2: 49.894 Hz — CF:3

		Order	U4 [V]	hdf[%]	Order	I4 [A]	hdf[%]
		Total	149.80		Total	5.523	
fPLL1:U4	49.903 Hz	dc	0.03	0.020	dc	0.005	0.087
fPLL2:I4	49.894 Hz	1	149.69	99.924	1	5.402	97.802
		2	0.14	0.093	2	0.008	0.137
Urms4	149.87 V	3	2.45	1.637	3	0.007	0.118
Irms4	5.515 A	4	0.07	0.047	4	0.008	0.139
P4	0.8035 kW	5	3.25	2.172	5	0.978	17.699
S4	0.8266 kVA	6	0.15	0.100	6	0.006	0.104
Q4	0.1937 kvar	7	2.07	1.379	7	0.376	6.810
λ4	0.9722	8	0.21	0.140	8	0.008	0.150
Φ4	G13.55 °	9	0.87	0.582	9	0.034	0.624
		10	0.13	0.084	10	0.005	0.082
Uthd4	3.897 %	11	1.86	1.239	11	0.372	6.729
Ithd4	20.853 %	12	0.22	0.144	12	0.006	0.116
Pthd4	0.467 %	13	1.55	1.035	13	0.215	3.894
Uthf4	2.544 %	14	0.10	0.069	14	0.003	0.058
Ithf4	6.685 %	15	0.55	0.365	15	0.027	0.488
Utif4	---0 F---	16	0.18	0.123	16	0.003	0.052
Itif4	0 F	17	1.57	1.049	17	0.140	2.543
hvf4	1.586 %	18	0.15	0.102	18	0.004	0.071
hcf4	8.681 %	19	1.10	0.734	19	0.115	2.076
Kfact4	3.4358	20	0.06	0.042	20	0.002	0.044

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Fig.5 Numerical data obtained with passive filter

C. Results with Active Filter

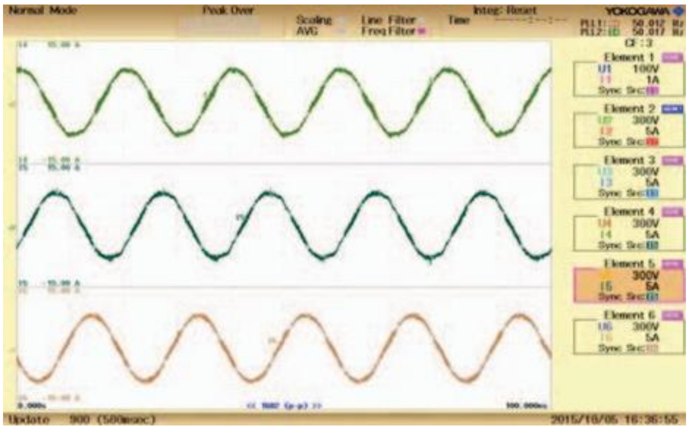

Fig.6 Three phase source currents with active filter

Potential harmonic components are present in the source current even after compensation of 5th harmonic with passive filter. In order to compensate these potential harmonics and to improve the source current quality, an active filter is introduced in the test system. Fig.6 shows the three phase source currents of the test system with shunt active filter only. There is a significant improvement in the source current wave form, compared to passive filter compensation. Fig.7 shows numerical data of the test system with the shunt active compensation. The 5th, 7th, 11th, 13th and 17th harmonic components in the source currents are greatly attenuated with shunt active compensation compared with uncompensated and passive compensation cases. The THD and Total Demand Distortion (TDD) are in the desired limits with the shunt active compensation. Due to the reduction in source current harmonic distortion, supply voltage distortion also reduced to 3.48% from 4.65%.

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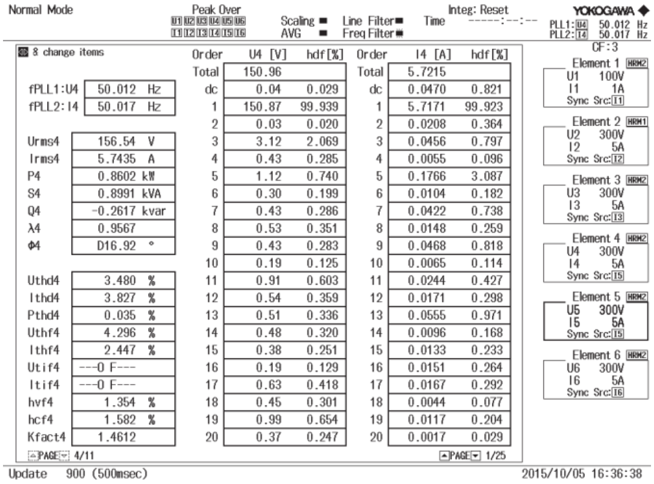

Fig.7 Numerical data obtained with active filter

D. Results of SHAPF with Fuzzy Controller

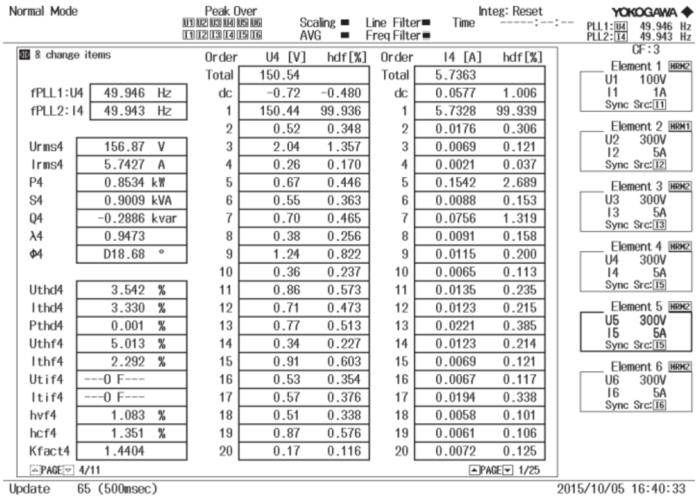

Fig.8 Numerical data obtained with SHAPF

From equation 26, So as to minimize the rating and cost of APF, burden on the APF should be reduced. This can be achieved with the application of passive filter in conjunction with active filter which is nothing but a hybrid active power filter. Fig.8 gives the numerical data of the test system with SHAPF. All dominant harmonics are attenuated to less than 1% each. As the dominant harmonics are attenuated to a great extent, the THD of source current is reduced to 3.33%. The source current THD with SHAPF has undergone significant change through compensation, but a small change from APF case. From the

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analysis, it is observed that the desired rating of APF is 0.95Sload, when it is employed in SHAPF but if the APF is operating alone, its rating is 0.97 Sload.

Fig.9 shows the top view of the prototype developed. Table 1 shows the parameters used in the prototype and Table 1

represent the comparative results obtained from the test system. From Table 1, it can be observed that fuzzy based SVPWM controllers have shown better response in terms of THD when compared to shunt passive and shunt active filter.

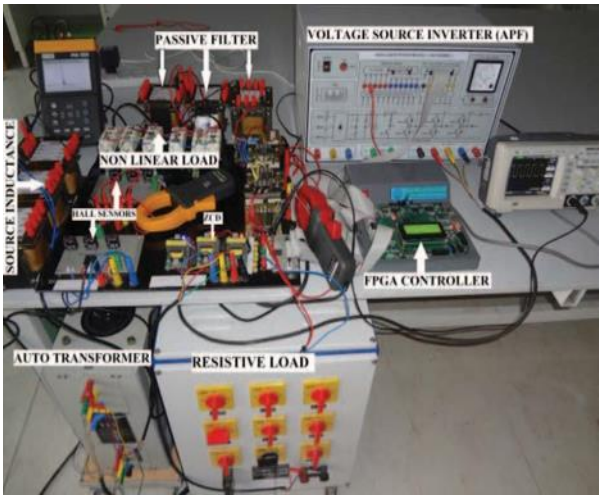

Fig.9 Experimental setup established in laboratory

TABLE 1 COMPARISON OF HARMONIC SOURCE CURRENTS AND % THD Source Currents (Is) in A

Harmonic Order	Harmonic Order	Harmonic Order	Harmonic Order
1	5.3914	5.402 5.7171	5.7363
5	1.1846	0.978 0.1766	0.1542

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7	0.5172	0.376 0.0422	0.0756
11	0.3550	0.372 0.0244	0.0135
13	0.2159	0.215 0.0555	0.0221
17	0.1321	0.140 0.0167	0.0194
19	0.1038	0.1115 0.0117	0.0061
%THD	**24.684**	**20.853 3.827**	**3.330**

CONCLUSION

The experiment examination of a SHAPF-based fuzzy controller is presented in this work in order to reduce power quality problems. To verify the viability of fuzzy controller-based SHAPF, a three-phase, 150V distribution system is modelled both with and without compensatory tools. In this, the distribution system's dominant harmonic is used to construct the passive filter, and the biggest influential harmonic component is used to design the active filter.

Real-time experiments are run on hardware having an FPGA Spartan controller. Without a filter, a passive filter, a fuzzy-controlled active filter, and a fuzzy-controlled SHAPF, the %THD was obtained as 24, 68, 20, 85, 3, and 3.3, respectively. The findings show that the harmonic distortion with fuzzy regulated SHAPF is below the established limitations as the norms for distribution regulation's set limitations.

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