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Investigating the ability of shunt hybrid power filter based on SRF method under non-ideal supply voltage

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Abstract. This study presents the capacity of a self-tuning filter based on the synchronous reference frame method with a fuzzy logic controller for the improvement of the efficiency of harmonic suppression of a shunt hybrid active power filter in an unbalanced distorted and un-distorted voltage supply conditions. The simulation results indicated that the filter with a fuzzy logic controller had a good filtering performance in steady and transient states, irrespective of whether the voltage supply is distorted or unbalanced.

1. Introduction

The issues with power quality have become critical in recent times due to the use of electronic circuits with non-linear behaviors in industrial and domestic devices such as inverters, power supply switches, single/ three phases of rectifiers. These circuits generate non-sinusoidal currents in the distribution power networks. The issues of reactive and active power occur usually due to the connection of nonlinear single-phase loads with either three-phase or four-wire structures. Even when these loads are stable, harmonic currents circulate through the neutral conductor, and this is bound to happen as a result of the presence of zero sequence elements [1-2]. These currents might have higher amplitudes compared to those of the component phase current. This difference of current amplitudes can lead to damage the transformers and neutral conductor which bear these loads [3-5].

To disband this problem of current harmonics in the power distributed network, several solutions have been proposed. These solutions can be grouped into two: the first group is the conditioning loads group which provides confer equipment with less sensitivity to energy instabilities, thereby, allowing service continuity even when there is a significant distortion in the voltage [6]. The other technique is the installation of conditioning structures which minimizes harmonic disturbances.

Harmonic currents can be minimized with passive filters (PFs) to compensate for reactive power. However, there are some issues with these PFs, such as heavy and bulky devices, parallel and series resonance with load and source impedances. The active filters were established to reduce the issues with the passive filters [4, 7, and 8] but they have high operational costs and also not appropriate for moderate or high voltage conditions. A synergistic combination of the passive and active filters in the

form of a hybrid power filter (HPF) is appealing [7]. Various forms of hybrid filters with varying control systems have been suggested for load harmonics compensation.
These structures allow the separate use of parallel/series active filters to design small-rated active filters. The harmonic extraction method for the detection of voltage and current harmonic as well as sub-harmonics and components are mainly according to either direct or indirect control technique which is dependent upon the theory of instantaneous reactive power [9]. The efficiency of the active power filters has also been improved using adaptive notch filters, synchronous rotational reference frame, flux-based controllers, and nonlinear controllers. However, most of these strategies are difficult to implement as they contain a number of transformations [10].
The fuzzy logic controllers [4,6] have recently gained attention in terms of application to APFs. A fuzzy logic controller is an ideal approach compared to the conventional methods because they do require any accurate mathematical model, can hand non-linearity, can apply inaccurate inputs, and are more vigorous to implement [11].
In this paper, a synchronous reference frame (SRF) with a self-tuning filter (STF) was used to shape ac current and regulate dc voltage intended for a-three-phase shunt HAPF under ideal and non-ideal power source conditions.

2. Control algorithms of the SHAPF

Figure 1 depicts the controlling algorithm block diagram. The signals of feedback are detected from the load currents, as well as AC source and DC bus voltages of SAPF [12]. The three-phase currents (i_L^a , i_L^b and i_L^c) were converted from from (a-b-c) phases reference frame to (α-β) phases static reference frame currents iα and iβ using

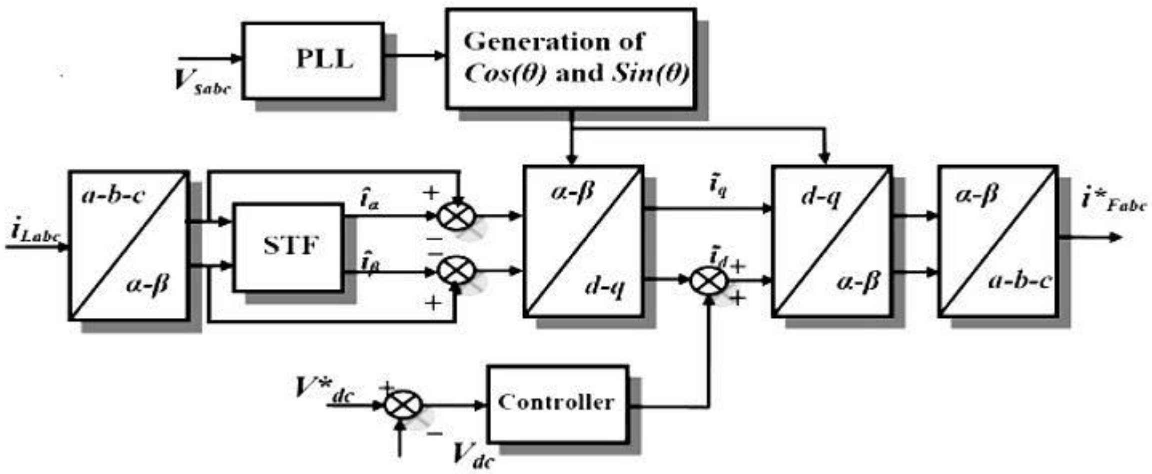

Figure 1. SRF control strategy with STF based on SHAPF.

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_L^a \\ I_L^b \\ I_L^c \end{bmatrix} \tag{1}$$

The instantaneous current could be represented as the total fundamental and alternative components:

$$\begin{cases} I_\alpha = \widetilde{I_\alpha} + \breve{I_\alpha} \\ I_\beta = \widetilde{I_\beta} + \breve{I_\beta} \end{cases} \tag{2}$$

Then the STF directly extracts the fundamental components from the currents in the α-β axis. Then, the α-β harmonic current components are generated by deducting the signals of STF input from the resultant outputs (Figure 1). The signals from this computation are the AC elements (ĩα and ĩβ) which are the corresponding harmonic elements generated in the stationary reference frame by the load currents for all phases i_L^a , i_L^b and i_L^c [13-14]. Cos(θ) and sin(θ) can be generated from the phase voltage source (Vsa, Vsb and Vsc) with the help of Phase Locked Loop (PLL). The currents ĩα and ĩβ within the d-q reference frame can be expressed as

$$\begin{bmatrix} \widetilde{I_d} \\ \widetilde{I_q} \end{bmatrix} = \begin{bmatrix} sin(\theta) & -cos(\theta) \\ cos(\theta) & sin(\theta) \end{bmatrix} = \begin{bmatrix} \widetilde{I_\alpha} \\ \widetilde{I_\beta} \end{bmatrix} \tag{3}$$

The reference currents (I_F^*) in the a-b-c frame are expressed as

$$\begin{bmatrix} I_{Fa}^* \\ I_{Fb}^* \\ I_{Fc}^* \end{bmatrix} = \sqrt{2}/_3 \begin{bmatrix} 1 & 0 \\ -1/_2 & \sqrt{3}/_2 \\ -1/_2 & -\sqrt{3}/_2 \end{bmatrix} \begin{bmatrix} I_\alpha^* \\ I_\beta^* \end{bmatrix} \tag{4}$$

The STF is used in Figure 2 as a harmonic isolator rather than filters which based on classical extraction methods. Hong-sock Song in [5] had earlier justified the inclusion of the SRF method

$$V_{XY}(t) = e^{j\omega t} \int e^{-j\omega t} V_{XY}(t)dt \tag{5}$$

By transfer function of filter, the equation (5) can be expressed: [15]

$$\widetilde{I_\alpha}(s) = \frac{k}{s}\left[I_\alpha(s) - \breve{I_\alpha}(s)\right] - \frac{WC}{S}\breve{I_\beta}(s) \tag{6}$$

$$\widetilde{I_\beta}(s) = \frac{k}{s}\left[I_\beta(s) - \breve{I_\beta}(s)\right] + \frac{WC}{S}\breve{I_\alpha}(s) \tag{7}$$

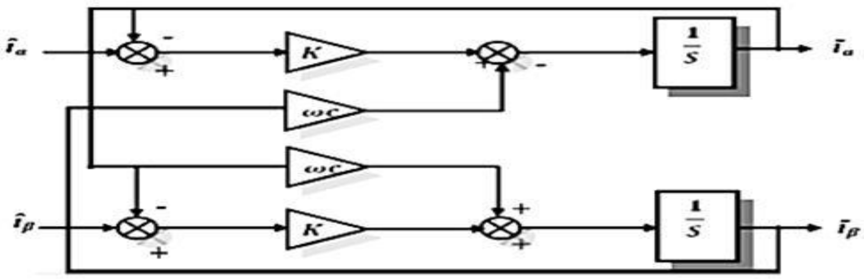

Figure 2. The structure of self-tuning filter tuned STF.

3. DC capacitor voltage control

The fuzzy control (FL) algorithm was used for the control of the DC capacitor voltage according to the processing of DC voltage error as well asits variation to maintain the dc voltage as a reference value, improve the SHAPF performance, and minimize the THD as shown in figure3.While designing a fuzzy control system [16]. FL was described by seven fuzzy sets entailing NM, NB, ZE, NS, PM, PS, and PB for its input and output variables, function oftriangular membership utilized for thesimplicity, defuzzification by means of the height technique and implication by means of Mamdani-type min-operator.

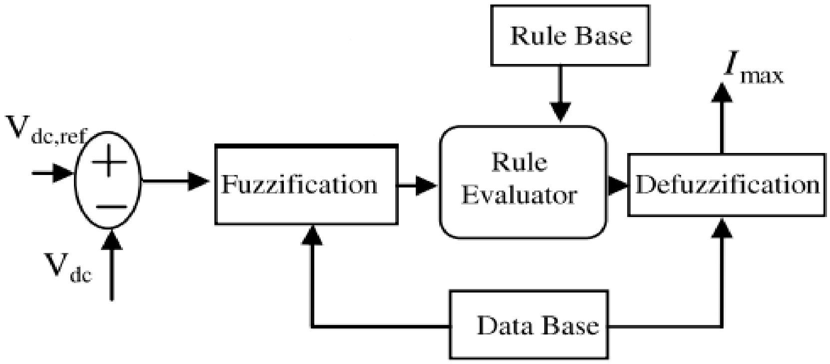

Figure 3. The structure of FLC.

4. Results and discussion

The source voltage, source current with filter, compensation current, compensation current, compensation current, dc link voltage and THD under conditions of balanced un-balanced and non-sinusoidal supply voltage with FLC are detailed in Figures 4, 5,6 and 7. The specification and circuit parameters are used in the simulations are written in table 1 below:

Table 1. presented system parameters.

PARAMETERS	VALUE
Source voltage	240V
voltage frequency	50 HZ
Inductor Ls	0. 0001 H
Resistor Rs	0. 0005 Ω
Inductor LL 1	0.05 H
Resistor RL 1	80 Ω
Inductor LL 2	0.5 H
Resistor RL 2	120 Ω
Inductor Lf	0. 000075 H
Resistor Rf	0.00050 Ω
DC bus voltage	450V
DC capacitor	350 µF

The system performance was initially investigated with nonlinear (0 to 0.25s) and additional nonlinear loads (0.25to 0.4 s) under balanced sinusoidal conditions and found to be effective at harmonics suppression (Figures 4 and 5). The THDs of the currents were reduced from 28.45% and 29.33% to 2.08% and 1.78% respectively. Meanwhile, there was an increase of 30% in load at t = 0.25s in the case of changing loads. As evidenced, the filter current was relational to the changes in the load as no significant current transition was observed. The line current remained sinusoidal and attained the steady value. Besides, the DC-link capacitor was maintained with very small ripple by the FLC at the required range (450v) during load changes.

The filter capability to compensate harmonicloads under unbalanced distorted ac source (includes a 5th and 7th harmonic components (THD= 14.67%) is shown in Figure 6. There was a decrease in the measured THD of the source current from 29.31% and 31.25% prior to compensation to 2.23% and 2.71% post-compensation for the non-linear loads as in (Figure 7). The voltage of the dc capacitors dc was within the reference range and the voltage variation was within the limit in the controller under distorted unbalanced supply.

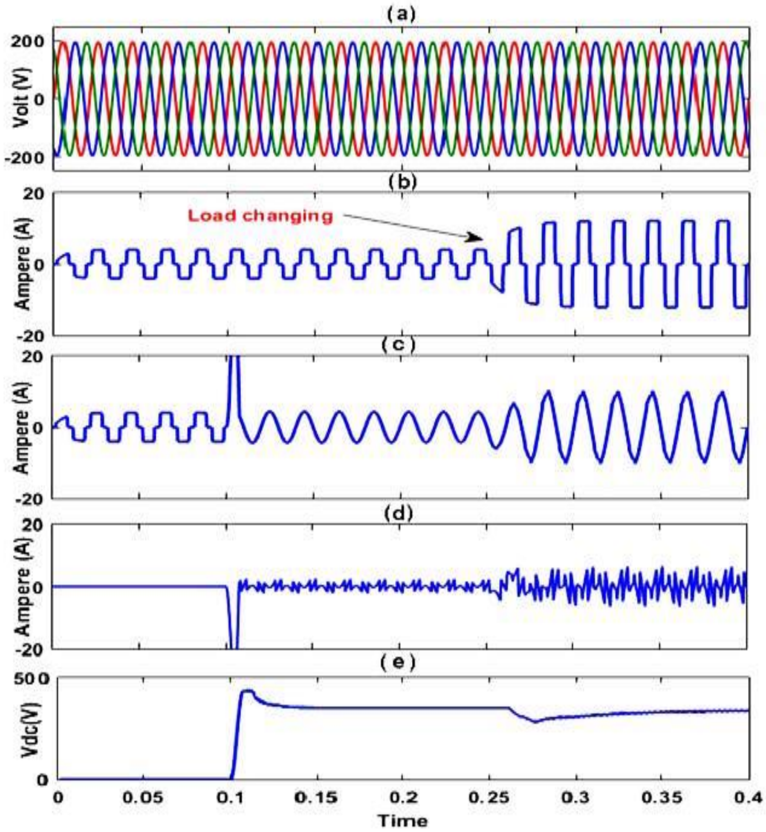

Figure 4. SHAF response under ideal voltage situation (a) Source voltage (Vs), (b) Load current (IL), (c) load current with filter, (d) Filter compensation current (If) , and (e) DC link voltageof system (Vdc).

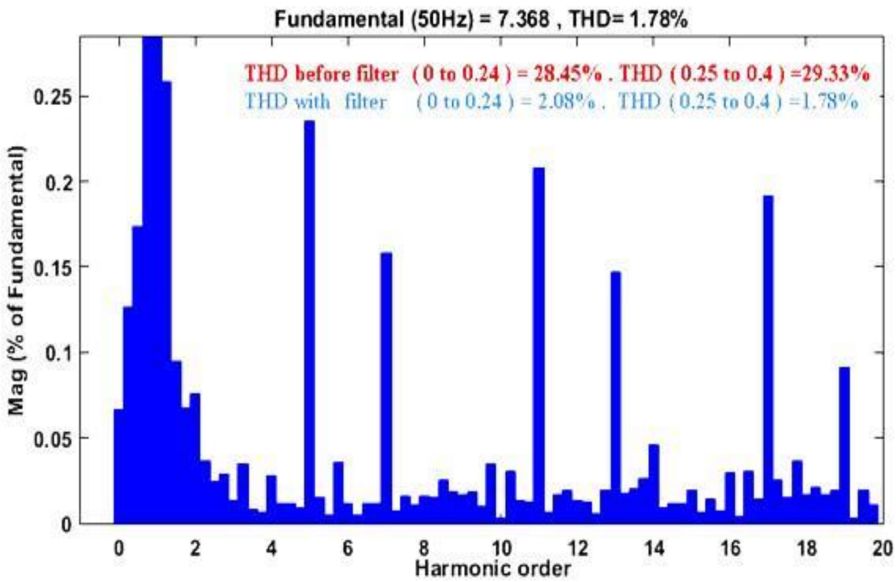

Figure 5. THD of current (Is)under ideal voltage supply.

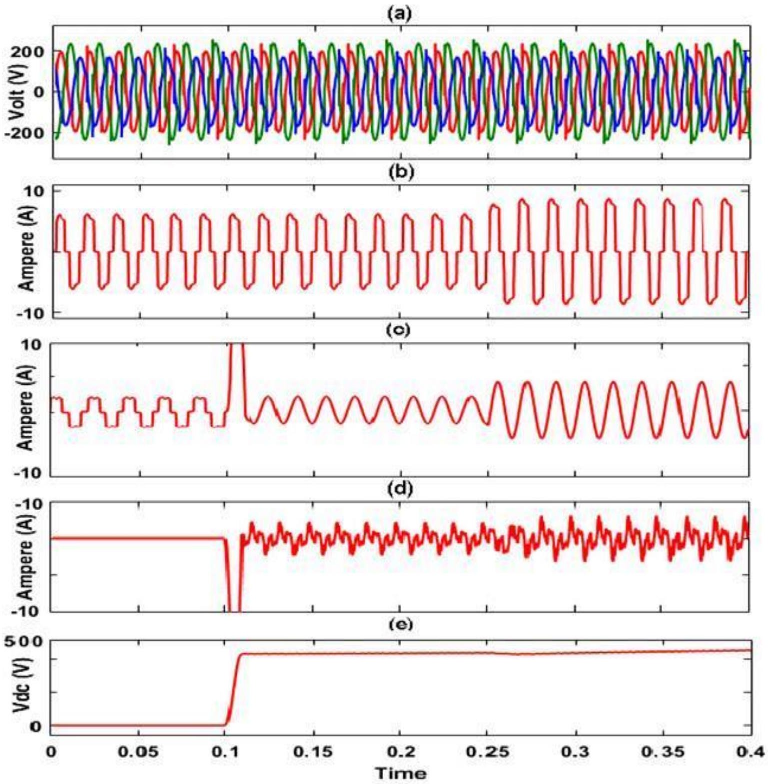

Figure 6. SHAF response under non ideal voltage situation (a) Source voltage (Vs), (b) Load current (Il), (c) load current with filter, (d)Filter compensation current (If), and (e) DC link voltageof system (Vdc).

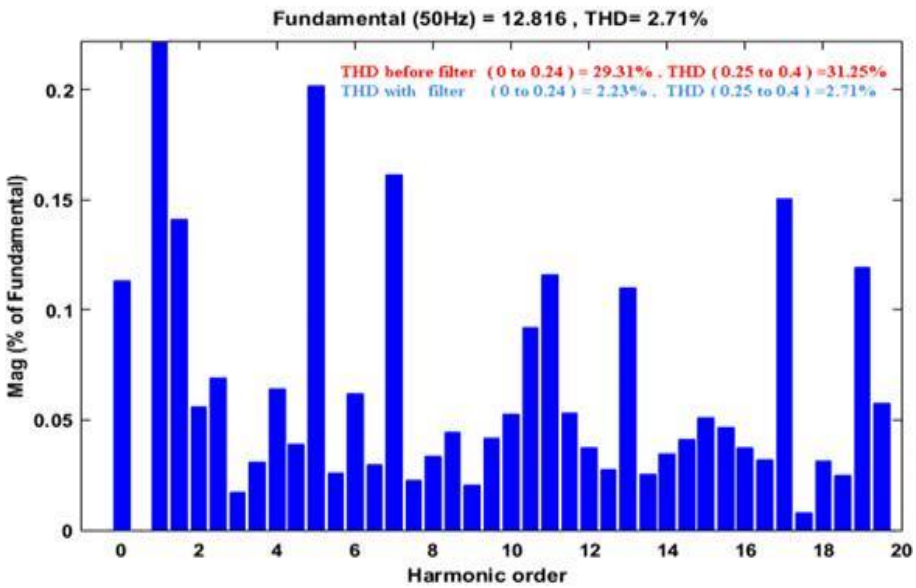

Figure 7. THD of current (Is) under non ideal source voltage.

5. Conclusion

This paper investigated the effectiveness of a synchronous reference frame (SRF) with a self-tuning filter (STF) control strategy in controlling the performance of a three-phase SHAPF system under conditions of non-ideal and balanced supply voltage. The fuzzy logic controller was utilized for the adjustment of the DC voltage. The performance of the SHAPF system was investigated under a dynamic and steady state and under different load operating conditions. The simulation results showed the SAPF to have successfully reduced current harmonics to about 1.7 and 2.7 % for both cases of source voltages.

Acknowledgments

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References

[1] Eltawil, M.A. and Zhao, Z., 2010. Grid-connected photovoltaic power systems: Technical and potential problems—A review. *Renewable and Sustainable Energy Reviews*, *14*(1), pp.112-129.

[2] Bhat, A.H. and Agarwal, P., 2008. Three-phase power quality improvement ac/dc converters. *Electric Power Systems Research*, *78*(2), pp.276-289.

[3] Wagner, V.E., Balda, J.C., Griffith, D.C., Mceachern, A., Barnes, T.M., Hartmann, D.P., Phileggi, D.J., Emannuel, A.E., Horton, W.F., Reid, W.E. and Ferraro, R.J., 1993. Effects of harmonics on equipment. *IEEE Transactions on Power Delivery*, *8*(2), pp.672-680.

[4] Mohamed, M.A., 2015. Design of shunt active power filter to mitigate the harmonics caused by nonlinear loads (Doctoral dissertation, *Universiti Tun Hussein Onn Malaysia*).

[5] Soomro, D.M. and Almelian, M.M., 2015. Optimal design of a single tuned passive filter to mitigate harmonics in power frequency.

[6] Ghosh, A. and Ledwich, G., 2012. Power quality enhancement using custom power devices. *Springer Science & Business Media*.

[7] Rahmani, S., Hamadi, A. and Al-Haddad, K., 2012, October. A comprehensive analysis of hybrid active power filter for power quality enhancement. In *IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society* (pp. 6258-6267). IEEE.

[8] Wang, Y.F. and Li, Y.W., 2013, September. An overview of grid fundamental and harmonic components detection techniques. In *Energy Conversion Congress and Exposition (ECCE), 2013 IEEE* (pp. 5185-5192). IEEE.

[9] Rahmani, S., Hamadi, A., Al-Haddad, K. and Alolah, A.I., 2013. A DSP-based implementation of an instantaneous current control for a three-phase shunt hybrid power filter. *Mathematics and Computers in Simulation*, *91*, pp.229-248.

[10] Green, T.C. and Marks, J.H., 2005. Control techniques for active power filters. *IEE Proceedings-Electric Power Applications*, *152*(2), pp.369-381.

[11] Mikkili, S. and Panda, A.K., 2012, March. Mitigation of harmonics using fuzzy logic controlled shunt active power filter with different membership functions by instantaneous power theory. In *Engineering and Systems (SCES), 2012 Students Conference on* (pp. 1-6). IEEE.

[12] Shahbaz, M., 2012. *Active Harmonics Filtering of Distributed AC System* (Master's thesis, Institutt for elkraftteknikk).

[13] Abdusalam, M., Poure, P. and Saadate, S., 2008, June. Hardware implementation of a three-phase active filter system with harmonic isolation based on self-tuning-filter. In *Power Electronics Specialists Conference, 2008. PESC 2008. IEEE*(pp. 2875-2881). IEEE.

[14] Abdusalam, M., Poure, P., Karimi, S. and Saadate, S., 2009. New digital reference current generation for shunt active power filter under distorted voltage conditions. *Electric Power Systems Research*, *79*(5), pp.759-765.

IOP Conf. Series: Materials Science and Engineering **342** (2018) 012083 doi:10.1088/1757-899X/342/1/012083

[15] Ghamri, A., Benchouia, M.T. and Golea, A., 2012. Sliding-mode control based three-phase shunt active power filter: Simulation and experimentation. *Electric Power Components and Systems*, *40*(4), pp.383-398.
[16] Mahajan, V., Agarwal, P. and Gupta, H.O., 2014. An artificial intelligence based controller for multilevel harmonic filter. *International Journal of Electrical Power & Energy Systems*, *58*, pp.170-180.