COMBINED SYSTEM OF STATIC VAR COMPENSATOR AND ACTIVE POWER FILTER FOR HARMONIC SUPPRESSION AND POWER FACTOR IMPROVEMENT

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***Abstract**: This paper presents a novel approach for power quality improvement in Power system. The proposed system consists of Static VAR compensator and shunt Active Power Filter (APF) for harmonic suppression, power factor correction and voltage stability. The system configuration and the control method for the Static VAR compensator are implemented using MATLAB-simulink software. An optimal non-linear PI controller is used to improve the performance of the Static VAR compensator and the Improved Generalized Integrator controller has been adopted to improve the performance of the APF. Moreover, the simulation results obtained for the non- linear system have been analyzed and reported.*

Key words: *Active power filter (APF), Static VAR Compensator (SVC), Improved SPX Algorithm, Harmonic suppression, Reactive power compensation*

1. Introduction

Power quality problems are common in most of the commercial, industrial and utility networks. Harmonics and reactive power are two of the serious problems associated with the grid. They are caused by non-linear loads, including saturated transformers, arc furnaces, and semiconductor switches [1]. The presence of harmonics and reactive power in the grid is harmful, because it will cause additional power losses and malfunctions of the grid component.

The Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating current [3]. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180^0. This principle is applicable to any type of load considered as a harmonic source. Moreover, with an appropriate control scheme, the load power factor can be compensating by active power filter.

To prevent the inflow of harmonic and reactive currents and to improve the operating ability of the transmission systems, a kind of Flexible AC Transmission System (FACTS) has been proposed. The Static VAR compensator (SVC) is an important component of FACTS. It usually installs in power transmission systems and serves in various ways to improve the system performance. By the rapid control of their reactive power output, the SVCs regulate system voltages, improve transient stability, correct power factor, reduce temporary over voltages, and damp synchronous resonances. Usually, an SVC is composed of a Thyristor-Controlled Reactor (TCR) and Fixed Capacitors (FCs). The FCs is often tuned in series with inductors to act as Passive Power Filters (PPFs) in the characteristic harmonic frequencies of the TCR.

2. System of SVC and APF

2.1 Configuration of the system

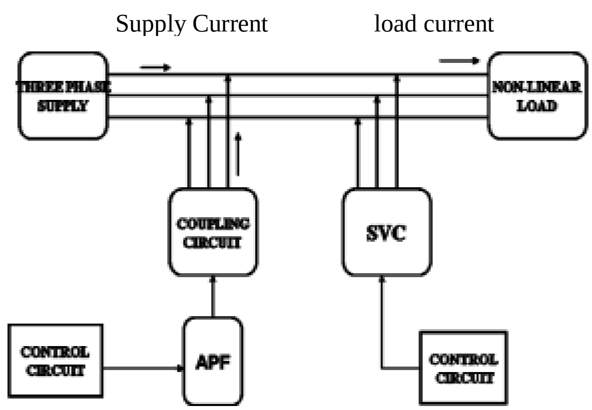

Fig.1. Configuration of the combined system

The combined system comprises a classical SVC and an active filter with a coupling circuit. The SVC consists of delta connected TCR and star connected FC. The conduction angle δ of the TCR depends on the firing angle α. The relationship between δ and α is:

$$\delta = 2(\pi - \alpha) \qquad (1)$$

The firing angle α can be controlled to take any value between 90^o and 180^o, corresponding to the value of δ between 180^o and 0^o. The coupling circuit consists of inductor (L_1) and capacitors (C_1, C_F) used for coupling the APF and the grid. L_1 and C_1 tuned at the fundamental frequency and then compose the coupling circuit with C_F. Moreover, its capacitor is in series with inductor to form single tune PPF. The APF in parallel with the fundamental resonance circuit is directly connected in series with a matching transformer. The coupling capacitor sustains fundamental sustains fundamental voltage of the grid, while APF only supports harmonic voltage, which greatly reduces the current requirements of APF and minimizes the voltage rating of semiconductor witching device. Because of these characteristics, the combined system is effective to suppress harmonics generated by both TCRs and nonlinear loads, to compensate reactive power dynamically, and to improve voltage stability.

3. Control method of SVC

The SVC mainly regulates system voltages and correct power factor. A non-linear PI controller is proposed to improve the dynamic response, decrease the overshoot of transient response and decrease the steady-state error of SVC. The K_p and K_I values of the non-linear PI controller is optimized using the Simplex algorithm.

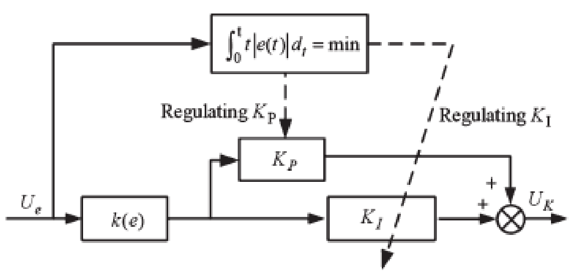

Fig.2. Control diagram of SVC

3.1 Non-linear function

The non-linear function of the PI controller is given by:

$$k(e) = 0.001 - \frac{2\exp(0.05e1)}{1+\exp(0.005e1)} \quad (2)$$

where,

$$e1 = \begin{cases} 0.105 + e, & |0.0105+e| \geq 0.2 \\ 0.2\sin(0.105 + e) & |0.0105+e| \leq 0.2 \end{cases}$$

For the value of the non-linear function k(e) that can reach infinity, which will bring on the response of SVC that has an over value, the SVC control system voltage will be oscillating.

3.2 Improved SPX Algorithm

The K_P and K_I values of the non-linear PI Controller are optimized by improved SPX algorithm. The SPX algorithm of Nelder and Mead is a heuristic optimization method based on geometric considerations. The geometric figure whose vertices are defined by a set of (n + 1) in an n-dimensional space is called a SPX. The basic idea in the SPX algorithm is to compare the values of the objective function at the (n + 1) vertices of a SPX, not to seek the optimum point in a direction. The algorithm discards the worst vertex, (i.e.), highest value for a minimization problem and a new vertex is chosen gradually toward the optimum point during the iterative process [6,7]. Moreover, it is adopted as the optimized objective function.

$$J = \int_0^t te(t)dt \quad (3)$$

Where the upper limit t is chosen as a finite time so that the integral can approach a steady-state value.

The convergence criterion of the SPX is presented as:

$$\left|\frac{J^{(max)} - J^{(min)}}{J^{(min)}}\right| < \epsilon \quad (4)$$

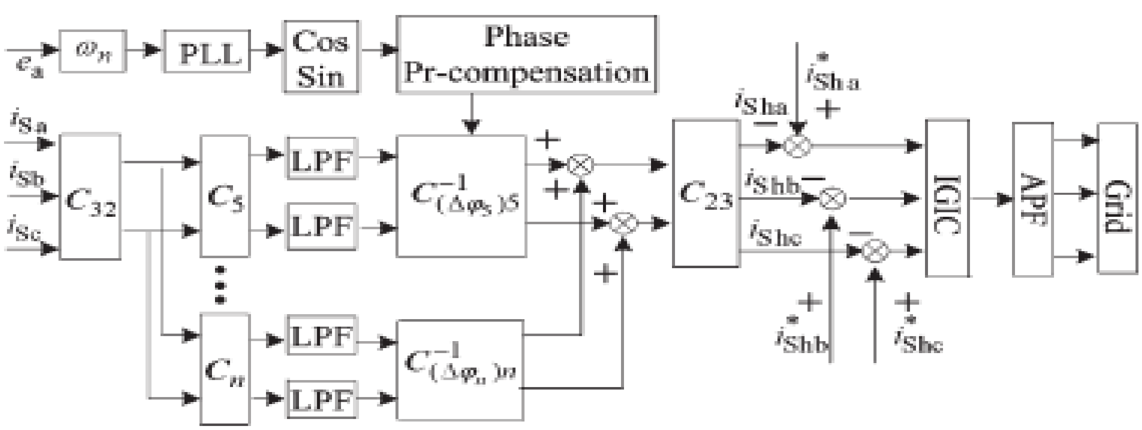

Fig. 3. Control block diagram of APF

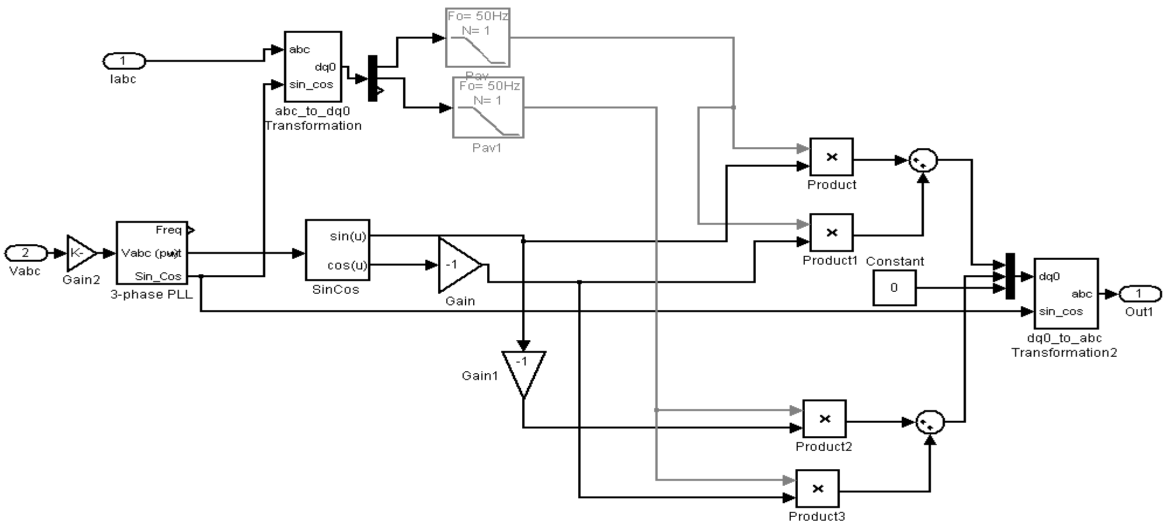

Fig. 4. Simulation diagram for reference current calculation

4. Control method of APF

The overall control circuit of the shunt active filter is shown in Fig.3. In this paper a new selective harmonic detection method is proposed. This can detect characteristic harmonics with precompensation of time delay. The selective harmonic detection method with Pre-compensation technique is implemented here. In the selective harmonic detection method, the frequency of harmonic is achieved by Phase Locked Loop (PLL), and the amplitude of that is achieved in the rotary coordinate.

4.1 Reference current calculation

The reference current can be calculated using dq transformation. To solve the problem of time delay completely, the inverse transform matrix C_n^{-1} has been modified with $\Delta\varphi_n$:

$$C^{-1}_{(\Delta\varphi_n)n} = \begin{bmatrix} \sin(n\omega t + \Delta\varphi_n) & -\cos(n\omega t + \Delta\varphi_n) \\ -\cos(n\omega t + \Delta\varphi_n) & -\sin(n\omega t + \Delta\varphi_n) \end{bmatrix} \qquad (5)$$

Where $\Delta\varphi_n$ is the electric angle of the n^{th} harmonic caused by time delay. The dc components i_{pn} and i_{qn} can be obtained though a low-pass filter. If the dc components i_{pn} and i_{qn} are calculated back to the abc-frame by the transform matrix $C^{-1}(\Delta\varphi_n)n$ and C_{32}, the n^{th} -order harmonic currents with pre-compensation can be obtained. After modification, the compensation current generated by APF will synchronize with the reference signal. The harmonic current compensation remainder rate will be small. If several order harmonics want to be detected at the same time, each order harmonic can be detected parallel. Then, the reference current can be obtained by adding them together. Then the harmonic current can be calculated by subtracting the reference current from the load current. The capacitor of the Shunt Active Filter can be maintained constant by using the PI controller. The simulation diagram for reference current calculation is shown in Fig.4.

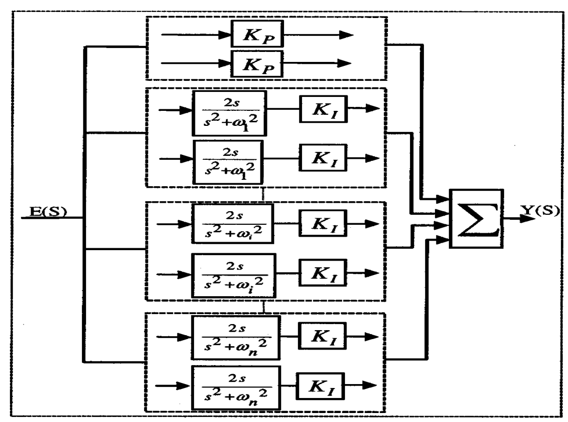

Fig.5. PI controller using the stationary-frame generalized integrators.

4.2 Improved Generalized Integrator Control

In this paper, an improved generalized integrator control (IGIC) was proposed to increase the performance of harmonic suppression [10].

IGIC is a PI controller used to eliminate error between the filter current and the harmonic current. It consists of several PI controllers. Each controller is tuned to reduce the particular harmonics. The structure of Improved Generalized Integrator Controller (IGIC) is shown in Fig.5.

5. Simulation Results

5.1 Parameters of the simulation system

The parameters for the simulation circuit are shown in Table 1.

Table1 System parameters

System parameters	R/ohm	L/mH	C/μF
System impedance	0.5	1	
Load	10.6	58.2	
Impedance SVC (TCR)		300	
Coupling circuit	0.1	20.71	478
(PPF)			160
Output filter	0.05	0.2	60

5.2 Simulation results without compensating device

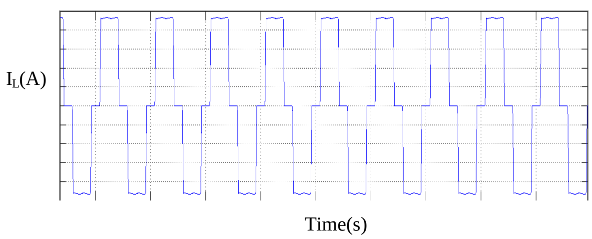

Fig. 6(a). Waveform for load current (before compensation)

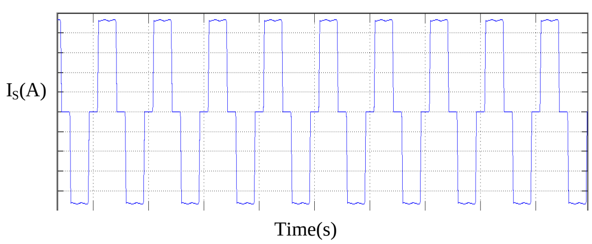

Fig.6(b).Waveform for supply current(before compensation)

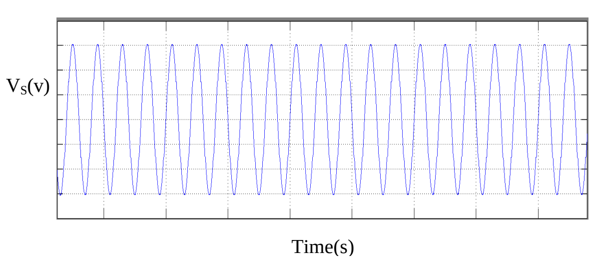

Fig.7(a).Waveform for supply voltage (before compensation)

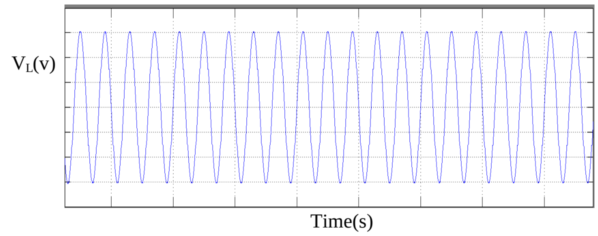

Fig.7(b). Waveforms for Supply voltage (before compensation)

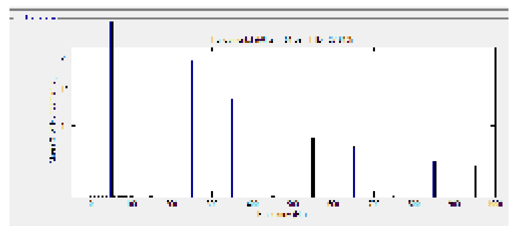

Fig.8 Spectrum analysis (before compensation)

The current and voltage waveforms (before compensation) are shown in Fig.6 and Fig.7. Due to non-linear load the supply and load currents contain harmonics so it becomes non-sinusoidal. The supply and load voltages are sinusoidal. The Total Harmonic Distortion of the supply current is 27.84%. The Total Harmonic Distortion analysis is shown in Fig.8.

5.3 Simulation results (after compensation)

The compensating current generated by the Shunt Active Power Filter is shown in Fig.9. The compensating current Suppress the harmonic current drawn from the supply side and make current sinusoidal.

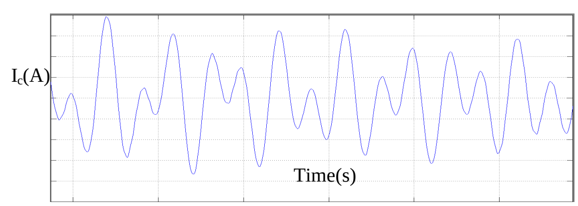

Fig.9 Compensating current produced by SAPF

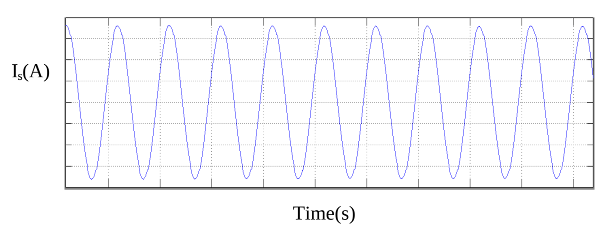

Fig.10(a) Waveforms for Supply current (after compensation)

After compensation the supply current become sinusoidal which can be shown in Fig.10(a). The supply and load voltages after compensation is shown in Fig.11(a) and Fig 11(b). After compensation the supply volage and load voltage are sinusoidal without any distortion.

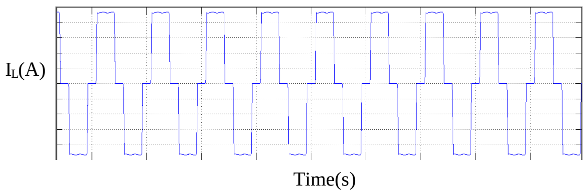

Fig.10(b) Waveforms for Load current (after compensation)

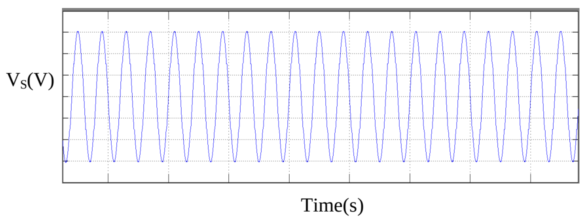

Fig.11(a) Waveforms for supply voltage (after compensation)

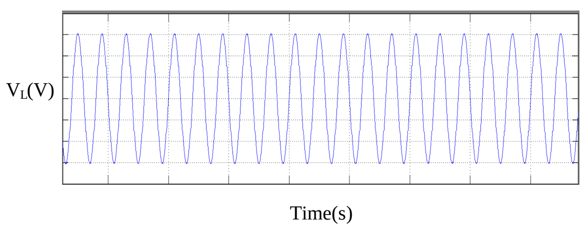

Fig. 11(b) Waveforms for load voltage (after compensation)

The FFT analysis of the load current after implementation of the combined system is shown in Fig.12. The Total harmonic distortion of the wave is 1.48%.

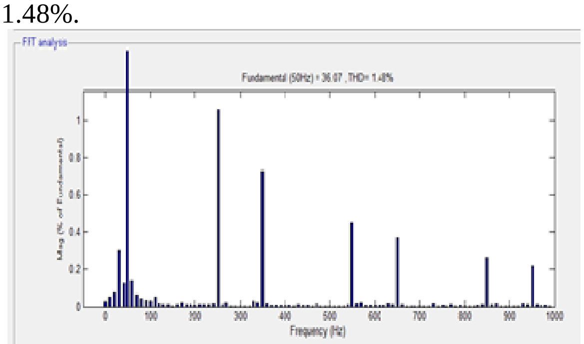

Fig.12. Spectrum analysis (after compensation)

The simulated values of the three phase system with and without any compensating devices are shown in Table 2.

Table 2 Comparison of results

System	Total Harmonic Distortion (%)	Power Factor
Without compensating devices	27.84	0.7961
With combined system of SVC and APF	1.46	0.9393

After compensation the Total Harmonic Distortion of the Supply current can be reduced to 1.48% from 27.84%. The power factor of the system without any compensating devices is 0.7961. SVC is the effective compensating devices. After implementation of the combined system the power factor can be improved to 0.9393.

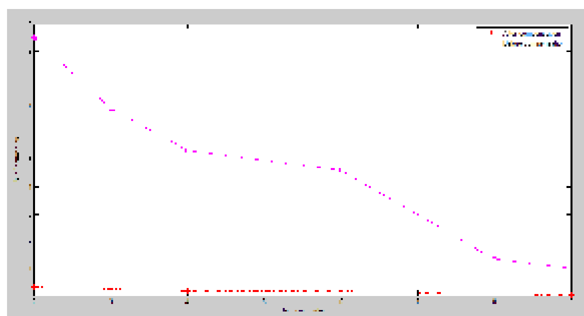

Fig. 13. Comparison of Harmonic order

The comparison of Harmonic orders for with and without any compensating devices is shown in Fig.13. From the chart we conclude that the percentage of harmonics of each order can be reduced after the implementation of the combined system. In the combined system the TCR is connected in delta connection so the third order Harmonics is zero. In this research work 5, 7, 9, 11 and 13 Order-harmonics are considered. The control methods implemented in this paper is more effective in the reduction of the harmonics.

6. Conclusion

In this research work, the combined system of a classical SVC and an APF has been tested and analyzed. The system have eliminated the harmonics generated by non-linear loads and there by improved the power factor in power system. The TCR in the SVC is star connected; hence the third order harmonics can be eliminated. Moreover the active power filter topology has been adopted to suppress the harmonics generated by TCR and reduce the resonance between the grid and PPF. Separate control circuits for SVC and APF has been implemented in this work. The performance of the active power filter can be improved by using the combined system. Also the harmonics can be reduced below 5% as per the IEEE standard.

References

[1]. C.K.Duffey and R.P.Stratford, "Update of Harmonic Standard IEEE-5 19: Recommended Practices and Requirements for Harmonic Control in Electric Power Supply Systems." IEEE Trans. IAS, pp. 1025-1034, Nov/Dec. 1989.

[2]. J.-C. Wu, H.-L. Jou, and Y.-T. Feng, “Novel circuit topology for three-phase active Power filter,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 444–449, Jan. 2007.

[3]. S Z. Shuai, A. Luo, R. Fan et al, “Injection branch design of injection type hybrid active power filter,” Autom. Elect. Power Syst., vol. 31, no. 5, pp. 57–60, Jun. 2007.

[4]. M. H. Abdel-Rahman, F. M. H. Youssef, and A. A. Saber, “New static var compensator control strategy and coordination with under-load tap changer,” IEEE Trans. Power Del., vol. 21, no. 3, pp. 1630–1635 Jul. 2006.

[5]. X. Yuan, W. Merk, H. Stemmler et al., Stationary-frame generalized integrators for current control of active power filters with zero steady-state error for current harmonics of concern under unbalanced and distorted operating conditions,” IEEE Trans. Ind. Appl., vol. 38, no. 2, pp. 523–532, Mar. /Apr. 2002.

[6]. Q . Tan,W. Li, L. Chang, and H. Huang, “A hybrid neuro-fuzzy system For robot control,” in Proc. IEEE Int. Conf. Intell. Syst. 21st Century, 1995, pp. 2916–2921.

[7]. Z. Chengyong, L. Xiangdong, and L. Guangkai, “Parameters Optimization of VSC-HVDC control system based on simplex algorithm,” in Proc. IEEE Power Eng. Soc. General Meeting, 2007, pp. 1–7.

[8]. C.K.Duffey and R.P.Stratford, "Update of Harmonic Standard IEEE-519: Recommended Practices and Requirements for Harmonic Control in Electric Power Supply Systems." IEEE Trans. IAS, pp. 1025-1034, Nov/Dec. 1989.

[9]. Hirofumi Akagi, Fellow, November/December 1996. “New trends in active filter for power conditioning”, IEEE Transaction on Industry Applications, Vol 32, no6.

[10]. K.-K. Shyu, M.-J. Yang, Y.-M. Chen, and Y.-F. Lin, “Model reference adaptive control design for a shunt active-power-filter system,” IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 97–106, Jan. 2008.

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