Mitigation of Harmonics by Shunt Active Power Filter

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Abstract- It is known from the fact that Harmonic Distortion is one of the main power quality problems frequently encountered by the utilities. The harmonic problems in the power supply are caused by the non-linear characteristic based loads. The presence of harmonics leads to transformer heating, electromagnetic interference and solid state device mal-functioning. Hence keeping in view of the above concern, research has been carried out to mitigate harmonics. This paper presents an analysis and control methods for active power filter using Space Vector Pulse Width Modulation (SVPWM) for Power conditioning in distribution systems. The reference current can be calculated by 'd-q' transformation. In SVPWM technique, the Active Power Filter (APF) reference voltage vector is generated instead of the reference current, and the desired APF output voltage is generated by SVPWM. The Total Harmonic Distortion (THD) will be mitigated significantly by SVPWM technique based Active power filters. Simulations are carried out for this approach by using MATLAB, it is observed that the %THD has been mitigated from 27.69% to 3.74% by the SVPWM technique.

Keywords – Active Power Filter (APF), Space Vector Pulse Width Modulation (SVPWM), Total Harmonic Distortion (THD), Voltage Source Inverter (VSI).

I. INTRODUCTION

Since the rapid development of the semiconductor industry, power electronics devices have gained popularity in our daily used electrical house-hold appliances. Although these power electronics devices have benefited the electrical and electronics industry, these devices are also the main source of power harmonics in the power system. These power harmonics are called electrical pollution which will degrade the quality of the power supply. As a result, filtering process for these harmonics is needed in order to improve the quality of the power supply. Thus, active power filter seems to be a viable alternative for power conditioning to control the harmonics level in the power system nowadays. Power system normally operates at 50 or 60 Hz. However, saturated devices such as transformers, arching loads such as florescent lamp and power electronic devices will produce current and voltage components with higher frequencies into the power line. These higher frequencies of current and voltage components are known as the power harmonics. The harmonics disturbances in the power supply are caused by the nonlinearity characteristic of the loads. Due to the advantages in efficiency and controllability of power electronic devices, their applications can be found in almost all power levels.

The ac power system harmonic problems are mainly due to the substantial increase of non-linear loads due to technological advances, such as the use of power electronics circuits and devices, in ac/dc transmission links, or loads in the control of power systems using power electronic or microprocessor controllers. Such equipment creates load-generated harmonics throughout the system.

Traditional solutions for these problems are power-factor-correction (PFC) techniques, passive filters due to their easy design, simple structure, low cost and high efficiency. These usually consist of a bank of tuned LC filters to suppress current harmonics generated by nonlinear loads.

Passive filters have many disadvantages, such as Resonance, Large size, fixed compensation character, possible overload. With the PFC approach, a PFC unit is usually in cascade in the energy pass, which processes all the power and corrects the current to unity power factor. Those kinds of approaches are usually suitable for low-power (less than 5kVA) applications

To overcome the disadvantages due to Passive Filters, Active Power Filters (APFs) [2] have been presented as a current-harmonic compensator for reducing the total harmonic distortion of the current and correcting the power factor of the input source. The Active Power Filter is connected in parallel with a nonlinear load. The approach is based on the principle of injecting harmonic current into the ac system, of the same amplitude and reverse phase to that of the load current harmonics. This will thus result in sinusoidal line currents and unity power factor in the input power system. In this case, only a small portion of the energy is processed, which may result in overall higher energy efficiency and higher power processing capability. These kinds of approaches are applicable for low-power (less than 5kVA) to high-power applications (around 100kVA).
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Numerous applications of SVPWM control were reported earlier in VSI fed induction motor drives [11]-[15]. In recent times, the SVPWM technique is also gaining importance in APF control [14]-[17]. However, the computational burden involved due to complex trigonometric calculations and sector identification limits the application of SVPWM technique for APF application. An improved SVPWM technique with "effective time concept" has been developed to overcome the above drawback in induction motor drive applications [13]. This effective time concept in the improved SVPWM technique is able to overcome the disadvantages of complex trigonometric calculations and sector identification and it finds a useful application in APF control.

II. PROPOSED HARMONIC MITIGATION APPROACH

Here introduced a promising solution based on one-cycle control. The control method eliminates the need of calculating the current reference as well as the use of multipliers and voltage sensors in the control loop. The control circuitry is simple and reliable. In pulse width-modulation (PWM) active power filter, all switches are triggered with switching frequency; therefore, the switching losses are relatively higher than that of the vector operated active power filters. In this project, a three-phase APF with six-switch bridge voltage-source converter with vector operation is presented. It is found that this voltage source converter can be decoupled into a parallel-connected dual-boost converter with two-quadrant operation. Three-phase unity power factor can be achieved by controlling the parallel-connected dual-boost converter using one-cycle control.

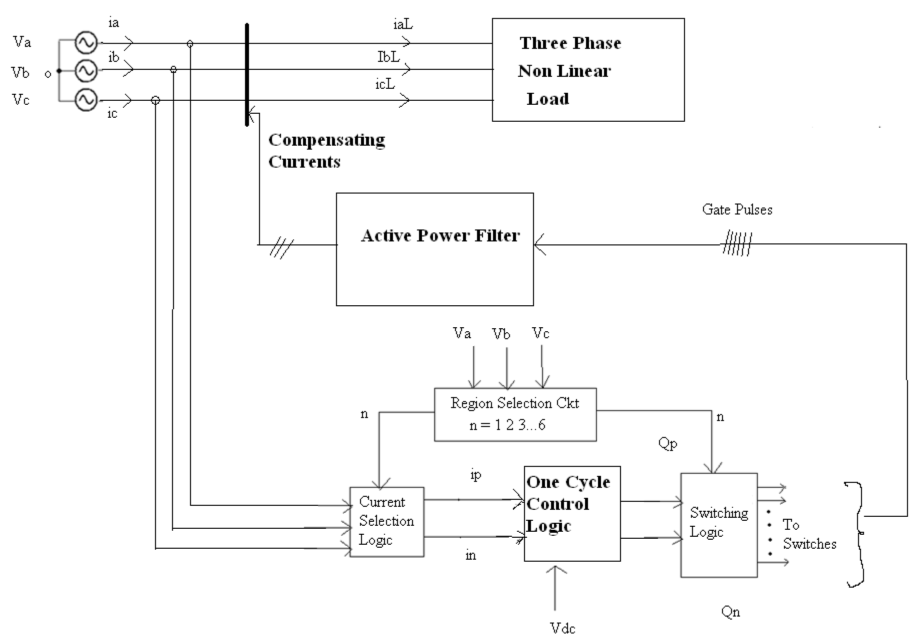


Fig.1 Block diagram of proposed active power filter

2.1 SHUNT ACTIVE POWER FILTER TOPOLOGY

The proposed topology for reactive power compensation and harmonic mitigation using Shunt Active Power Filter (SAPF) is shown in Fig. 1. The proposed scheme consists of Shunt Active Power Filter (SAPF) connected in parallel with a distribution system. Distribution system consists of a wide percentage of harmonic producing non linear loads. Shunt active power filters compensate current harmonics by injecting equal but opposite harmonic compensating current. 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^{o}. As a result, components of harmonic currents contained in the load current are cancelled by the effect of the active filter, and the source current remains sinusoidal and in phase with the respective phase-to-neutral voltage. This principle is applicable to any type of load considered as a harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non-linear load and the active power filter as an ideal resistor.

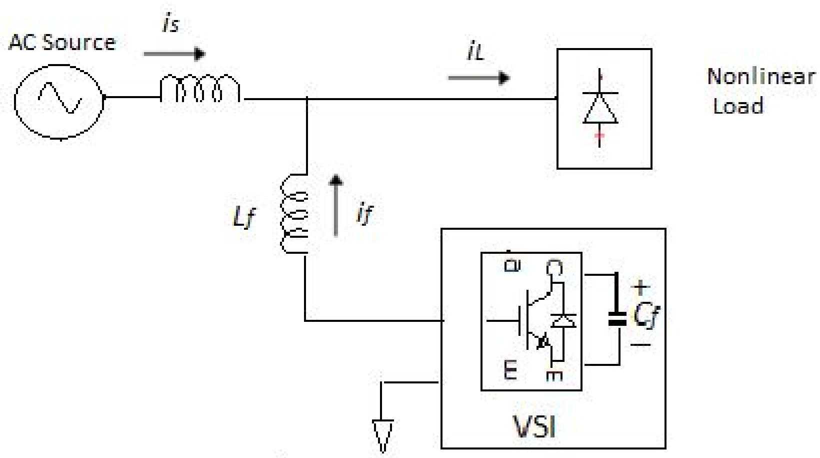


Fig.2 Principle configuration of VSI based Shunt APF

The compensation currents of the APF are given by

$$i_{fa} = i_{la} - i_{sa} \qquad (1)$$

$$i_{fb} = i_{lb} - i_{sb} \qquad (2)$$

$$i_{fc} = i_{lc} - i_{sc} \qquad (3)$$

The voltage-source PWM Inverter with a current controller should provide the ability of controlling the harmonic currents. The control circuit should extract the harmonic current from the nonlinear load, not only in steady states but also in transient states. As for three phase APFs, the instantaneous reactive power theory (IRPT) also called as p-q theory [1] or the synchronous reference frame (SRF) theory [6] are generally applied for estimation of the necessary compensation signals, and the PWM strategies for generation of gating signals. In the proposed shunt APF topology, SRF theory is used for harmonic current extraction and SVPWM technique is used to generate the switching signals. Furthermore, SVPWM does not require the triangle waveform generation circuit and is more suitable for realisation in digital control circuit

The source current $i_{s,abc}$ is forced to be free of harmonics by suitable voltages from the APF, and the harmonic current emitted from the load is then automatically compensated. The proposed APF is connected into the network through the inductor L_f. The function of L_f is to attenuate the high frequency switching ripple generated by APF and to connect two AC voltage sources of the inverter and the supply system.

2.2 SYNCHRONOUS REFERENCE FRAME THEORY FOR HARMONIC EXTRACTION

In this work SRF is used for harmonic current extraction [6], [23]-[25]. The block diagram of proposed shunt APF control scheme. In order to maintain sinusoidal source currents with unity power factor at PCC, the source has to supply only the fundamental real component of load current. Hence, the harmonics, reactive component of load current should be supplied from APF. Therefore, the load currents are sensed and transformed to *dq0* reference frame as follows

$$\begin{pmatrix} i_{lq} \\ i_{ld} \\ i_{l0} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix} \begin{pmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{pmatrix} \quad (4)$$

The harmonic currents for each of the three phases are derived by removing the fundamental frequency component from load currents. Thus, the reference currents normally consist of harmonic components drawn by the load. A low pass filter (LPF), with cut off frequency of 50Hz is used to extract i_{ld}. Here, i_{ld} corresponds to harmonic load currents in *a-b-c* frame. The loss component of VSI is $i_{dc,d}$ must be added to i_d in order to acquire complete d-axis reference filter current. As i_{lq}, i_{l0} currents must be supplied directly, LPFs are not required in *q-axis* and *0-axis* controller as shown in Figure.3. Therefore, the *dq0* reference harmonic currents are given by

$$i_d = \bar{i}_{ld} + i_{dc,d} \quad (5)$$

$$i_q = i_{lq} \quad (6)$$

$$i_0 = i_{l0} \quad (7)$$

The *dq0* transformation generates the following set of equations

$$V_{fd} = L_f \frac{di_{fd}}{dt} - \omega L_f i_{fq} + E_{sd} \quad (8)$$

$$V_{fq} = L_f \frac{di_{fd}}{dt} + \omega L_f i_{fd} + E_{sq} \quad (9)$$

$$V_{f0} = L_f \frac{di_{fd}}{dt} + E_{s0} \quad (10)$$

Where, V_{fd}, V_{fq}, V_{f0} are the variables to be controlled, in order to achieve the desired filter currents at PCC in *dq0* frame, ω is the system frequency and i_{fd}, i_{fq} and i_{f0} are the stationary frame reference currents. E_{sd}, E_{sq} and E_{s0} are the stationary frame reference voltages. Neglecting the zero sequence terms, the dynamics of the APF ac side variables in an SRF (*dq* frame) is derived. Since the *d* and *q* components are orthogonal. Hence V_{fd} and V_{fq} from Equation (8) are considered for SVPWM switching signals generation.

2.3 SVPWM ALGORITHM FOR APF

The voltage space vector synthesization is critical in the conventional SVPWM method. As it uses Clarke transformation to transform the reference voltages to *d-q* coordinates in order to generate reference vectors. Subsequently, the reference vectors are synthesised by some optimally selected basic vectors with specific time duration. In that method, the sectors of reference vectors are determined by their phase angles, and the time duration of basic vectors are calculated through the computation of phase angles and reference vectors. As these computations involve huge quantities of irrational numbers and trigonometric functions, the computation burden would be enormous. These operations may bring about major calculation errors which would corrupt the performance of shunt APF.

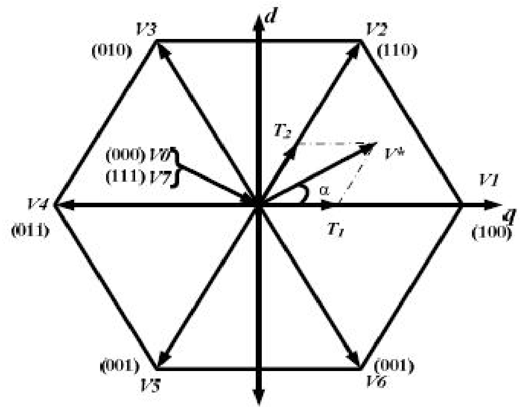


Fig.3 VSI switching states vectors

The APF reference voltages V_{sa}*,V_{sb}* *and* V_{sc}* for each phase are found from the stationary reference voltages.

$$\begin{pmatrix} V_{sa}^* \\ V_{sb}^* \\ V_{sc}^* \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} V_{fq} \\ V_{fd} \end{pmatrix} \quad (11)$$

In order to obtain the actual switching time directly from the APF phase voltages, the stationary reference frame voltages are utilized and effective times are transformed to the phase voltages

$$\begin{aligned} T_1 &= \frac{\sqrt{3}.T_s}{V_{dc}}\left[\frac{\sqrt{3}}{2}.V_{fq} + \frac{1}{2}.V_{fd}\right] \\ &= \frac{T_s}{V_{dc}}\left[V_{fq} + \frac{1}{2}.V_{fq} + \frac{\sqrt{3}}{2}.V_{fd}\right] \\ &= \frac{T_s}{V_{dc}} V_{sa}^* - \frac{T_s}{V_{dc}} V_{sb}^* = T_{sa} - T_{sb} \end{aligned} \quad (12)$$

$$\begin{aligned} T_2 &= \frac{\sqrt{3}.T_s}{V_{dc}}\left[0.V_{fq} + 1.V_{fd}\right] \\ &= \left[\frac{T_s}{V_{dc}}\left[-\frac{1}{2}.V_{fq} - \frac{\sqrt{3}}{2}.V_{fd}\right] - \left[-\frac{1}{2}.V_{fq} - \frac{\sqrt{3}}{2}.V_{fd}\right]\right] \\ &= \frac{T_s}{V_{dc}} V_{sb}^* - \frac{T_s}{V_{dc}} V_{sc}^* = T_{sb} - T_{sc} \end{aligned} \quad (13)$$

From the above equations the effective times *T1, T2* can be calculated by the time difference between the times *Tsa, Tsb* and *Tsc* matching to the phase voltages. Furthermore in the remaining sectors case, the effective times can be substituted with the phase voltage times in the same method described above. This result, demonstrates that the effective time calculated in the conventional SVPWM is the difference between two applied times resultant to the phase voltage. Hence, despite of the sector location of the reference vector, the resultant times for each phase voltages are defined as following.

$$T_{sa} = \frac{T_s}{V_{dc}}.V_{sa}^* \quad (14)$$

$$T_{sb} = \frac{T_s}{V_{dc}}.V_{sb}^* \quad (15)$$

$$T_{sc} = \frac{T_s}{V_{dc}}.V_{sc}^* \quad (16)$$

The effective time *Teff* will be defined as the time duration between *Tmax* and *Tmin,* and the effective voltage is supplied to the VSI during this time interval. Therefore, the actual switching times for each VSI arm can be obtained as follows.

$$T_{ga} = T_{sa} + T_{offset} \qquad (17)$$

$$T_{gb} = T_{sb} + T_{offset} \qquad (18)$$

$$T_{gc} = T_{sc} + T_{offset} \qquad (19)$$

To allocate the zero voltage symmetrically during one sampling period, the offset time T_{offset} is calculated as follows.

$$T_{eff} = T_{max} - T_{min}$$

$$T_0 = T_s - T_{eff} \qquad (20)$$

and, *Tmin+Toffset=T0/2* Therefore *Toffset = T0/2-Tmin* Thus, the actual switching times can be obtained from above equations.By using the effective time concept, the actual switching times can be directly computed from the stationary reference frame voltages. Therefore, the computation effort of the proposed PWM method is greatly reduced. With this PWM method the Harmonic compensation signals are generated at PCC using VSI.

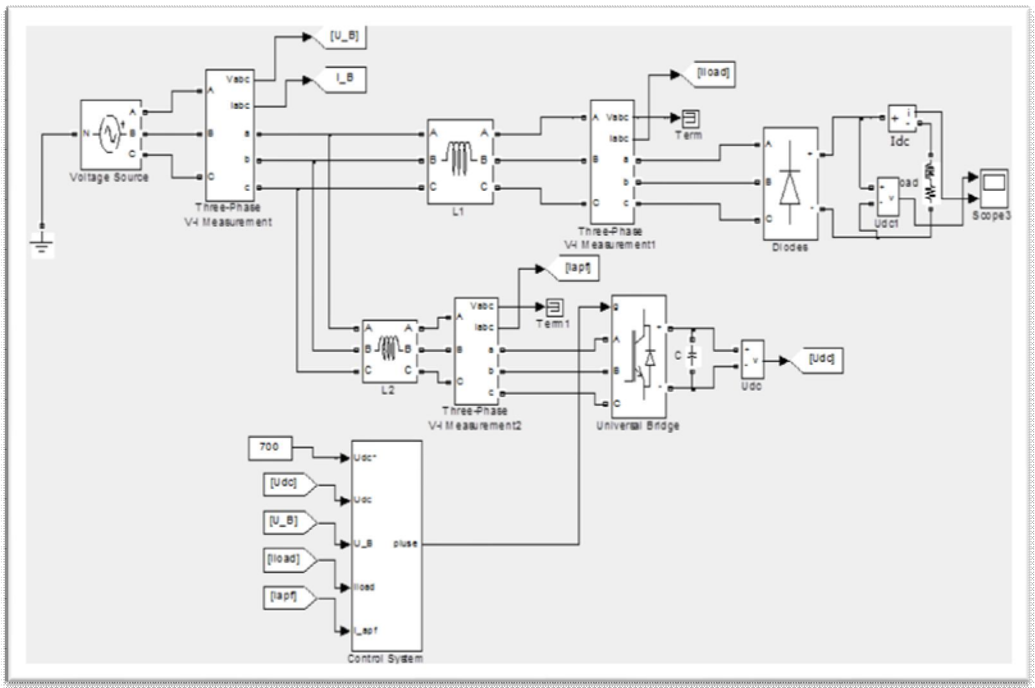
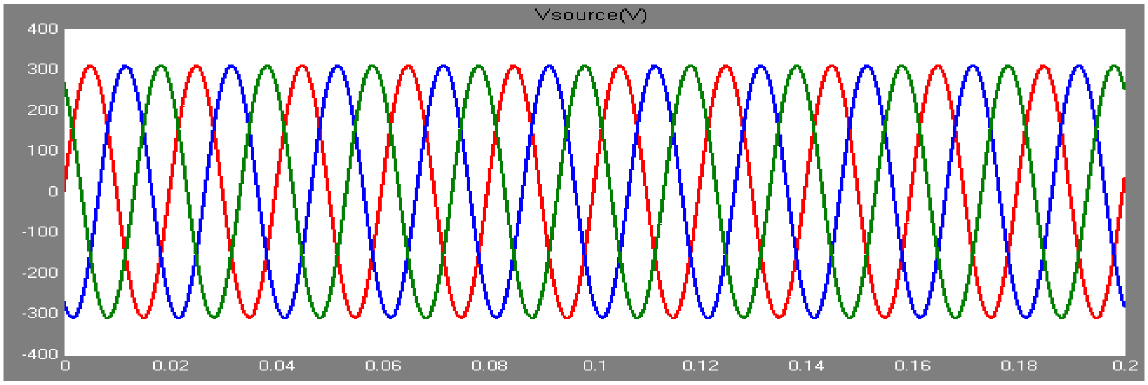
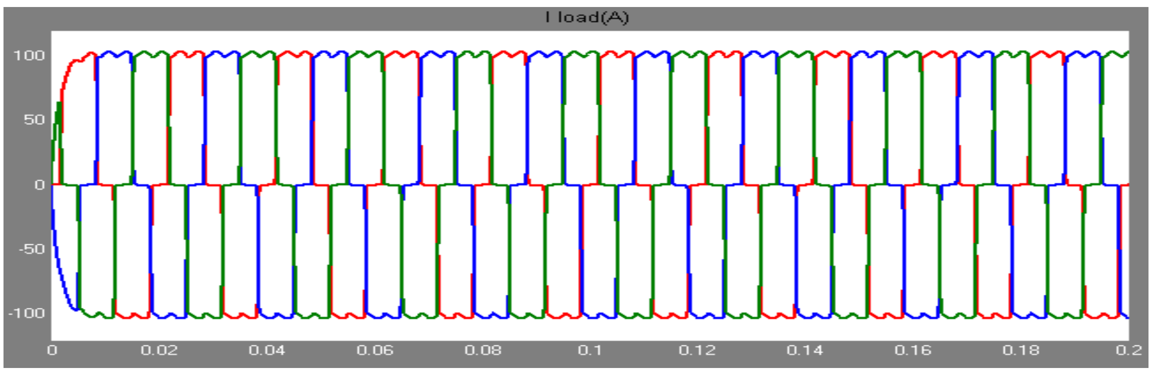


Fig.4. SIMULINK model

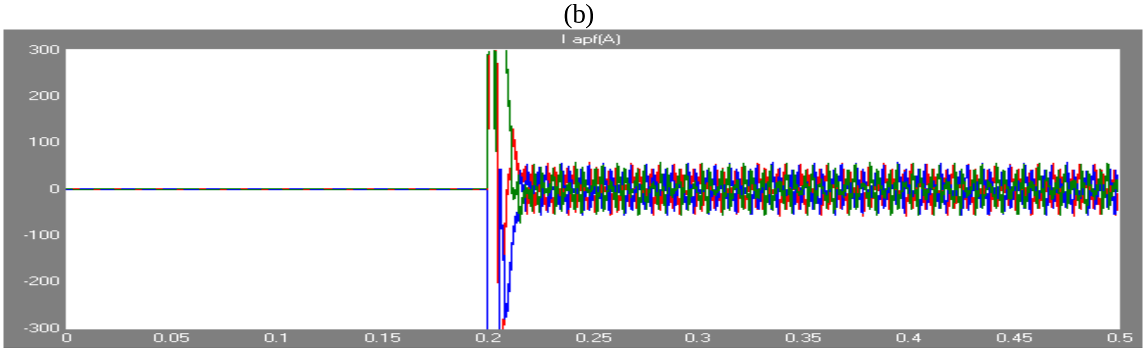
III. Simulation Results



(a)



(b)



(c)

Fig.5. Simulation results (a) Source voltages (b) Load currents (c) Filter currents (APF)

IV.CONCLUSION

In this paper, A SVPWM based shunt APF is proposed, which is suitable for digital control realization This method requires less computation when compared to the conventional SVPWM technique as it eliminates the complex trigonometric calculation and sector identification, The performance of shunt APF with this proposed SVPWM method for harmonic compensation is examined and proved to be worthy where the THD of the source currents was reduced from 27.21% to 3.47% and the response time for harmonic compensation is 0.2 sec.

Table.1. THD comparison

Without shunt APF(%THD)	**With shunt APF(%THD)**
27.21%	3.47%

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