ANALYSIS OF ACTIVE POWER FILTER FOR HARMONIC VOLTAGE RESONANCE SUPPRESSION IN DISTRIBUTION SYSTEM

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ABSTRACT

The analysis of active power filter for harmonic voltage resonance suppression in distribution system has been presented in this paper. Traditional active power filter (APF) can prevent harmonic current from injecting into the power system, but cannot damp harmonic propagation in distribution system whereas voltage detection can do. This paper proposes a compound control method of APF based on detection of load current and the Harmonic voltage at the point of installation. In addition, based on the relationship between the rated volt-ampere of APF and the load volt-ampere, the conductance value could automatic adjustment. The objective of the shunt active filter is not only to compensate the harmonic but also to damp the harmonic. When the rated volt-ampere is a limit, the harmonic compensation is prior considered. The MATLAB/Simulation results are presented to validity and effectiveness of the shunt active filter equipped with the compound control.

Keywords :

Active power filter,
Harmonic voltage,
Distribution Generation,
Compound control.

I. INTRODUCTION

A number of electronic-based appliances such as diode thyristor rectifiers and industrial electric power source generate a large amount of harmonic current in power systems [1]. What is more, harmonic propagation resulting from harmonic resonance between line inductors and shunt capacitors for power factor correction made the harmonic voltage has become a serious problem. Regularly, shunt active filter is installed near high capacity nonlinear load to prevent harmonic current from injecting into power system [2,3]. But this proposal has two problems: the first is that this proposal is only suited to high capacity nonlinear load when there are many loads which produce a negligible amount of harmonic current, this proposal is not applicable; Secondly, load current detection APF cannot damp voltage harmonic in distribution system [4]. Akagi proposed a shunt active power filter based on detection of harmonic voltage in the paper, the APF can damp voltage harmonic.

Taking advantage that the voltage detection can dump harmonic can cover the shortage of load current detection; this paper proposes a compound control method based on detection of load current and harmonic voltage. In addition, based on the relationship between the rated volt-ampere of APF and the volt-ampere needed to compensate the nonlinear load, the conductance value could auto adjustment, compared with the fixed gain, the auto gain adjusting with the variation of volt-ampere has a clear advantage [5]. The objective of the APF is not only to compensate the harmonic but also to damp the harmonic. When the rated volt-ampere is limit the harmonic compensation is prior considered.

This paper proposes and validates a compound control method of APF based on detection of load current and the harmonic voltage at the point of installation. In addition, based on the relationship between the rated volt-ampere of APF and the load volt-ampere, the conductance value could automatic adjustment. The objective of the shunt active filter is not only to compensate the harmonic but also to damp the harmonic. The simulation results are presented in the following sections.

II. ACTIVE POWER FILTERS

Active Filters are commonly used for providing harmonic compensation to a system by controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power or voltage control at high voltage distribution level [6]. These functions may be combined in a single circuit to achieve the various functions mentioned above or in separate active filters which can attack each aspect individually. The block diagram presented in section shows the basic sequence of operation for the active filter. This diagram shows various sections of the filter each responding to its own classification.

The block diagram is shown in Fig. 1 represents the key components of a typical active power filter along with their interconnections. The reference signal estimator monitors the harmonic current from the nonlinear load along with information about other system variables. The reference signal from the current estimator, as well as other signals, drives the overall system controller [7]. This, in turn, provides the control for the PWM switching pattern generator. The output of the PWM pattern generator controls the power circuit through a suitable interface. The power circuit in the generalized block diagram can be connected in parallel, series or parallel/series configurations, depending on the transformer used.

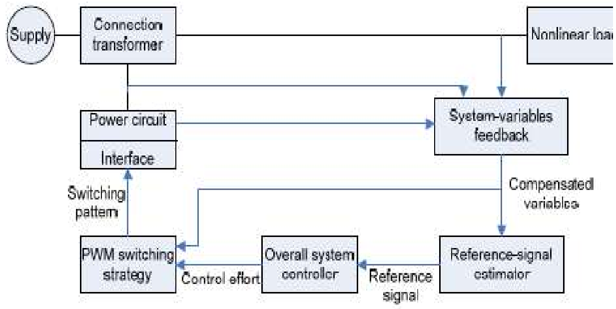


Fig. 1 Block diagram of Active power filter

III. DISTRIBUTION SYSTEM

Electrical power is transmitted by high voltage transmission lines from sending end substation to receiving end substation. At the receiving end substation, the voltage is stepped down to a lower value (say 66kV or 33kV or 11kV). The secondary transmission system transfers power from this receiving end substation to secondary substation [8,9]. A secondary substation consists of two or more power transformers together with voltage regulating equipment, buses, and switchgear. At the secondary substation, voltage is stepped down to 11kV. The portion of the power network between a secondary substation and consumers is known as a distribution system. The distribution system can be classified into the primary and secondary system. Some large consumers are given high voltage supply from the receiving end substations or secondary substation [10].

The area served by a secondary substation can be subdivided into a number of sub- areas. Each sub-area has its primary and secondary distribution system. The primary distribution system consists of main feeders and laterals. The main feeder runs from the low voltage bus of the secondary substation and acts as the main source of supply to sub- feeders, laterals or directly connected distribution transformers. The lateral is supplied by the main feeder and extends through the load area with connection to distribution transformers. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures or may be pole mounted.

The distribution transformers for a large multi-storied building may be located within the building itself. At the distribution transformer, the voltage is stepped down to 400V and power is fed into the secondary distribution systems. The secondary 14 distribution system consists of distributors which are laid along the roadsides. The service connections to consumers are tapped off from the distributors. The main feeders, laterals, and distributors may consist of overhead lines or cables or both. The distributors are 3- phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads. Most of the residential and commercial consumers are given single phase supply. Some large residential and commercial consumer uses a3-phase power supply. The service connections of the consumer are known as service mains.

IV.THE PRINCIPLE OF COMPOUND CONTROL

Fig.2 shows the principle of compound control, each harmonic voltage amplifying by a gain G add to the load current amplifying by a gain K_2 produces each current reference in Eq.(1).

$$i_c^* = -GV_{Th} + K_2 i_{Lh} \qquad \text{..........................(1)}$$

Assume the rated volt-ampere of APF is APF W, the volt-ampere needed to compensate the nonlinear load is LOAD W, the volt-ampere needed to damp harmonic voltage in power system is COM W, G is the equivalent harmonic conductance, K_2 is the compensation coefficient of load current detection. In reality practice, there are three conditions [11]

$$W_{APF} \geq W_{LOAD} + W_{COM}; W_{LOAD} \prec W_{APF} \prec W_{LOAD} + W_{COM}; W_{APF} \prec W_{LOAD} \quad \ldots\ldots\ldots\ldots(2)$$

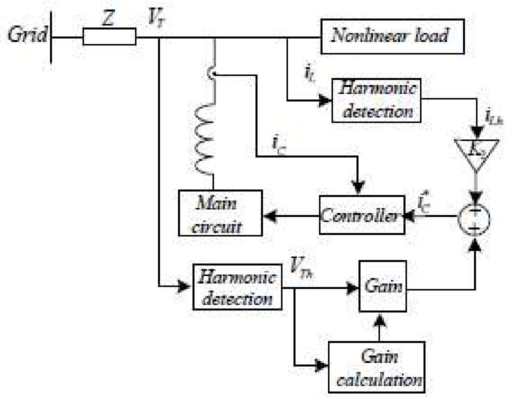


Fig.2 Principles diagram of compound control

Fig.3 shows the principle of auto gain adjustment under constrained volt-ampere with compound control V_{dh} and V_{qh} is the ac components of three phase voltages under the synchronization reference frame [12]. The square of harmonic voltage V_h^2 is calculated in Eq.(3), and the typical value V_h^{*2} is defined in Eq.(4), if V_h^2 is more than V_h^{*2} , the counter counts up to Get a bigger G in the auto gain adjustment block, adjust G to a stable value until V_h^2 is lower than V_h^{*2}.

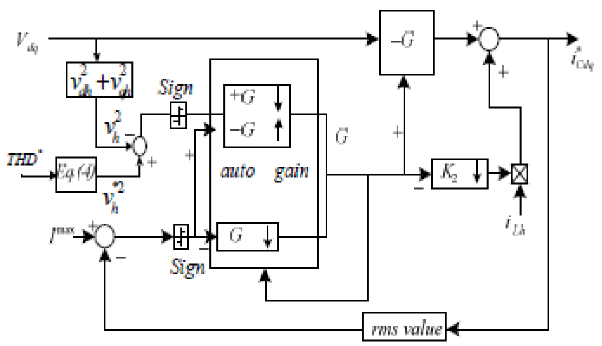


Fig.3 auto gain adjustment under constrained volt-ampere

$$v_h^2 = v_{dh}^2 + v_{qh}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$v_h^{*2} = 3.\left(V_s.THD^*\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

In order to promise the volt-ampere of APF operates underrated volt-ampere, it's necessary to limit G less than a certain value. The volt-ampere of APF relies on the RMS value of voltage in the installation bus and the RMS value of compensation current, as in Eq. (5).

$$D^h = 3VI = 3V\sqrt{I_5^2 + I_7^2 + \ldots + I_n^2} \ldots\ldots\ldots(5)$$

There are two feasible methods to limit the volt-ampere of APF underrated volt-ampere. The first is a cut-off method; the second is a scaling-down method. The former is simple but it will draw into new harmonic, we use the latter here. In Fig.3, a current limitation outer loop is added into current reference calculation block. Compared the RMS value of current limitation I^{max} with the compensation current I_c^* , if I_c^* is less thanI^{max}, G adjusts normally, otherwise, decrease G until I_c^* is less than I^{max}

$W_{APF} \geq W_{LOAD} + W_{COM}$. In this condition, I_c^* is less thanI^{max}, the current limitation outer loop does not work, G adjusts normally.

$W_{LOAD} \prec W_{APF} \prec W_{LOAD} + W_{COM}$, The current reference scaling-down under the rated volt-ampere can be achieved by reducing G, as shown in Fig.3, the current limitation outer loop work. In this condition, decrease G to a certain value until I_c^* is less than I^{max}.

$W_{APF} \prec W_{LOAD}$, Decrease G to zero and keep G zero, and then, decrease K_2 from 1 to a certain value until the APF is working on rated volt-ampere, the APF cannot keep the THD at the installation bus within a specified range, there are parts of nonlinear load current injecting into the distribution system.

V. SIMULATION RESULTS AND DISCUSSION

In order to analyze the performance of the active power filter for harmonic voltage resonance suppression in the distribution system, a simple distribution network as shown in Fig.4 is implemented. There are different analyses conditions like with active power filter and without active power filter and compound current conditions are considered and designed using MATLAB/SIMULINK software for validation of the proposed control strategies as shown in the output voltage waveforms are shown in Fig. 5 to Fig. 7 with different load conditions.

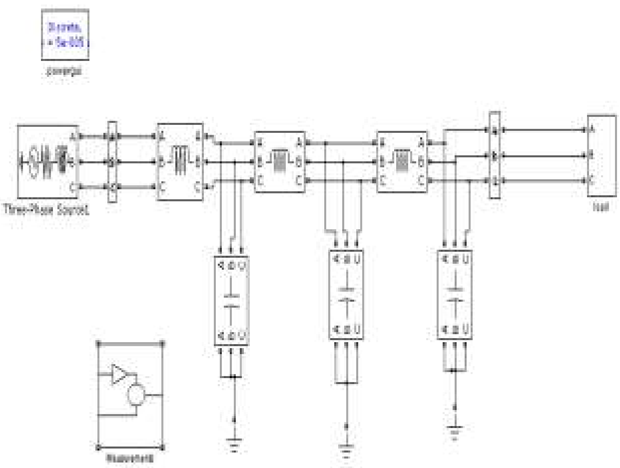


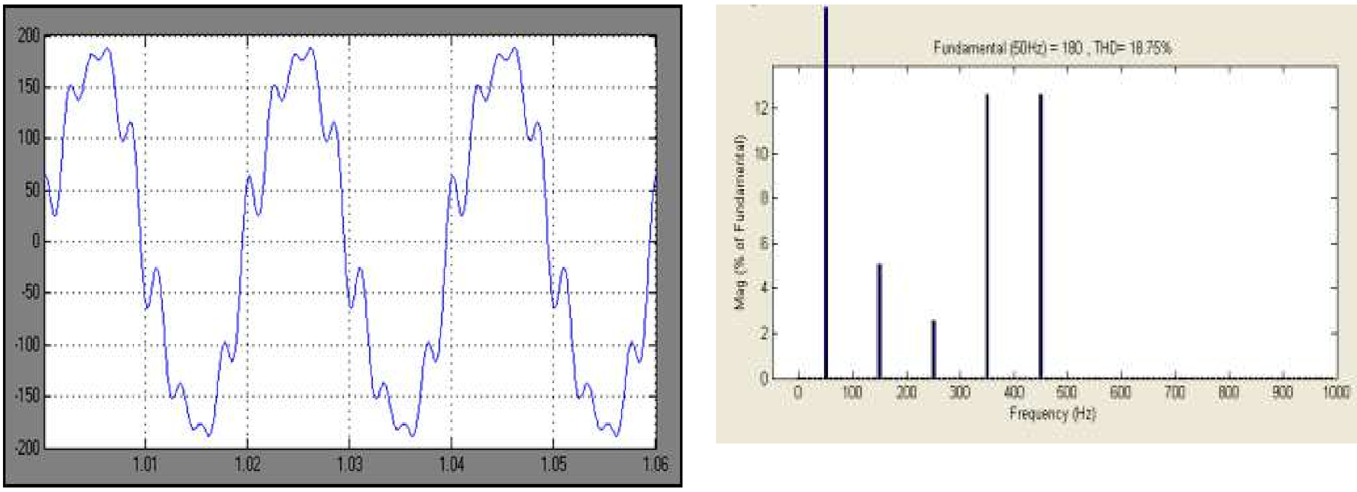
Fig. 4 MATLAB/Simulink Model of proposed system

Fig.4 depicts the simulation diagram, U_s is pure grid voltage, a seventh harmonic current source of 1.4A (1.4%) is connected downstream of bus 2, a nonlinear load is installed on bus 3. The most serious harmonic propagation occurs around 350Hz. The parameters in the simulation are given as follows:

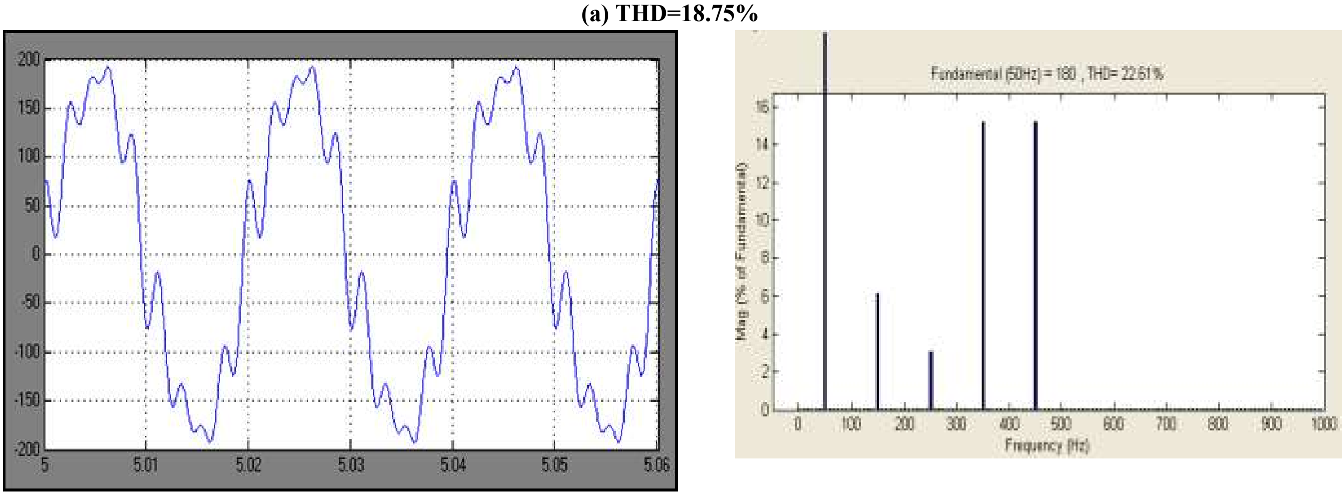
Grid voltage is 220V (line-to-line), 50Hz. The transmission line parameters are L=0.33mH, C=150uF; a diode rectifier with filter (2mH) inductor and a load resistor (10Ω) is installed on bus 3; APF is installed on bus 3, the AC inductor is 0.4mH, DC capacitor is 400uF, switch frequency is 10 kHz.

A. Simulation results without APF

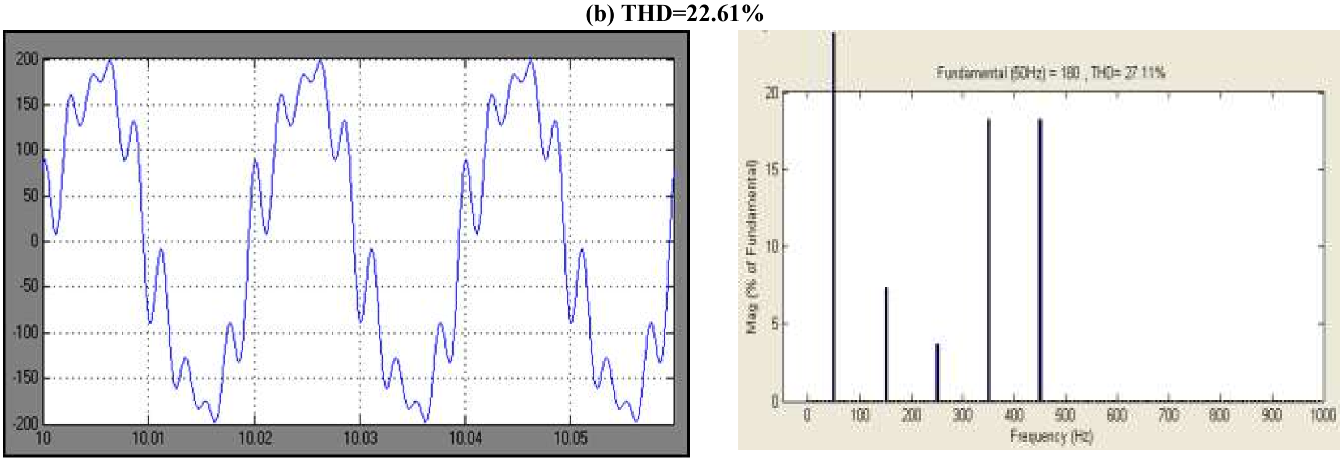
Fig.5 shows the voltage waveform on bus 3 without high capacity nonlinear load, the volt-ampere of nonlinear increases over time.



(a) THD=18.75%



(b) THD=22.61%

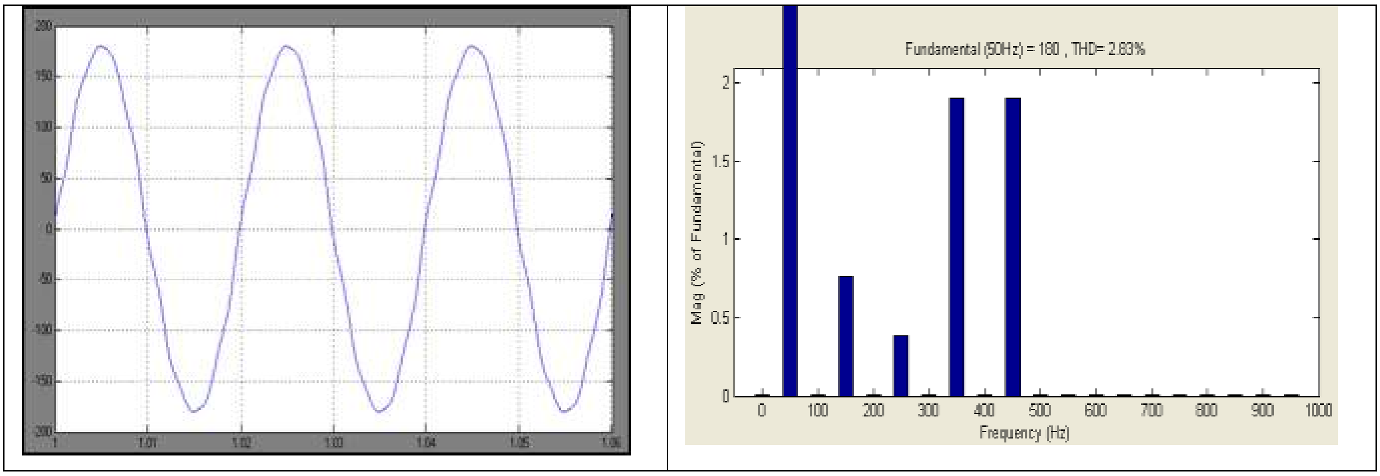


(c) THD= 27.11%

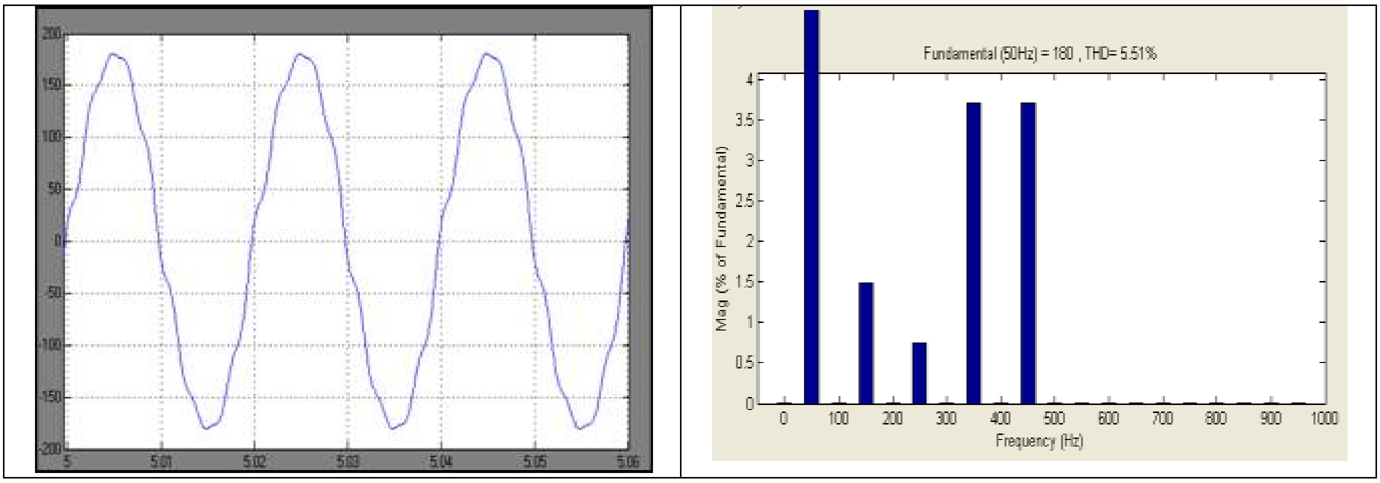
Fig. 5 (a,b,c) Voltage waveform on bus 3 with high capacity nonlinear load

Fig.5 shows voltage waveforms on bus 3 with high capacity nonlinear load, the nonlinear load injects lots of harmonic current into the distribution system, moreover, the harmonic voltage will resonant around 350 Hz, the voltage THD are 18.78%, 22.65%,and 27.15%respectively.

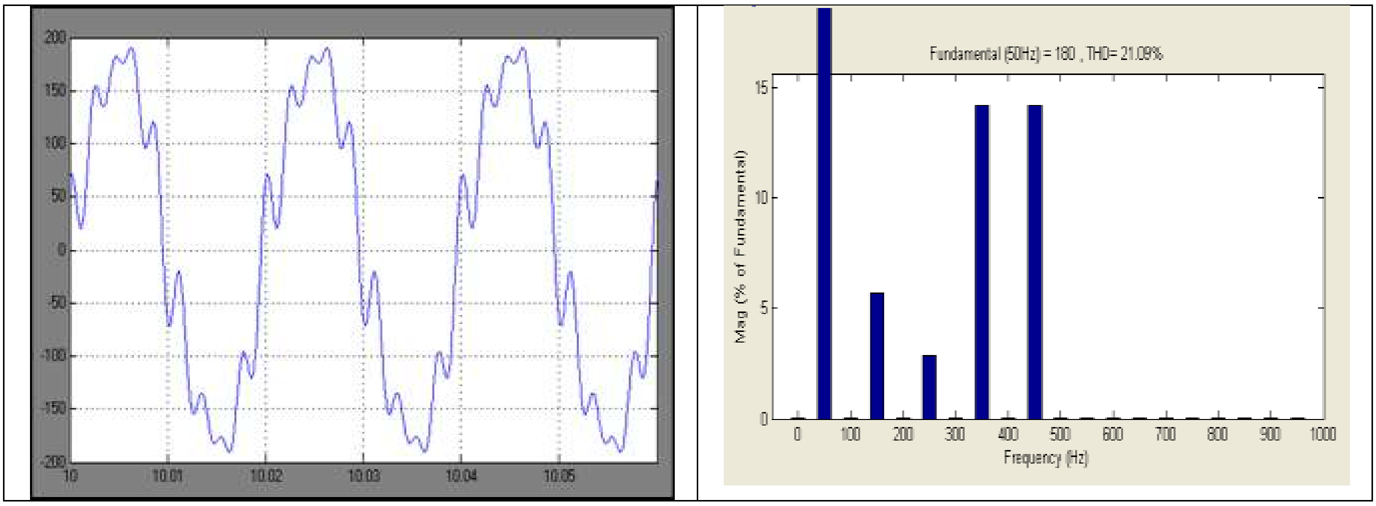
B. Simulation results with APF



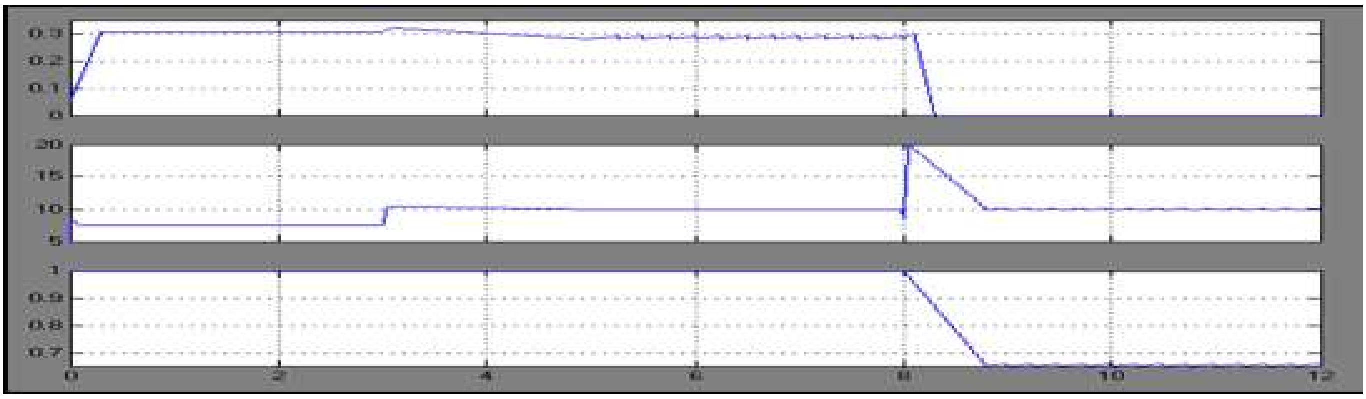
(a) THD= 2.83%



(b) THD= 5.51%



(c) THD = 21.09%



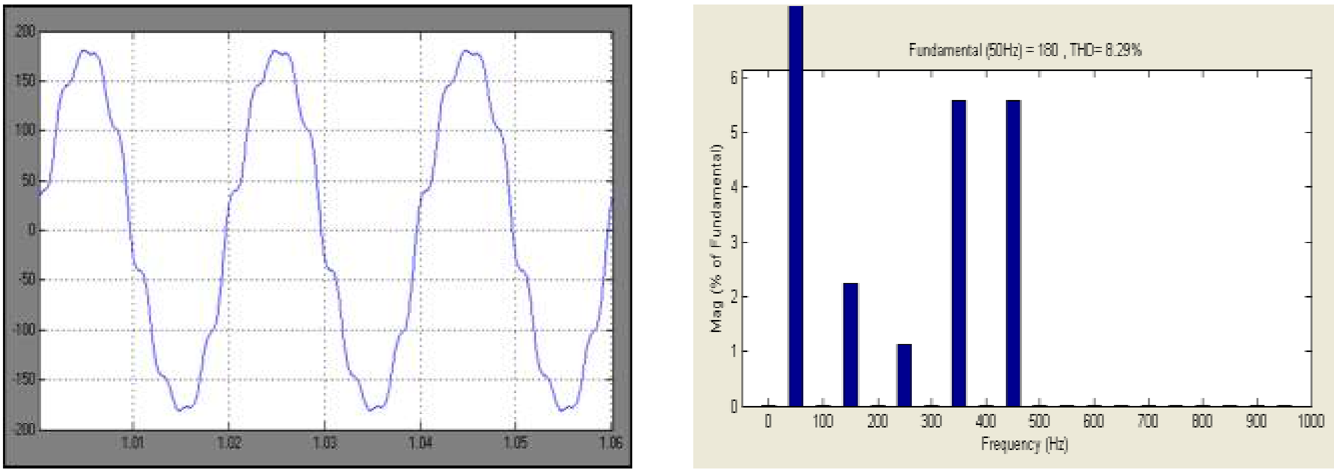
(d)

Fig. 6 (a,b,c and d) Output waveforms of Auto gain adjustment, current limit and value of K_2 of APF

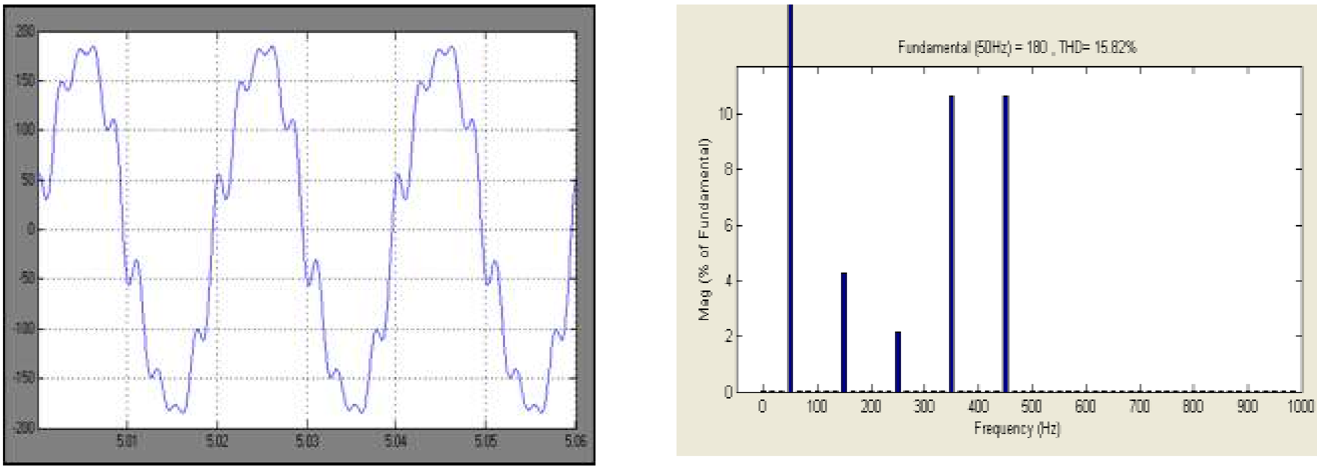
C. APF traditional

Fig. 7 shows voltage waveform on bus 3 with compound control, the volt-ampere of nonlinear increases over time,the subgraph (a), (b), (c) show voltage wave forms corresponding to the conditions are

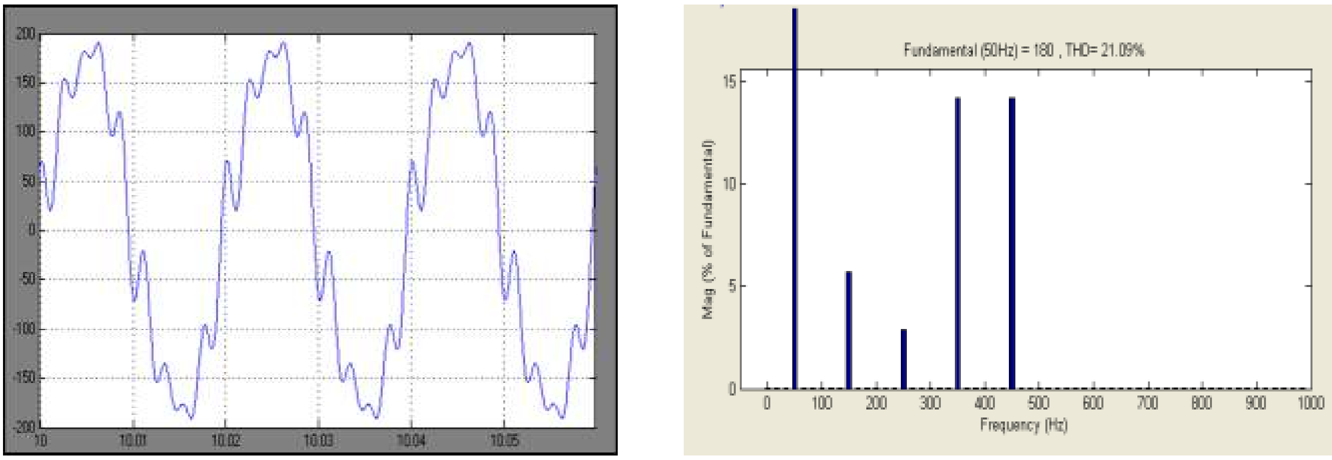
$$W_{APF} \geq W_{LOAD} + W_{COM} ; W_{LOAD} \prec W_{APF} \prec W_{LOAD} + W_{COM} ; W_{APF} \prec W_{LOAD}$$



(a) THD = 8.29%



(b) THD =15.82%



(c) THD = 21.09%

Fig. 7 (a,b and c)Voltage waveforms on bus 3 with traditional load current detection

VI. CONCLUSION

This paper proposes a compound control method of APF based on detection of load current and voltage to solve the problem that load current detection APF cannot change the harmonic impedance in the distribution system. In addition, based on the relationship between the rated volt-ampere of APF and the load volt-ampere, the conductance value could automatic adjustment. Computer simulation and laboratory system are designed and constructed to verify the validity and effectiveness of the shunt active filter equipped with the compound control. The results obtained from the computer simulation and laboratory system, along with theoretical results, are summarized as follows: The shunt active filter with compound control not only can compensate the nonlinear load harmonic current but also can help to damp the harmonic voltage in the distribution system. Compared with the fixed gain control which cannot change with the volt-ampere variation of nonlinear load the gain adjusting with the variation of volt-ampere has a clear advantage.

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