

Investigation of Power Quality Enhancement Using Current Compensator (PAF) With Different Loads

L. Queentin Valanarasi¹ and Prof. Arulselvi²

¹UG Student, Department of Electrical and Electronics Engineering, IFET College of Engineering, Villupuram, Tamilnadu, India.

²Faculty, Department of Electrical and Electronics Engineering, IFET College of Engineering, Villupuram, Tamilnadu, India.

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ABSTRACT

Application of non-linear electrical devices has produced distortion in the output sine waveforms of source current and voltage. It may lead equipment (connected to it) to overheat and sometimes cause damage. This paper concentrates on the design and application of three-phase active power filter (APF) by using the control strategies namely, unit vector template (UVT) method and reactive power (IRP) theory. UVT method is used to obtain the voltage signal for the control system at the time of source voltage distortion. The phase locked loop (PLL) is used to check the detected correct source voltage phase angle. Reference current for the APF will be obtained from this voltage signal. To obtain result for this project, the MATLAB/Simulink was used as a simulation tool.

Keywords: Non-linear electrical devices, UVT method and MATLAB/Simulink.

1. INTRODUCTION

Now a days the increasing usage of power electronic devices and the nonlinear loads have resulted in current harmonic generation in the power system and leads to voltage waveform distortion at the point of common coupling (PCC). This will result in the line current distortion, malfunctioning of sensitive electronic equipment, over heating of winding equipment and increased loss of electric energy. By using the Fourier analysis as a periodical oscillation at different frequency [1]-[2], we can analyze the waveform distortion. The IEEE Standard 519 and IEC 61000-3-2 Standard gives the tolerable voltage and current harmonic distortion level at the point of common coupling [3],[4]. The perseverance of these standard are given a advice of the harmonic distortion limits to entire electrical distribution system, from service to consumer so the system can function appropriately and voltage total harmonic distortion (THD) that allowed at the PCC is 5%. Filters are used to overcome the power quality problems. There are different filter topologies are present to overcome these problems. At first passive filters are used but they are reliant on heavily to the system parameters. They are suitable for filtering out the particular frequency harmonics, also have the problems of resonance with system impedance [5],[6]. Therefore, to overcome the problems of passive filters, active filters are used.

2. BASIC COMPENSATION PRINCIPLE

Shunt active power filters compensate load 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°. A voltage source inverter (VSI) is used as the shunt active power filter. This is controlled so as to draw or supply a compensating current from or to the utility, such that it cancels current harmonics on the AC side this active power filter (APF) generates the nonlinearities opposite to the load nonlinearities. Fig 1 shows the different waveforms i.e. the load current, desired source current and the compensating current injected by the shunt active power filter which contains all the harmonics, to make the source current purely sinusoidal. This is the basic principle of shunt active power filter to eliminate the current harmonics and to compensate the reactive power.

3. CONTROL STRATEGY

The control strategy used in this APF design is UVT method and IRP theory. For the unbalanced and stiff voltage conditions, IRP theory based controller used to the APF. It is satisfactorily performed by this controller [8],[9]. But in this IRP theory not suitable for the load produces high level of neutral harmonic current that causes voltage waveform distortion and unbalanced condition in the power system. By combining with UVT method will able to drive an accurate compensation signal in this load condition. So the UVT method is added with IRP theory control system to improve the working of APF. It functions to drive a proper PCC voltage that will be used to determine the reference current for the APF [10]-[11].

3.1 Unit Vector Template Method

In this method, the input voltage $V_{a,b,c}$ are sensed by the three phase line voltage. This input voltage will multiply by the gain (K), which is equal to $1/V_m$. The $1/V_m$ value is equal to the

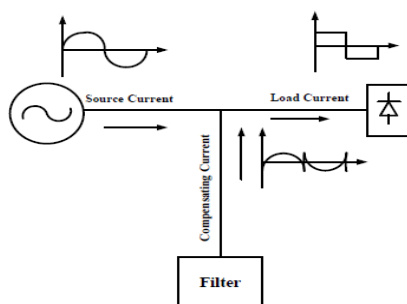


Fig.1. Basic principle

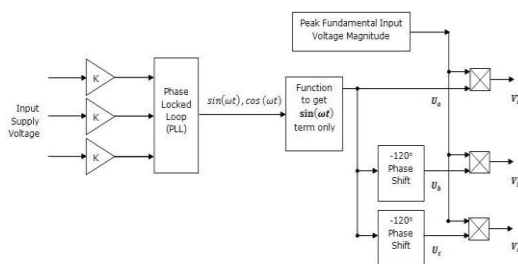
peak amplitude of fundamental input voltage, so the amplitude of this unit input is unity when given to PLL. The function of PLL is to generate a stable output signal whose phase is related to the input signal. The output of PLL contains synchronizing signals $\sin(\omega t)$ and $\cos(\omega t)$. In this control system, the only $\sin(\omega t)$ signal is used for generating the unit vector signals. Equation (1), (2) and (3) show the setting for phase abc delay with the unit vector templates. These unit vectors are the pure sinusoidal signal with amplitude as unity [12], [13].

$$U_a = \sin(\omega t) \quad (1)$$

$$U_b = \sin(\omega t - 120^\circ) \quad (2)$$

$$U_c = \sin(\omega t + 120^\circ) \quad (3)$$

Multiplying the peak amplitude of fundamental input voltage magnitude with unit templates from Equation (1), (2) and (3) will give the stable voltage signals $V_{a,b,c}^*$ of as shown in Equation (4). These $V_{a,b,c}^*$ voltage signal will send to Clarke's Transformation together with the sensed three-phase load currents to determine reference current for the APF.



Figs.2 and 3. Unit vector template method circuit

$$V_{a,b,c}^* = V^* U_{a,b,c} \quad (4)$$

3.2 Determination of Reference Current of APF

If the systems voltages are given as:

$$V_a = \sum_{n=1}^{\infty} V_{an} \sin\{n(\omega t) - \phi_{an}\} \quad (5)$$

$$V_b = \sum_{n=1}^{\infty} V_{bn} \sin\{n(\omega t) - 120^\circ - \phi_{bn}\} \quad (6)$$

$$V_c = \sum_{n=1}^{\infty} V_{cn} \sin\{n(\omega t) - 240^\circ - \phi_{cn}\} \quad (7)$$

Then the system voltages after applying UVT method are given as:

$$V_a^* = V_m \sin(\omega t) \quad (8)$$

$$V_b^* = V_m \sin(\omega t - 120^\circ) \quad (9)$$

$$V_c^* = V_m \sin(\omega t - 240^\circ) \quad (10)$$

If the nonlinear load currents are given as:

$$I_{La} = \sum_{n=1}^{\infty} I_{La} \sin\{n(\omega t) - \theta_{an}\} \quad (11)$$

$$I_{Lb} = \sum_{n=1}^{\infty} I_{Lb} \sin\{n(\omega t - 120^\circ) - \theta_{bn}\} \quad (12)$$

$$I_{Lc} = \sum_{n=1}^{\infty} I_{Lc} \sin\{n(\omega t - 240^\circ) - \theta_{cn}\} \quad (13)$$

If i_{Ln} is the load neutral current then,

$$I_{La} + I_{Lb} + I_{Lc} - I_{Ln} = 0 \quad (14)$$

$$I_{La} + I_{Lb} + I_{Lc} = I_{Ln} \quad (15)$$

3.3 Instantaneous Reactive Power Theory

In 1983, Akagi [14] proposed the generalized theory of the instantaneous reactive power in ac networks. It is also known as instantaneous reactive power theory, or p-q theory. This theory is valid for three phase three wire, three phase four wire as well as single phase networks. The first step in p-q theory is an algebraic transformation of the three-phase voltages and currents from a-b-c coordinates to the α - β -0 coordinates. Clarke's transformation is used to complete this task. The a, b, and c axes are fixed on the same plane. They are placed 120° apart from each other. α and β axes are placed 90° apart from each other. Three phase voltages and currents are represented as space vectors [15] and these space vectors are transformed into α - β coordinates as follows:

$$\begin{bmatrix} v_o \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a^* \\ v_b^* \\ v_c^* \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (17)$$

The IRP theory will consider the three-phase system as a unit. The transformation of three-phase voltage and current from Equation (16) and (17) will use to calculate the instantaneous zero sequence power (p_0), real (p) and instantaneous reactive power (q) as given as in Equation (18).

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_o & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (18)$$

Thus, the $\alpha\beta$ current references of the compensator for harmonic elimination, reactive power compensation are given as follows.

These compensation currents can be transformed in abc quantities to find the reference APF currents in abc coordinate system with the Equation (20).

$$\begin{bmatrix} i_{Ca}^* \\ i_{Cb}^* \\ i_{Cc}^* \end{bmatrix} = \sqrt{2/3} \begin{pmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} -i_o \\ i_{Ca} \\ i_{Cb} \end{pmatrix} \quad (20)$$

The compensating current for the neutral is given as,

$$\dot{i}_{Cn}^* = -\dot{i}_{Ln} \quad (21)$$

$$i_{Cn}^* = -(i_{La} + i_{Lb} + i_{Lc}) \quad (22)$$

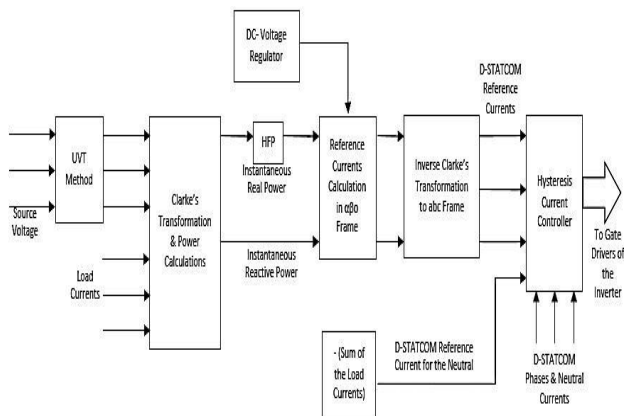


Fig.4. Reference current Generator for three phase 4 wire circuit

The block diagram of the controller is shown in Fig. 4.2 These compensating currents calculate from Equation (19) are compared with actual APF currents from Equation (20), for generating the proper firing signals for the inverter. The flying capacitor multilevel inverter (FCMLI) is used in this APF. The phase shifted multicarrier pulse width modulation (PSPWM) technique is used for generating switching signals for given pulse for the inverter.

The hysteresis current controller is used to controls the switches of the inverter to follows the reference current [16], [17]. Therefore, the switching operation of the power semiconductors automatically depends to the reference compensating currents.

4. DESIGN OF APF

4.1 Design of APF in the Proposed System

The power rating of three-phase inverter selected is 40 kVA. The kVA rating of the three-phase inverter switches is calculated based on the product of the peak harmonic load current and the peak voltage (equal to the DC bus voltage).

The design of APF involves the selection of the DC bus voltage, DC bus capacitor, and coupling inductor.

The value of the dc bus voltage, dc V depends on the peak utility voltage and instantaneous energy available to the APF [17], [18]. For the proper operation of APF, the DC bus voltage is selected by using Equation (23).

$$V_{dc}=2\sqrt{2}/\sqrt{3}m \quad (23)$$

Where m is the amplitude modulation index (normally equal to 1), V is the value for a utility voltage (source voltage, 415 V). The calculated dc V value is 677 V and 700 V is selected because the dc V value must be equal or higher than the calculated value. The value of DC bus capacitor (dc C) of Voltage Source Converter (VSC) of APF can determine through the principle of energy conservation by using Equation (24).

$$1/2C_{dc}=[V_{dc}^2-V_{dc1}^2]=3\text{volts} \quad (24)$$

Where $dc\ V$ is the reference DC bus voltage and $dc1\ V$ is the minimum voltage level of DC bus, a is the overloading factor, V is the phase voltage, I is the phase current, and t is the time by which the DC bus voltage is to be recovered [18], [19]. The selection of the coupling inductance (fL) of APF depends on the current ripple $i_{cr,p-p}$, switching frequency (sf) of the inverter, DC bus voltage ($dc\ V$), and therefore it is given as,

$$L_f = \sqrt{3}mV_{dc}/12f_s i_{cr,p-p} \quad (25)$$

Where m is the amplitude modulation index and a is the overload factor. If hysteresis controller is used, the design of AC coupling inductor is not required.

4.2 Supply Parameters

Source voltage: 220v, three phase

Source inductance: 0.5mH

Source resistance: 0.02 ohm

Line frequency: 50Hz

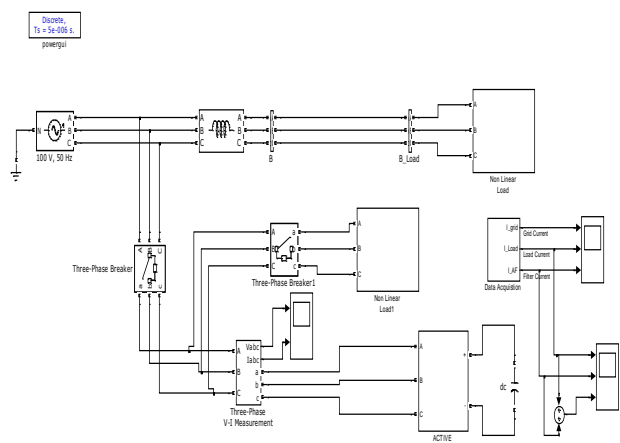


Fig.5. Simulation Model of APF

5. SIMULATION RESULTS

The three-phase breaker is setting to closing on 0.05s. When the three-phase breaker is close, the APF will inject the compensating current to the PCC.

5.1 Output

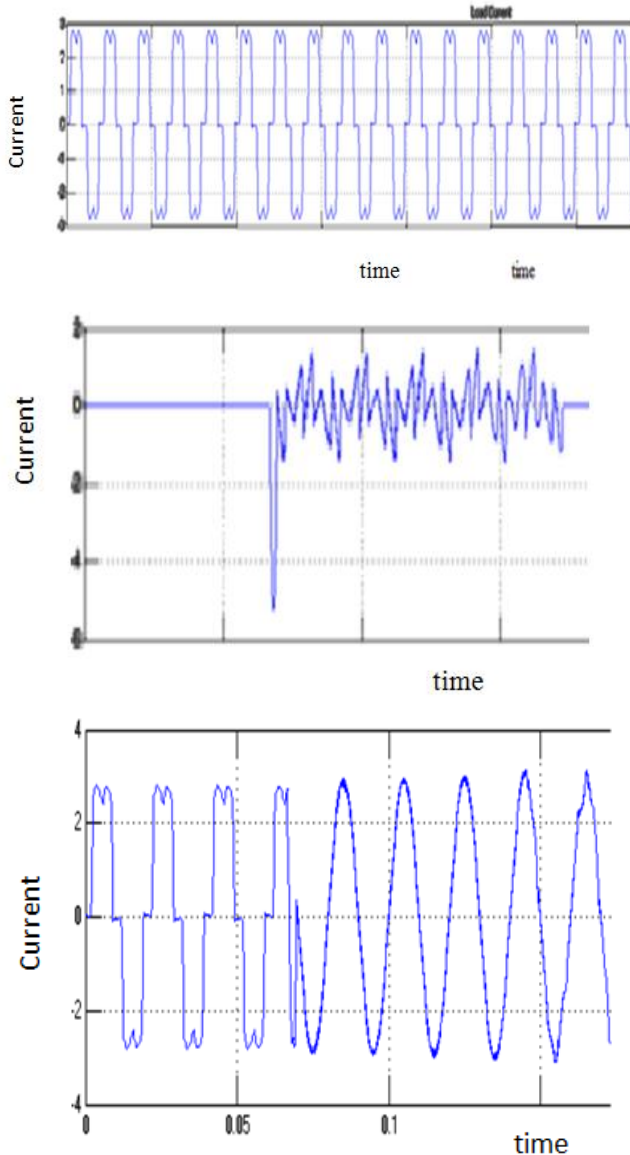


Fig.6. Output of the APF

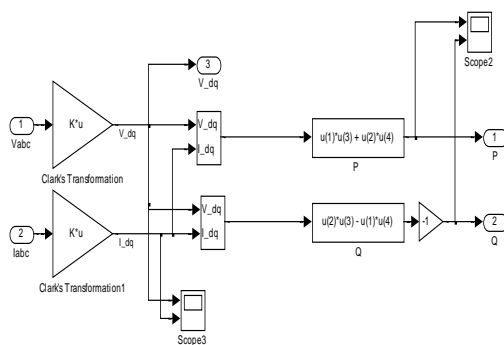


Fig 6.5 IRP Simulink module

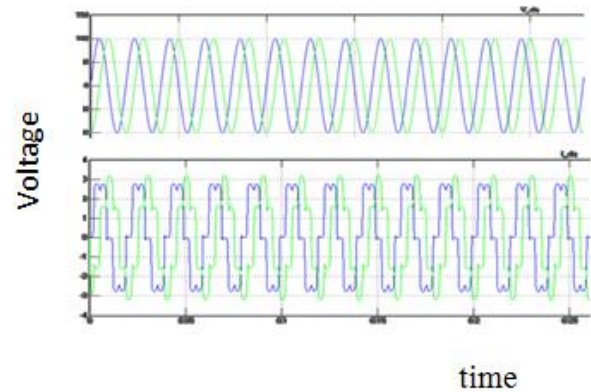


Fig.7. IRP output

6. CONCLUSION

The designed simulation model of shunt APF based on IRP theory and UVT method is presented. Subsequently, the supply current is almost pure sinusoidal .by using the UVT method in this system, system produces improved output. Using hysteresis control mode in the control system also provides better switching for compensating the neutral current. So here unbalanced load problem also cleared. Moreover, from the transient condition performance prove that the compensation ability of designed shunt APF in steady state and dynamic condition. Therefore, append on the simulation result, further analysis can carry out by constructing a prototype.

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