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Harmonic Reduction For Non-Linear Loads Using Stationary Reference Frame Theory

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ABSTRACT: Prominent harmonics in IT offices are essentially due to the presence of SMPS in computers large numbers. In a three-phase, four-wire system, current harmonics leads to flow zero sequence current in neutral conductor, increased losses in motors, false tripping of circuit breakers. In this paper, VSI is designed as a compensator based instantaneous reactive power theory. And is used to mitigate the current harmonic caused by 6 pulse diode rectifier is mitigated. Simulation is done with MATlab software and results are verified.

Keywords:non-linear load; current harmonics; instantaneous reactive power theory; sinusoidal current.

1 Introduction

Harmonics in the electrical distribution system are the by-products of modern electronics. They are especially prevalent where there are large numbers of personal computers, printers, copiers, medical test equipment, fluorescent lighting and adjustable speed drives. Harmonics do no useful work; they degrade the level of power quality and efficiency in a commercial building or industrial facility Custom power devices are in use to overcome these power quality problems [1], [2]. Active power filter is one of the custom power devices, used for supplying reactive, harmonic currents of load demand. In recent years active power filters have undergone lot of modification and development to compensate current unbalance and also used to suppress harmonic generated by static power converters. Thus, VSI makes the source currents balanced and sinusoidal with almost UPF operation, as it supplies only the fundamental real power to load. Active power filter consists of voltage source inverter (VSI), and is connected in parallel to load at the point of common coupling (PCC) through filter. Pulse Width Modulating signals are used to control VSI to inject required compensating currents. Various switching control strategies like hysteresis current control, sine pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) are available for control of VSI in active power filter application [3]-[5]. Synchronous rotating current controller for grid connected VSI in distributed power generation application presented in [6].]. Proper current controller is required to generate modulating signals. In this instantaneous reactive power theory based controller is designed to generate PWM signals to Active Power Filter. APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APF performances are independent of the power distribution system properties [7]. On the other hand, APFs have some drawbacks. APF necessitates fast switching of high currents in the power circuit resulting high frequency noise that may cause an electromagnetic interference (EMI) in the power distribution systems [8]. Akagi, H., [9] proposed the classification of active filters based on their objectives, system configuration, power circuits and control strategy. APF can be mainly connected in three circuit configurations, namely shunt APF, series APF and hybrid APF. This is the most important configuration widely used in active filtering applications for current harmonic reduction and power factor improvement. A shunt APF consists of a controllable voltage or current source inverter. The voltage source inverter (VSI) based shunt APF is the most commonly used type, due to its well-known topology and straight forward installation procedure. SAPF acts as harmonic current source which injects an anti-phase but equal magnitude of the harmonic and reactive current as that of nonlinear load. As a result components of harmonic currents contained in the load current are cancelled and the source current remains sinusoidal and in phase with the respective phase to neutral voltage. APF consists of a three leg six- Switch Bridge connected at the point of common coupling (PCC) through an interfacing inductor and with capacitor connected on DC-side. A three phase diode bridge rectifier with an inductive load on DC side is assumed as nonlinear load. This is achieved by “shaping” the compensation current waveform, using the VSI switches. The shape of compensation current is obtained by measuring the load current and subtracting it from a sinusoidal reference.

2 Current Harmonics

Current harmonic (I_h) is defined as the presence of fundamental current component (I_1)and its integer multiple components (I_n).

$$I_h = I_1 + I_3 + I_5 \dots\dots\dots\dots . I_n \qquad (1)$$

Where, 'I_n'is the magnitude of n^{th} harmonic component. The presences of even harmonics are get cancel due to positive and negative cycles in the ac system.A measure of harmonic content in a signal is the total harmonic distortion (THD). In IEEE specification, total harmonic distortion expresses the total harmonic current as a percentage of the total fundamental components. Thus total harmonic distortion can be given as,

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} {I_n}^2}}{I_1} \qquad (2)$$

2.1 Non-linear Loads

IT facilities are having number of computers as high as five hundred numbers or more than that. In such facilities SMPS used in computers plays important role for deciding harmonic contents. SMPS uses AC-DC converter. When electronic equipment turns AC to DC, it draws current in pulses. These pulses cause distorted current wave shapes that is rich in harmonics. Harmonic order (HO) can be calculated as given in equation (3),

$$\mathrm{HO} = \mathrm{nP} \pm 1 \qquad (3)$$

Where, ‘n’ is the integer and ‘P’ is the pulse number or number of switching devices. For example, in 6 pulse diode rectifier, harmonic order can be calculated as,

$$\mathrm{HO} = 1 \times 6 \pm 1 = 5^{\mathrm{th}} \text{ or } 7^{\mathrm{th}} \quad \text{harmonics}$$

It is known that depends upon the number of switches in the converter, harmonic content will vary. Higher order harmonics can be easily eliminated using passive filters. Lower order harmonics can be eliminated using active filters. Presence harmonic leads to poor power factor, increased skin effect and other various problems in power system. In Fig 1, harmonic current due to 6 pulse diode rectifier is shown. Also, its THD is shown in Fig 2.

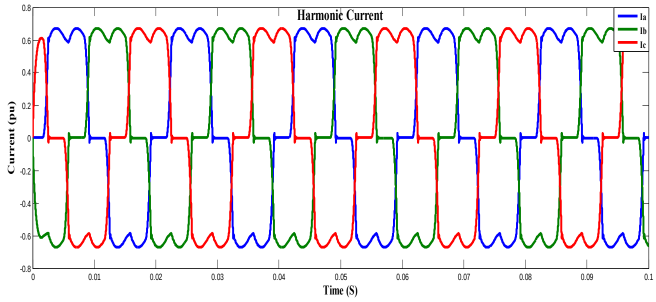

Fig 1. Harmonic current due to 6 pulse diode rectifier.

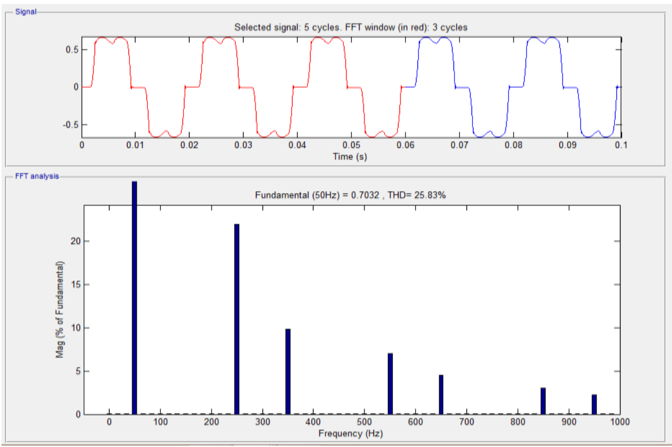

Fig 2. THD due to 6 pulse diode rectifier.

From fig 2, it is observed that for the simulated system, 5^{th} harmonic is about 22% and 7^{th} harmonic is about 7%.

3 System Description

V_{abc} is the three phase source voltage with magnitude of 1pu and each phase is equally displaced with 120 degree. i_{abc} is the source current through the line a, b and c phase respectively. Here 6 pulse rectifier is used as non-linear load for analysis as shown in fig 3.

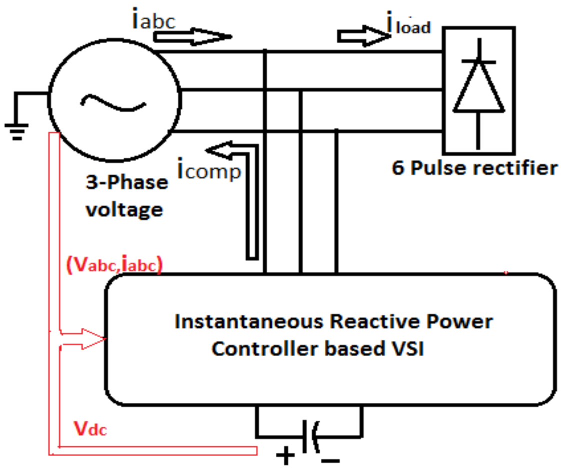

Fig 3. Block diagram of overall system

Several methods are available to compensate the harmonics in the source current. Here instantaneous reactive power controller is designed to obtain reference source current.

3 Stationary Reference Frame Theory

A reference frame is chosen for a rotating phasor. The angle between them is fixed and remains constant for each phase. Hence, it is called as stationary reference frame. Implantation of this theory for controller design is simple. In this instantaneous reactive power theory, 3 phase abc variables are transformed to orthogonal variables αβ [6] as given in equation (4)

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{2}/\sqrt{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (4)$$

where i_a, i_b and i_c the source currents of phases a, b and c respectively. Similarly, source voltage V_{abc} can be given as

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{2}/\sqrt{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (5)$$

Instantaneous input real power ‘p_{in}’ and reactive power ‘q_{in}’ can be given as

$$\begin{bmatrix} p_{in} \\ q_{in} \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (6)$$

Source should meet the real power required by the load (p_{load}) and power required by the compensator (p_{loss}) as given in equation (7)

$$p_{in} = p_{load} + p_{loss} \qquad (7)$$
$$p_{load} = V_\alpha \times i_\alpha + V_\beta \times i_\beta \qquad (8)$$

Reference source current can be obtained as by taking inverse of the equation (9)

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_{load} + p_{loss} \\ q_{in} \end{bmatrix} \quad (9)$$

It also can be decomposed into real and reactive part separately as shown below

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_{load} + p_{loss} \\ 0 \end{bmatrix} + \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ q_{in} \end{bmatrix} \quad (10)$$

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$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} i_{\alpha p}^* \\ i_{\beta p}^* \end{bmatrix} + \begin{bmatrix} i_{\alpha q}^* \\ i_{\beta q}^* \end{bmatrix} \quad (11)$$

Then real part of $i^*_{\alpha\beta\,(p)}$variables are transformed to $i^*_{abc\,(p)}$ by taking inverse park transformation. The generated real constant. Similarly, when the magnitude of the source current increases beyond the reference current, the average dc voltage of the capacitor increases. As a result error voltage decreases, proportionally p_{loss} also reduces. Therefore power requirement from the source is limited to regulate the dc link voltage. Thus the average capacitor voltage is held constant depending upon the change in compensator current i_{comp} as given in equation (11)

$$v_{dc} = \frac{1}{cap}\int i_{comp}\,dt \quad (11)$$

after computing p_{loss}, it is substituted in equation (9) to obtain reference current as expressed in equation (12)

$$\begin{bmatrix} i_{\alpha p}^* \\ i_{\beta p}^* \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_{load} + p_{loss} \\ 0 \end{bmatrix} \quad (12)$$

After computing the real part of the reference currents ($i^*_{\alpha\beta\,(p)}$) in αβ reference frame, it is transformed to abc reference frame ($i^*_{abc\,(p)}$). To obtain compensating currents (i_{comp}), actual source current (i_{abc}) is compared with the reference currents ($i^*_{abc\,(p)}$) as given below

$$i_{comp}\,(a) = i_a - i^*_{a(p)} \quad (13)$$

$$\mathrm{i_{comp}\,(b) = i_b - i^*_{b(p)}} \quad (14)$$

$$\mathrm{i_{comp}\,(c) = i_c - i^*_{c(p)}} \quad (15)$$

where $\mathrm{i_{comp}\,(a)}$, $\mathrm{i_{comp}\,(b)}$ and $\mathrm{i_{comp}\,(c)}$ are compensating currents of the phases a, b and c respectively. Once the reference currents are generated, they are tracked in a hysteresis band current control scheme. The switching frequency for this choice of hysteresis band is 10 kHz.

5 Simulation Study

Simulation circuit of the system is shown in fig 6.

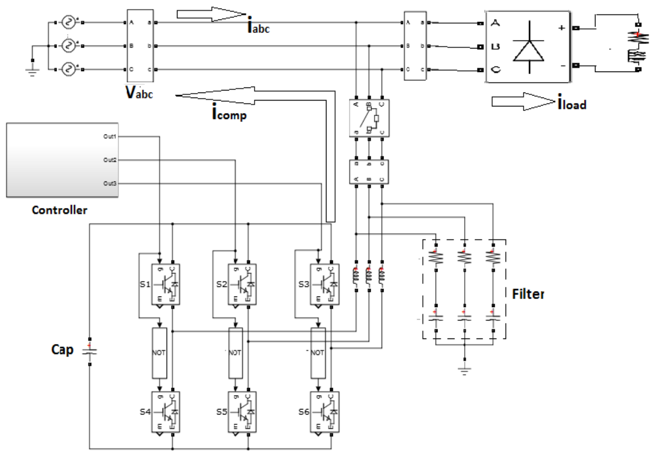

Fig 6. Simulation circuit of current harmonic compensation

5.1 Simulation Of Harmonic Current Compensation

A. Input voltage source

Fig 7 shows the balanced three phase voltage source with peak magnitude of 1 pu with fundamental frequency of 50 Hz.

B. Inference 1

1. Before compensation, source currents are non-sinusoidal as depicted in fig. 8. Before compensation, it is observed that overall THD is around 25.83% as shown in fig 3. After compensation, source currents become pure sinusoidal and overall THD is reduced to 1.5% as shown in fig 10.

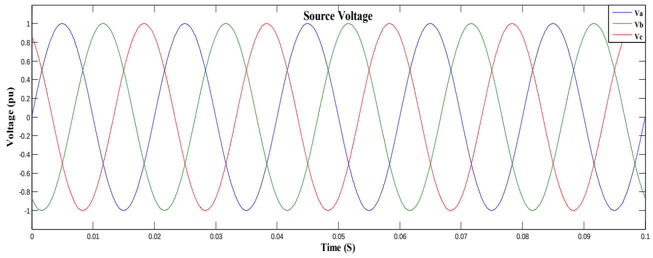

Fig 7. Three phase source voltage

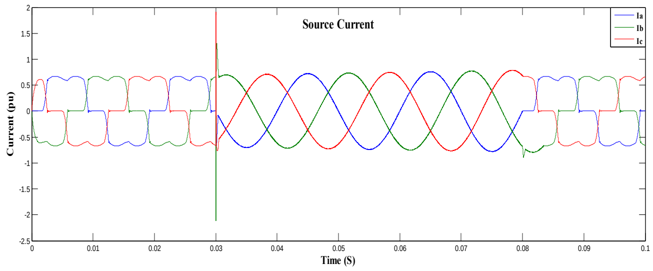

Fig 8. Three phase source current after compensation

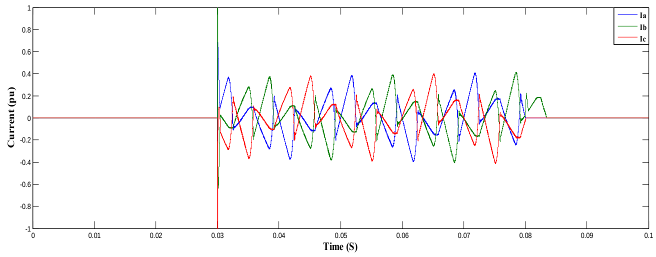

Fig 9. Compensator current

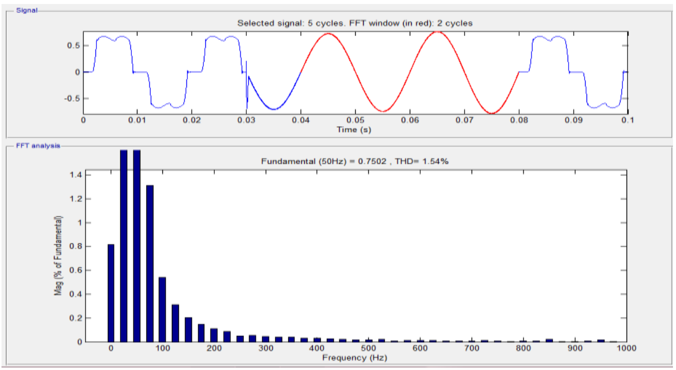

Fig 10.THDafter compensation

C. Inference 2

1. It is evident from Fig 11, after compensation power factor is improved to 0.968.

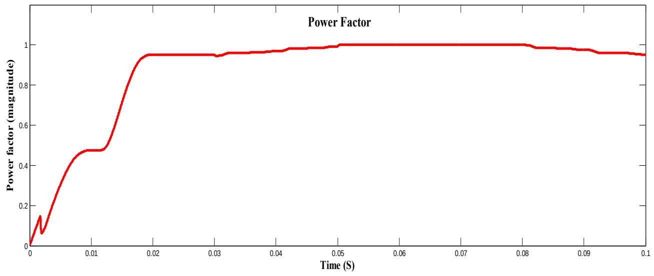

Fig 11. Power factor before and after compensation

6 Conclusion

In this paper, an instantaneous reactive power theory is used to compensate current harmonics. Also it has ability to improve power factor. Overall THD present in the source current is reduced according to IEEE standard 519-1992.

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