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Synchronous Reference Frame Method For A Four Legactive Power Filter Using UDCS Frequency Scheme Undernon-Stiff Source Conditions

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Abstract:

A combination of synchronous reference frame method and user defined constant switching frequency based algorithm is used in this paper to make the shunt active filter more simple and effective. The complications associated with neutral current sensing and compensating is entirely eliminated. Synchronous reference frame method is already proven as one of the simplest method. Out of the current control techniques listed in the literature the user defined constant switching frequency method is found as most effective for a four leg active filter.

Keywords: Shunt active power filter, Synchronous reference frame, Harmonics, Constant frequency switching, User-defined constant switching frequency

Introduction

The problems associated with harmonic interferences causes severe issues as far as industrial applications are concerned. Thus, it seems vital to mitigate these harmonics. Shunt passive filters are being used to suppress harmonics in power system. The passive filters are used almost everywhere and is an operative method for harmonic eradication. However, shunt passive filters have many problems to dispirit their application. Active power filters play an important role in eliminating the harmonics and reactive power in the power system. The different types of active filters areshunt active filter, series active filter, etc. The shunt active filter is paralleled to the source at the point of common coupling (PCC)[1].A shunt active power filter operation can be effectively classified into two sections. The first part is generation of reference currents for the three phases. Latter part is the current control technique for the filter. The synchronous reference frame theory is one of the modestmethods to compute the current reference for shunt active filters.The inverter, which acts as the active filter, isequipped to synthesis the harmonic currents to be injected at the point of common coupling. The reference currents areextracted using synchronous reference frame technique, and the reference current is switched by the inverter using a suitable current control method which produces less sub harmonics in the circuit.

The voltage source converters are the most beneficial power converters and have large range of applications such as in industrial drives, uninterruptible power supply (UPS), shunt active power filters, and dynamic voltage restorers etc. Many different current control schemes are implemented in these converters and the converter responds pretty positive to most of the techniques. Presently, a hysteresis band pulse width modulation is very popular with shunt active power filters[2].The hysteresis band is employed to control the load current and to synthesis the switching pulse for inverter gates. An unavoidable problem in implementing the hysteresis control in power converters is the switching frequency variationthat causes the production of sub harmonics. Therefore this technique is not recommended for high power system applications due to origination of sub harmonics and other lower-order harmonics. A method to control the switching frequency is of at most importance at this scenario. Addressing this issue, a constant switching frequency scheme is implemented in this paper to control and reduce the switching frequency which is already implemented with the Instantaneous reactive power theory[3].The block diagram of a shunt active power filter (APF) linked to a three-phase source is shown in Fig.1. In this Figure, a three-phase source is connected to a nonlinear diode bridge rectifier load. As the load connected is non-linear, the source current will get distorted. To mitigate the distortion in the current drawn from the supply, an active filter,with an interfacing inductance, is connected to the point of common coupling(PCC). The PCC is the point where the source and loads are getting connected.

A Diode Bridge

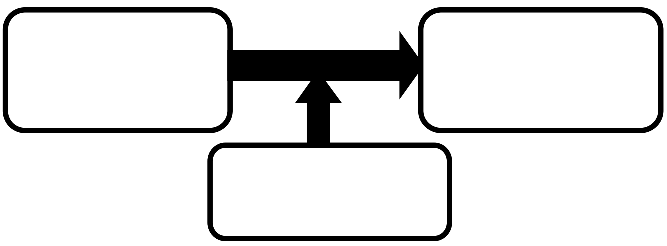

Figure 1: Block Diagram of Shunt APF Connected to a Three-Phase Four Wire System

Reference Current Generation Algorithm For Active Power Filter

There are various methods for generating the current reference for shunt APFs. The basic methods involve the calculation of system voltages and load currents. Most of these methods fail to generate the current references if the source is unbalanced or non-stiff. In this paper, the current reference for APF is generated using synchronous reference frame (SRF) method [4].This method works well under balanced and un-balanced source conditions. This method is very simple because it has a lesser number of computations compared to conventional methods.

A. Computational Algorithm

In this technique an abc-dq transformation is used to transform the distorted current drawn by the load. Once the currents are converted, there will be a d-axis component of DC current which will have a particular magnitude. The q-axis current has to be ideally zero, to have reactive power compensation. The input signals are thecurrents, sensed at the point of common coupling. For the phase angle information a Phase Locked Loop (PLL) is used in this method.The converted output will still have a dc component and a ripple component. A low pass filter is used to filter out these components. Now the output of low pass filter will be pure dc component.An inverse Park'sTransformation is employed to this component to yield the fundamental component of the source current. The low pass filter is realized from a simple transfer function of corner frequency 4Hz.The block diagram is shown in Fig.2.

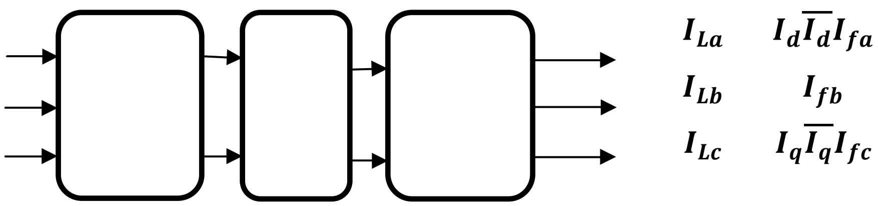

Figure 2: Fundamental Component Extraction -Block diagram

Here I_{La}, I_{Lb}, I_{Lc} are the distorted currents drawn from the supply . I_d, I_q are corresponding d-axis and q-axis component of current. I_{fa}, I_{fb}, I_{fc} are the fundamental component of current [5].The values of I_d and I_q can be calculated by using the following equations.

$$I_d = I_a \cos\theta + I_b \cos(\theta - 2\pi/3) + I_c \cos(\theta + 2\pi/3) \quad (1)$$

$$I_q = I_a \sin\theta + I_b \sin(\theta - 2\pi/3) + I_c \sin(\theta + \frac{2\pi}{3}) \quad (2)$$

The equations involved in inverse Park's transformation are as follows.

$$I_a = I_d \cos + I_q \sin\theta \quad (3)$$

$$I_b = I_d \cos(\theta - 2\pi/3) + I_q \sin(\theta - 2\pi/3) \quad (4)$$

$$I_c = I_d \cos(\theta + 2\pi/3) + I_q \sin(\theta + 2\pi/3) \quad (5)$$

The equations to compute the reference currents are as given below.

$$I_{ca}* = I_{La} - I_{fa} \quad (6)$$

$$I_{cb}* = I_{Lb} - I_{fb} \quad (7)$$

$$I_{cc}* = I_{Lc} - I_{fc} \quad (8)$$

I_{La} , I_{Lb} ,and I_{Lc} are the currents drawn from the source, which are sensed from the point of common coupling, and I_{fa} , I_{fb} , I_{fc} are the extracted fundamental current components using SRF method . $I_{ca}*$, $I_{cb}*$ and $I_{cc}*$ are the reference currents generated using this technique.These currents are used as reference to the controller circuit of the inverter to generate the appropriate switching pulses.

The method supports selective harmonic elimination which is an added advantage.

The computational algorithm is very simple compared to other methods. The technique responds quite satisfactorily under non-stiff source conditions.

Current Control Technique of APF

Many current control techniques have been proposed for voltage source inverters in the literature [6]-[8].Out of these methods the most popular and conventional method is hysteresis current control method. The method has good current tracking capacity and is very robust in operation [9].

A four leg voltage source inverter based active power filter is used to synthesis the filter currents. The current error signals are obtained from comparing the filter currents with the reference currents for the legs a,b,c of the inverter. The controller produces the required gating signals for the first three legs of the inverter. The most noticeable advantage of the method is that the neutral current tracking is not necessary. To the fourth leg of the inverter a square pulse of 50% duty cycle is been applied with a user defined frequency. This method make use of the inherent potential of the zero vector states called uncontrollable states to accomplish constancy and decrease in switching frequency[3].There will be two uncontrollable switching states in every cycle.The uncontrollable state is always interrupted by the change in status of thegating pulse applied to neutral leg.The other legs following this change one after the other can be observed. The choice of gating pulse frequency is bound to some upper and lower limits and the duty cycle should be kept as 50% for a perfect tracking.It can be observed that the other legs switching frequency is getting limited to the frequency of the square pulse or in other words the switching frequency of the inverter got confined to the user defined frequency. Switching frequencies can be decreased by the selection of lower frequency switching pulse. During the zero states, the dc capacitor gets disconnected from the active power filter. So appropriate current synthesis does not occur;this causes the filter currents to disrupt the band. Here it works as a flexible hysteresis band method, whereby the band deviation is attainedby the user-defined switching frequency [3].

Simulation Studies

The simulation is performed in a three-phase four-wire system. The source voltage has been made non-stiff by creating an unbalance. A three-phase diode bridge is used as the non-linear load. The software used for simulation is MATLAB/SIMULINK.

The synchronous reference frame technique works quite pleasingly even when the source is non-stiff.Even under unbalanced condition of source, the reference currents can be generated by using a synchronous reference current algorithm. This is promising because the calculation of reference current generation does not contain any voltage information.

Fig.3.shows the unbalanced source voltage.

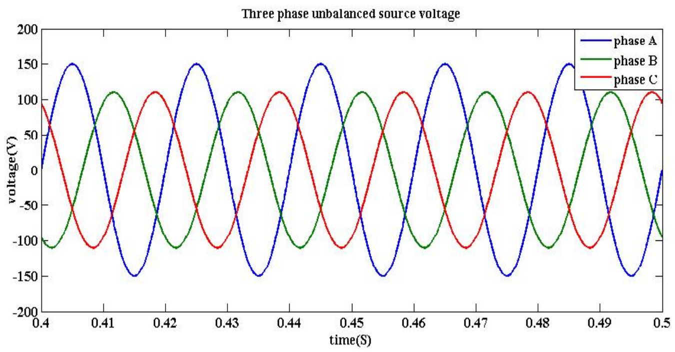

Figure 3: Unbalanced Source voltages

The unbalance in simulation can be achieved by giving dissimilar value of voltage to one of thephases. Thedistorted current drawn by the non-linear load is also shown in Fig.4.

The non-linear load used is a three-phase bridge rectifier.

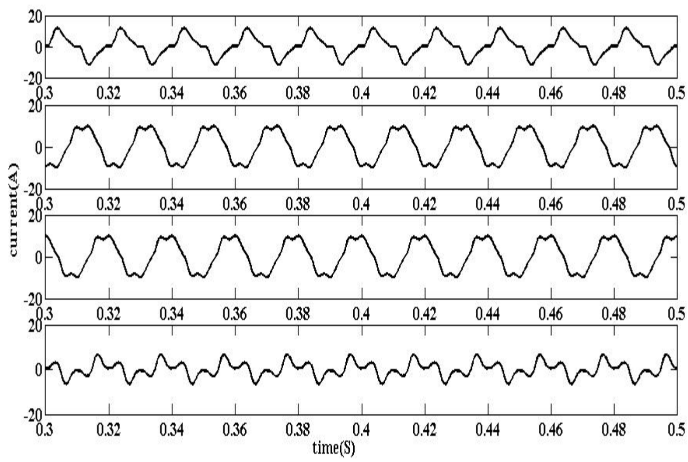

Figure 4: Distorted Source Current Drawn By Nonlinear Load

The reference currents are obtained by using the equations (1) to (8). The extracted harmonic current is shown in Fig.5.It is extracted by implementingPark's Transformation and inverse Park's Transformation equations.

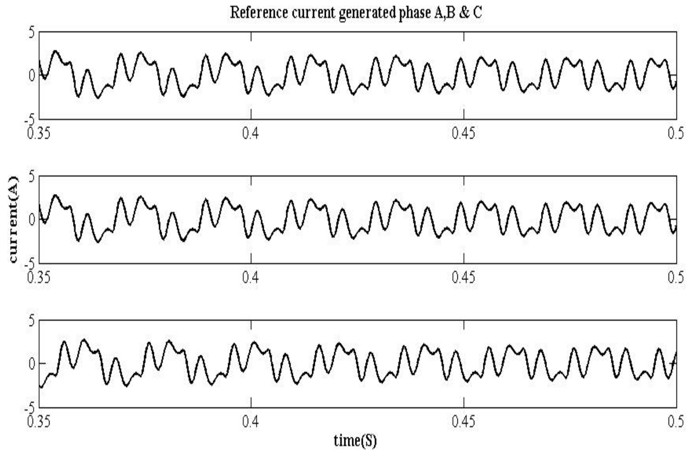

Figure 5: Extracted Harmonic Currents of Phase A,B &C

The pulses generated whileusing the UDCS frequency is shown in Fig.6.The frequency of the user-defined pulse is 2.57 kHz.It can be perceived that the frequency of theother legs of the filter is also getting restricted to the user-defined frequency.The frequency of conventional hysteresis switching technique is a variable frequency.

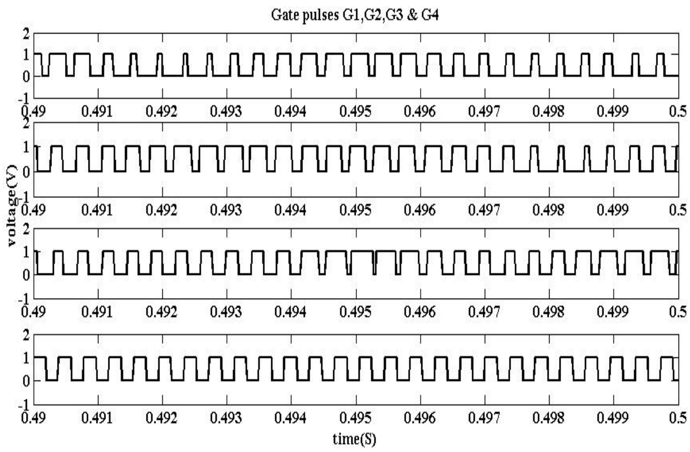

Figure 6: Constant frequency pulses generated while using UDCS controller

The constant frequency gating signals switch the inverter to generate the compensating current. The compensated source currents and neutral current are shown in Fig.7.

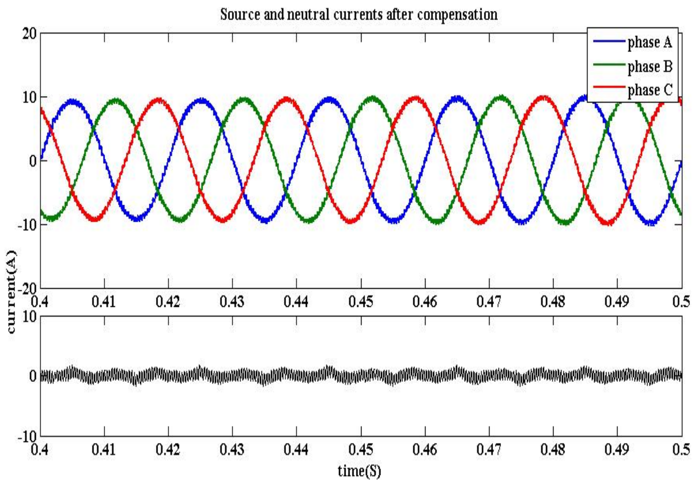

Figure 7: Phase A, B And C Compensated Source Currents and Neutral Current

The THD analysys of the source current is done before and after compensation and is observed that the total harmonic distortion is reduced by 31.67%

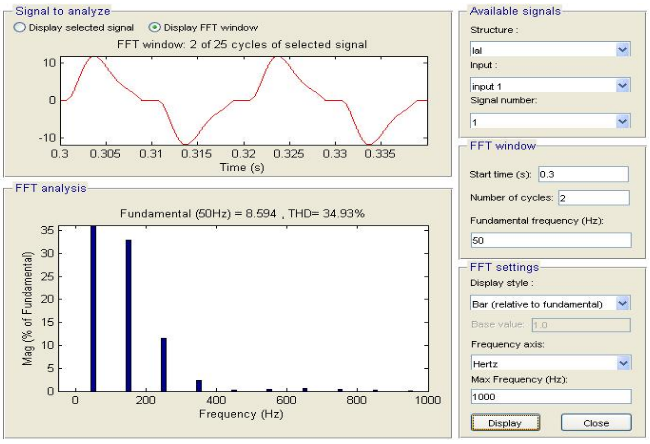

Figure 8:THD of source current before compensation

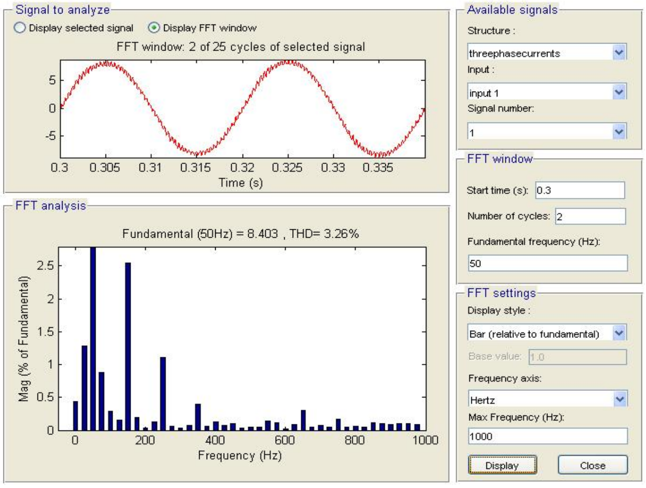

Figure 9: THD of source current after compensation

Conclusion

Here a shunt active power filterusing synchronous reference frame method is portrayed. The total harmonic distortion is observed to be reduced from 34.93% to 3.26%.This is shown by the bar diagram in Figures8 and 9.The switching frequency has been decreased to a constant frequency of 2.57 kHz from a range of inconstant frequency of 3KHz to 2.8MHz. The issues associated with conventional hysteresis control is been given prior importance, and a technique to control the switching frequency is studied. The simulation work has been done under a non-stiff source conditions. By the usage of UDCS scheme, the switchingfrequency became constant and overall filter became simple in analysis and for hardware implementation. This is the major advantage of this filter compared with other filters which use variable frequency controller and voltage dependent reference current generation algorithms. An added advantage is that the proposed method has very less computational intensive compared with other methods.The simulation study has been done using MATLAB/SIMULINK environment. The solver used is Variable step, ode 45.

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