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POWER QUALITY IMPROVEMENT USING MODIFIED SYNCHRONOUS REFERENCE FRAME THEORY

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ABSTRACT

This Paper describes the development of mathematical modeling and analysis of modified Synchronous Reference Frame (MSRF) theory for mitigation of harmonics injected in power system due to employment of non- linear loads. The Use of non-linear loads is increasing manifolds due to the advancement in power electronic technology. Though this improves life quality, it also contributes substantially to the injection of harmonics in to the Power System. This, in turn, has severe effects on power quality of the system. It, thus, becomes necessarily essential to mitigate the harmonics & improve the power quality of System. This paper focuses on mitigation of power system harmonics using MSRF theory approach for generation of reference current signal. The MSRF technique is Modeled & analyzed using MATLAB Simulink.

Keywords: Non-Linear Loads, Harmonic Mitigation, Power Quality, Reference Current Generation, MSRF Theory.

I. INTRODUCTION

Over the recent years, power quality has been given tremendous attention. The reason behind this is intensive use nonlinear loads such as power electronic controlled application. Due to the benefits posed by the non-linear loads, its use is increasing day by day. Though the power electronics applications make our life convenient, they inject harmonics into power system. The harmonic generated by the most common nonlinear loads affect the amplitude and nature of source current and hence performance of system. The Power Quality problem has, thus, become a very serious issue. The connection of a nonlinear load, such as rectifiers, thyristor converters to the system, draws a current that is non-sinusoidal in nature [1-3]. This is due to the presence of harmonics.

The harmonics generated due to nonlinear loads affect the amplitude and nature of source current, and hence the performance of system is affected. The presence of harmonics in the system can cause problems like heating, losses, failure of electrical equipment and interference with communication system. So, elimination of harmonics is an important issue. Several algorithms to extract reference current signal have been proposed [1-5].

II. POWER QUALITY AND ITS EFFECT ON POWERSYSTEM

Any power problem manifested in voltage, current, or frequency deviation that results in failure or maloperation of customer equipment is referred as power quality. The term electric power quality broadly refers to maintaining a nearly sinusoidal power distribution at rated magnitude and frequency. In addition to this, the energy supplied to the consumer should be reliable and uninterrupted. With the increasing use of sophisticated controls and equipment in industrial as well as commercial facilities, the continuity, reliability and quality of electrical service has become extremely crucial to many power users. Electrical systems are subjected to wide variety of power quality problems which can interrupt production process, affect sensitive equipment, and cause down time scrap and hence capacity losses. Power Electronics are the most important cause of harmonics, inter-harmonics, notches etc. Harmonics are also produced due to rectifiers, ASDs, soft starters, electronic ballast for discharge lamps, switched-mode power supplies etc. Due to their nonlinearity, all these loads cause disturbances in the voltage waveform. Equipment affected by harmonics includes transformers, motors, cables, interrupters, and capacitors. Notches are produced mainly by converters, and they affect electronic control devices. Neutral currents are produced by equipment using switched mode power supplies such as PCs, printers, photocopiers and it seriously affects the neutral conductor temperature and transformer capability. Inter-harmonics are produced by static frequency converters, cyclo-converters, induction motors and arcing devices. There are economic impacts on utilities, their customers and suppliers of load equipment due to the harmonics. Thus, when any power quality problem occurs, huge financial loss may happen, with the consequent loss of productivity and competitiveness. Therefore suitable measures must be taken to improve the power quality to the desired range.

III. MODIFIED SYNCHRONOUS REFERENCE FRAME (MSRF) THEORY

As the name suggests, the MSRF method is similar to the SRF except for a slight modification. It is also called as the instantaneous current component (I_{dq}) method.The transformation angle θ is obtained with the voltages of AC network in MSRF method, as against that obtained from PLL in SRF method. Both, SRF and MSRF, methods are based on the principle that harmonics change their frequency in a rotating reference frame, and hence are better isolated with filters.

The difference lies in the speed of reference frame, which is no longer constant due to voltage harmonics and imbalance. Depending on the waveform of the three phase voltage system, it varies instantaneously. The peculiarity of this algorithm is that it obtains the compensating currents from the instantaneous active and reactive current components of the nonlinear load. This method quickly and precisely extracts the harmonic content and the reactive component of a distorted current.

Reference frame transformation transforms the coordinates from a three-phase a-b-c stationary coordinate system to the 0-d-q rotating coordinate system as shown in Figure 1. Therefore similar to synchronous reference frame (SRF) method, here the three phase a-b-c stationary coordinate system is first converted to two-phase α-β stationary coordinate system, called as Clark's transformation. This two phase α-β stationary coordinate system is then converted into two phase d-q rotating coordinate system, called as Park's transformation.

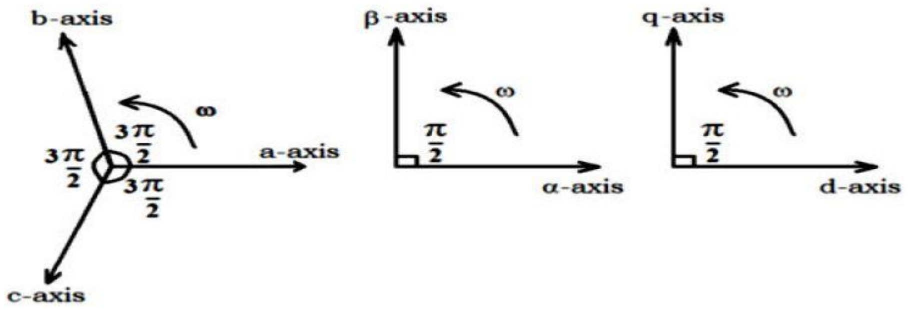

Figure 1: Reference Frame Transformation

Clark's transformation is applied, in first step, to the source current and source voltage.

The source currentsI_a,I_b,$I_c$and the source voltagesv_a, v_b, $v_c$are transformed to two phase stationary reference frame using equations(1) and (2) below.

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

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

The two phase current quantities $i_a$and $i_\beta$of stationary αβ-axes are then transformed into two-phase synchronous rotating reference frame ($i_d$and i_q) using Parks transformation as stated below in equation (3).

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{\sqrt{v_\alpha^2+v_\beta^2}}\begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

Instantaneous active and reactive load currents can be decomposed into oscillatory and average terms. The fundamental currents of the d-q components appear as dc values and harmonics in the form of ripples. The isolation of harmonics from the d-q transformed signal is required for reference current generation. This is accomplished using LPF with an appropriate cut-off frequency and damping constant. This gives us reference current in d-q form, free from harmonics, as shown below in equation (4).

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \overline{i_d} + \tilde{i_d} \\ \overline{i_q} + \tilde{i_q} \end{bmatrix} \quad (4)$$

Where,

$\overline{i_d}$–Mean value of instantaneous real current. It is the only desired current component to be supplied by the power source.

$\tilde{i_d}$– Alternating value of the instantaneous real current. Since it does not involve any energy transfer from the power source to load, it must be compensated.

$\overline{i_q}$– Mean value of instantaneous imaginary current.

$\tilde{i_q}$– Alternating value of the instantaneous imaginary current.

The reference current signal in d-q rotating frame is converted back into a-b-c stationary reference frame using inverse Park's transformation and inverse Clark's transformation as shown below in equations (5) and (6).

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{\sqrt{v_\alpha{}^2+v_\beta{}^2}} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & 1 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (6)$$

These are the three phase stationary reference a-b-c current swhich are free from harmonics. These reference currents are used for the generation of the PWM pulses using the hysteresis current controller (HCC).

In the hysteresis current controller the reference current is compared with the load current to get the pulses for the inverter using the equation (7) below.

$$\left\{ \begin{array}{l} i_{ca}^* = i_{sa}^* - i_{La} \\ i_{cb}^* = i_{sb}^* - i_{Lb} \quad (7) \\ i_{cc}^* = i_{sc}^* - i_{Lc} \end{array} \right.$$

These pulses are used to trigger the IGBTs used in the inverter circuit. With these GATE pulses the output of inverter is the filter current i.e. the compensating current required to eliminate the harmonics. This filter current is fed to the system to compensate the harmonics in the system.

IV. BLOCK DIAGRAM OF MODIFIED SRF METHOD

Figure 2 shows the basic block diagram of modified SRF method for reference current generation. The a-b-c phase currents are converted to α-β using Clark's transformation. Then these currents are converted to d-q form using Park's transformation. The LPF removes the harmonics from current. Finally, the reference current in a-b-c is obtained using inverse Clark's and inverse Park's transform.

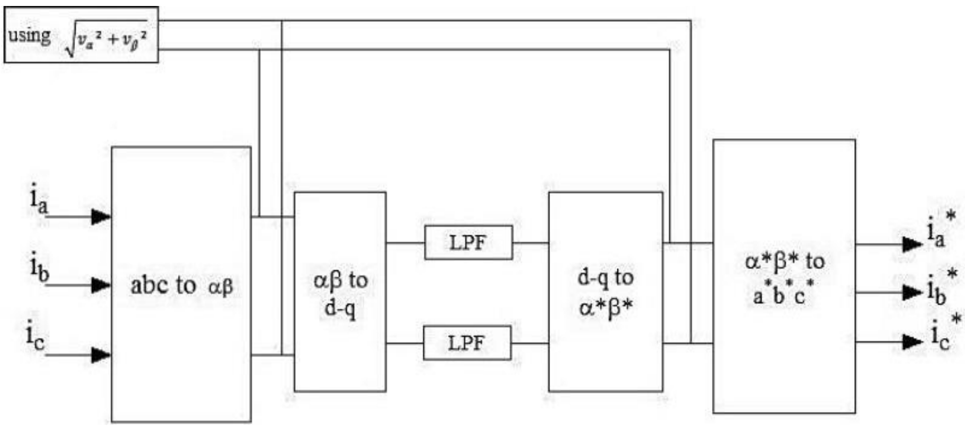

Figure 2: Block Diagram of MSRF method

V. RESULTS

Figure 3 shows the source current before compensation and Figure 4 shows FFT analysis of source current waveform. It gives us %THD in source current. The THD before compensation was 26.69%. So, it can be clearly seen that without SAPF, %THD substantially exceeds the specified IEEE standard value.

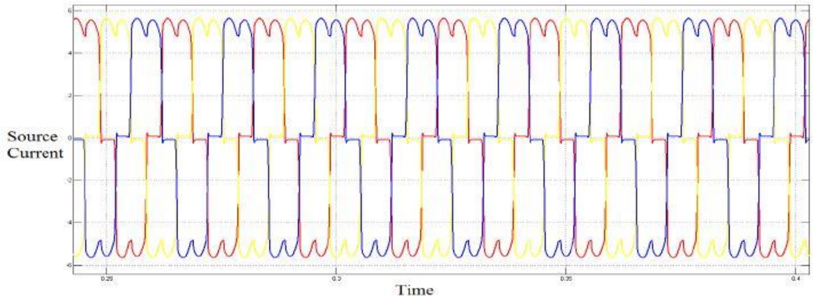

Figure 3: Source Current before compensation

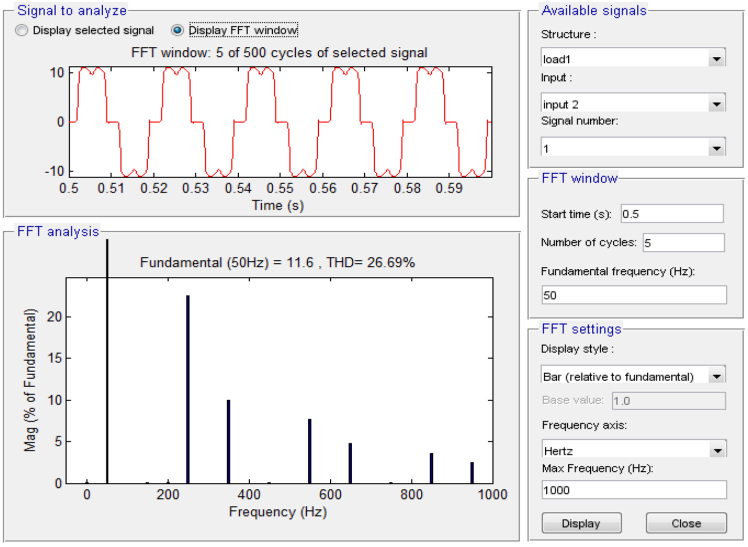

Figure 4: FFT Analysis of Source Current before Compensation

Figure 5-8 below represent the waveforms when SAPF is connected in system and modified SRF theory is used for reference current generation. Second waveform shows filter current which is equal and opposite to the harmonic current. Third waveform shows load current and forth waveform shows three phase source current. It is clearly seen that when SAPF is connected, the source current becomes sinusoidal.

Figure 9 shows FFT analysis of source current waveform when Shunt Active Power Filter (SAPF) is connected and MSRF is used for reference current generation. The THD in source current gets reduced to 3.25% after compensation.

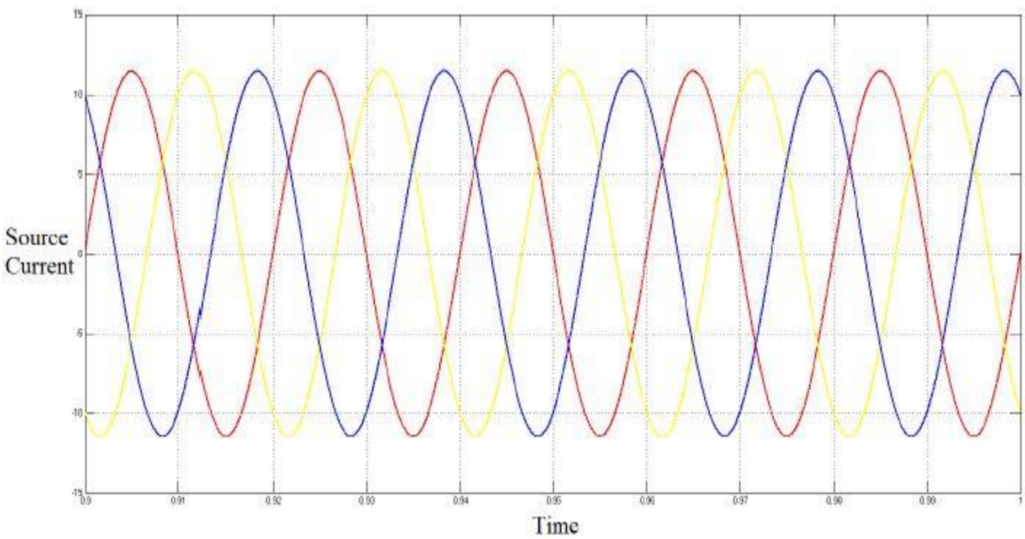

Figure 5: Reference Current

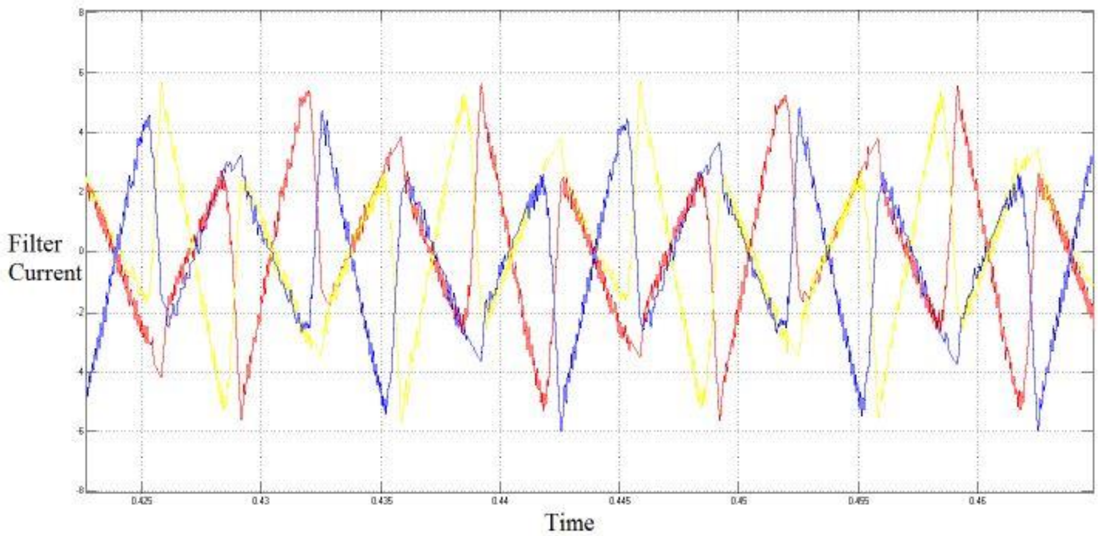

Figure 6: Filter Current

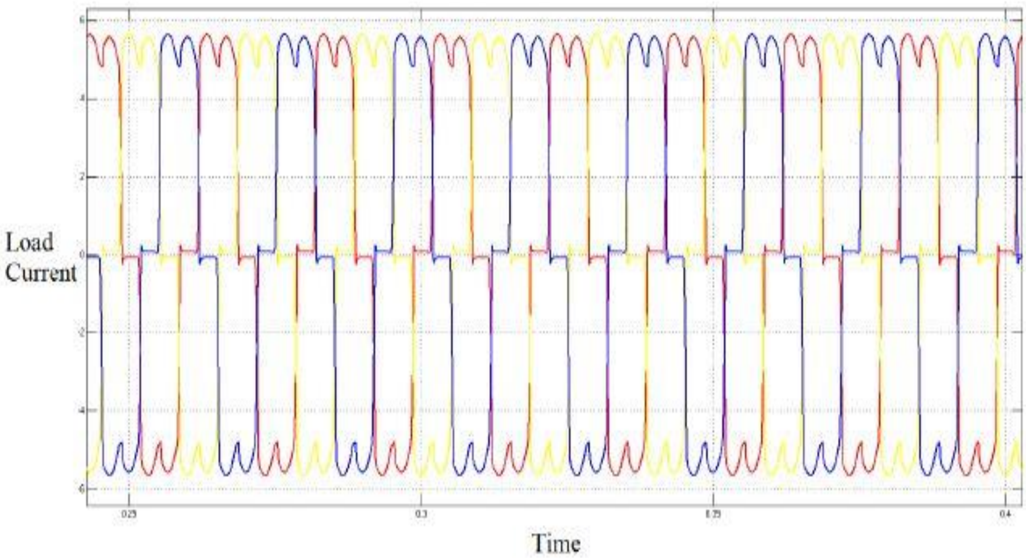

Figure 7: Harmonic Current

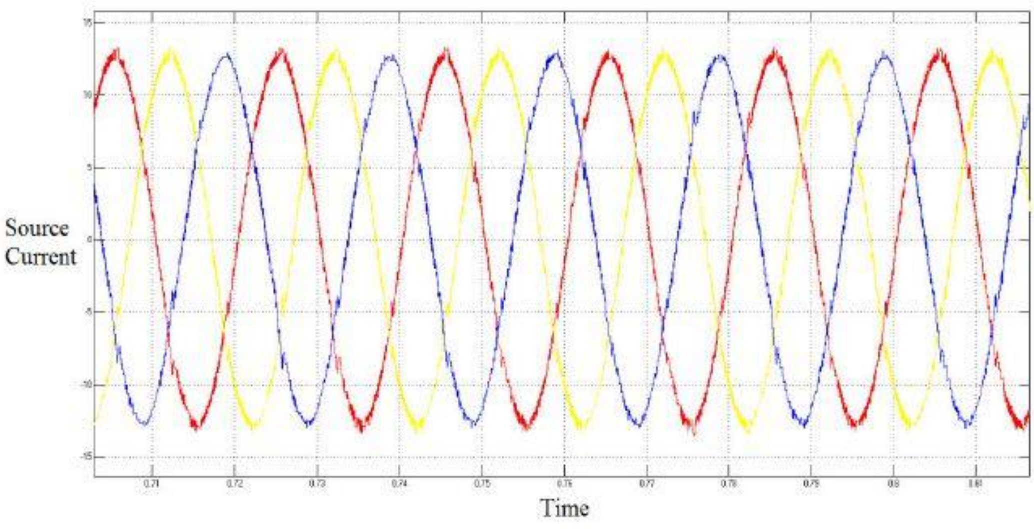

Figure 8: Source Current

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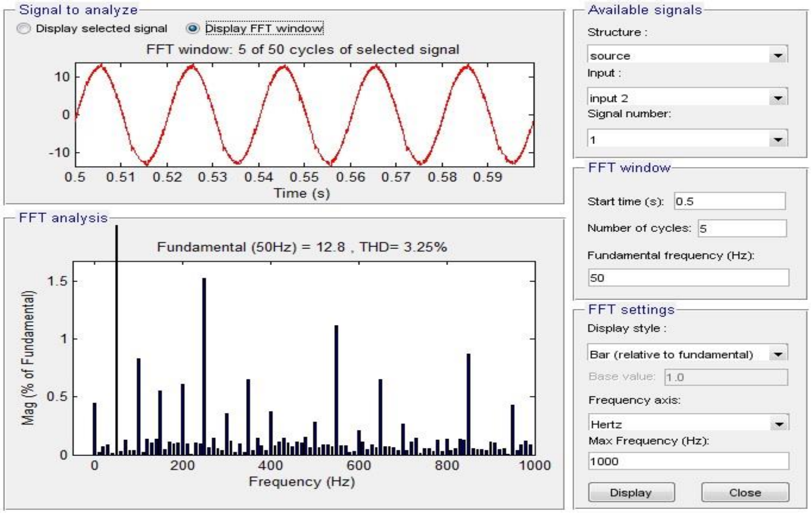

Figure 9: FFT analysis of source current with MSRF theory

Table 1 below gives the data of THD before and after compensation. It could be seen that the THD has been reduced to 3.25%, which is within the IEEE Standard limits, using the proposed technique.

Table 1: THD comparison before and after compensation

Control Theory	THD before compensation in %	THD after compensation in %
Modified SRF Theory	26.69%	3.25%

VI. CONCLUSION

With the rapidly increasing number of applications of industry electronics connected to the distribution systems, a complex problem of power quality is characterized by the harmonics. To eliminate the harmonics, a new approach with shunt active power filter has been proposed for power quality improvement. The simulation model for Modified reference current generation technique has been developed and simulated in MATLAB Simulink to analyze the performance improvement of the system.

It is found from the simulation results that shunt active power filter substantially improves the power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The system without shunt active power filter contains 26.69% THD. After the employment of shunt active power filter in the system, the THD percentage got reduced to 3.25%. which is within the IEEE 519 standard limit of 5%. The results show that the proposed technique can help to considerably improve the power quality of the system.

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