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VERY FAST FOURIER TRANSFORM BASED ON MOADALINE

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Abstract- In this paper a novel Fourier series as Very Fast Fourier Transform (VFFT) has been investigated. Also a combination of VFFT and Multi Output ADAptive LINEar (MOADALINE) approaches has been proposed for extracting and minimizing of the error between desired and actual amounts of a signal. In electrical engineering application Fourier transform generally is used for extraction of a signal spectrum. In this condition generation of a desired signal with known Fourier coefficients is essential. This paper propose a new approach which is able to generate each desired signal with known Fourier coefficients. Proposed approach can be used in three phase electrical engineering application such as power quality compensation problems. Power quality problems can be compensated by the use of UPQC (Unified Power Quality Conditioner). Results are presented to confirm the validity of the proposed approach to achieve a high quality output.

Keywords VFFT, MOADALINE, Electrical Engineering.

I. INTRODUCTION

Fourier transform has the capability of different order components extraction of a periodic signal. Based on the general equations of Fourier transform, integral limits are between zero and T (period of signal) which in time variant periodic signals settling time of the related integral will be T sec. This problem causes week capability in any conditions which need high speed response. Proposed Very Fast Fourier Transform (VFFT) will be responsible for improving the mentioned problem.

Based on Multi Output ADAptive LINEar (MOADALINE) each $n\times 1$ signal can be written as a weighted linear combination of its components. Scope of the paper is proper combination of VFFT and MOADALINE approaches. In the proposed approach each time variant periodic signal can be written as weighted linear of its components which weight factors are Fourier coefficients and components are $\sin(\omega t)$ and $\cos(\omega t)$. This is for the extraction of a desired signal which is a sinusoidal one with known magnitude and phase. As the other word Fourier coefficient of desired signal is known.

In this paper the proposed approach has been used in electrical engineering application for extraction of the reference signals in a special application named power quality compensation [1-2].

Nowadays, most of the equipment based on power electronic devices used by the industry, lead to power quality problems. These devices not only need high quality energy to work properly but also are the major cause for decreasing power quality. In these conditions, both electric utilities and customers are increasingly affected from the quality of electric power. Between the different technical approaches available for the compensation of power quality problems, Active Power Filters (APFs) have an important alternative [3-5].

One of the most efficient solution systems for power quality problems is Unified Power Quality Conditioner (UPQC). The used configurations consist of two shunt and series inverters as current and voltage compensators with a common dc link [6-9].

The scope of this research is to use UPQC for improvement of power quality and main principle of the proposed control theory is based on composition of VFFT and MOADALINE approaches. Simplicity and flexibility in extraction of different reference signals can be one of the proposed algorithm advantages [10-13].

Section II Investigates the VFFT technique. Section III explains the MOADALINE approach. Section IV present the proposed approach. Section V generally introduces UPQC. Section VI simulates the paper. Finally section VII concludes the results [14-16]

II. VFFT TECHNIQUE

Fourier transform has the capability of different order components extraction of distorted periodic signal. Based on the general equations of Fourier transform, in the time variant periodic signals, settling time is one cycle which causes week capability in dynamic conditions. Basic of VFFT technique for different order extracting of a signal is that not only it is need to have the signal but also it is need to have $2\pi/3$ left and right phase shifted of it. So for using of the VFFT for a signal it should be shifted $2\pi/3$ to the right and left. First order components of a signal can be written as Equations (1) and (2) [1].

$$a_1 = \frac{2}{2\pi}\int_0^{2\pi} v(\omega t)\cos(\omega t)d\omega t = \frac{4}{2\pi}\int_0^{\pi} v(\omega t)\cos(\omega t)d\omega t \quad (1)$$

$$b_1 = \frac{2}{2\pi}\int_0^{2\pi} v(\omega t)\sin(\omega t)d\omega t = \frac{4}{2\pi}\int_0^{\pi} v(\omega t)\sin(\omega t)d\omega t \quad (2)$$

It is assumed that $v(\omega t)=\sin(\omega t+\varphi)$, so it can be resulted for any amount of φ:

$$\frac{4}{2\pi}\int_0^{\pi}\sin(\omega t+\varphi)\cos(\omega t)d\omega t=\sin\varphi \tag{3}$$

and,

$$\begin{aligned}&\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_{\frac{2\pi}{6}}^{\frac{3\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_{\frac{4\pi}{6}}^{\frac{5\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t=\sin\varphi\end{aligned} \tag{4}$$

So Equations (5) and (6) can be resulted in:

$$\begin{aligned}&\frac{4}{2\pi}\int_0^{\pi}\cos(\omega t)\sin(\omega t+\varphi)d\omega t=\\&=\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_{\frac{2\pi}{6}}^{\frac{3\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_{\frac{4\pi}{6}}^{\frac{5\pi}{6}}\sin(\omega t+\varphi)d\omega t=\sin\varphi\end{aligned} \tag{5}$$

$$\begin{aligned}&\frac{4}{2\pi}\int_0^{\pi}\sin(\omega t)\sin(\omega t+\varphi)d\omega t=\\&=\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\sin(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_{\frac{2\pi}{6}}^{\frac{3\pi}{6}}\sin(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_{\frac{4\pi}{6}}^{\frac{5\pi}{6}}\sin(\omega t)\sin(\omega t+\varphi)d\omega t=\cos\varphi\end{aligned} \tag{6}$$

It can be possible rewrite of Equations (5) and (6) as Equations (7) and (8), respectively.

$$\begin{aligned}a_1&=\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}(-\cos(\omega t-\frac{2\pi}{3}))(-\sin(\omega t+\varphi-\frac{2\pi}{3}))d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t+\frac{2\pi}{3})\sin(\omega t+\varphi+\frac{2\pi}{3})d\omega t=\\&=\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t+\frac{2\pi}{3})\sin(\omega t+\varphi+\frac{2\pi}{3})d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\cos(\omega t-\frac{2\pi}{3})\sin(\omega t+\varphi-\frac{2\pi}{3})d\omega t\end{aligned} \tag{7}$$

$$\begin{aligned}b_1&=\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\sin(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}(-\sin(\omega t-\frac{2\pi}{3}))(-\sin(\omega t+\varphi-\frac{2\pi}{3}))d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\sin(\omega t+\frac{2\pi}{3})\sin(\omega t+\varphi+\frac{2\pi}{3})d\omega t=\\&=\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\sin(\omega t)\sin(\omega t+\varphi)d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\sin(\omega t+\frac{2\pi}{3})\sin(\omega t+\varphi+\frac{2\pi}{3})d\omega t+\\&+\frac{8}{2\pi}\int_0^{\frac{\pi}{6}}\sin(\omega t-\frac{2\pi}{3})\sin(\omega t+\varphi-\frac{2\pi}{3})d\omega t\end{aligned} \tag{8}$$

Equations (7) and (8) can be rewritten as Equation (9):

$$\begin{bmatrix}a_1\\b_1\end{bmatrix}=\int_0^{\frac{\pi}{6}}(S\times W)d\omega t \tag{9}$$

which, matrices S and W can be determined as Equations (10) and (11) [2]:

$$S=\begin{bmatrix}\cos(\omega t) & \cos(\omega t-\frac{2\pi}{3}) & \cos(\omega t+\frac{2\pi}{3})\\ \sin(\omega t) & \sin(\omega t-\frac{2\pi}{3}) & \sin(\omega t+\frac{2\pi}{3})\end{bmatrix} \tag{10}$$

$$W=\begin{bmatrix}\sin(\omega t+\varphi)\\ \sin(\omega t+\varphi-\frac{2\pi}{3})\\ \sin(\omega t+\varphi+\frac{2\pi}{3})\end{bmatrix} \tag{11}$$

Equations (10) and (11) show that it is possible to extract the first order component of a signal by using of three similar signals which have $2\pi/3$ phase shift each other. Also reduction of integral limit to $\pi/6$, shows that VFFT responds twelve times faster than general Fourier transform. But, the problem of this is the unfiltered steady state oscillations in the response which is because of small data window length. This is based on this fact that integral of a sinusoidal signal in a period will be zero which reduction of integral limit can generates unwanted oscillations in the response. Thus, for accessing the fast response, as well as good steady state response, proper composition of $\pi/6$ and π data window lengths have been used. So the proposed approach uses $\pi/6$ integral limit in signal magnitude change instances, for accessing the fast response, and π integral limit in other times, for accessing the good response without oscillation.

III. MOADALINE APPROACH

Based on MOADLINE each $n\times 1$ signal of y can be written as a weighted linear combination of its components [3]. If S be $n\times m$ component matrix of y at time t and W be $m\times 1$ vector of weighted coefficient then, the signal of y can be written as Equation (12). Weighted factors can be updated in each stage of an adaptation approach for extraction of a desired signal. Equation (13) shows adaptation rule that is based on Least Mean Square (LMS) algorithm [2].

$$y = SW \tag{12}$$

$$W(t+dt) = W(t) + kS^T(t)[S(t)S^T(t)]^{-1}e(t) \tag{13}$$

where, $e(t)$ is the error between desired and actual signal of y. K can be determined as a way for convergence of the related adaptation rule.

IV. PROPOSED APPROACH

It is possible to extract the desired signals by composition of VFFT and MOADALINE approaches. This is because of reach to the advantages of the two mentioned approaches simultaneously. Vector of W is related to the actual Fourier coefficients of a signal but vector of y is related to the desired Fourier coefficients of that signal. In the proposed combined approach the vector of y were determined selectively. So the adaptive rule generates the desired signal based on the selective vector of y. Component matrix of S is constant. After a few iterations error between the actual signal and the desired signal can be zero. Figure 1 shows block diagram of the proposed approach. Equation (14) shows the relation between y, S and W. For decreasing of the mathematical calculation volume the related equations have been written in discrete time conditions.

$$y = \sum SW \tag{14}$$

In the proposed approach matrixes of y, S and W can be determined as Equations (15), (16) and (17).

$$y = \begin{bmatrix} a_n \\ b_n \\ a_0 \end{bmatrix} \tag{15}$$

$$S_1(t) = \frac{8}{m-1}\begin{bmatrix} \cos(n\omega t_0) & \cos(n\omega t_1) & \dots & \cos(n\omega t_{m-1}) \\ \sin(n\omega t_0) & \sin(n\omega t_1) & \dots & \sin(n\omega t_{m-1}) \\ \frac{1}{2} & \frac{1}{2} & \dots & \frac{1}{2} \end{bmatrix}$$

$$S_2(t) = \frac{8}{m-1}\begin{bmatrix} \cos(n\omega t_0 - \frac{2\pi}{3}) & \dots & \cos(n\omega t_{m-1} - \frac{2\pi}{3}) \\ \sin(n\omega t_0 - \frac{2\pi}{3}) & \dots & \sin(n\omega t_{m-1}) - \frac{2\pi}{3} \\ \frac{1}{2} & \dots & \frac{1}{2} \end{bmatrix} \tag{16}$$

$$S_3(t) = \frac{8}{m-1}\begin{bmatrix} \cos(n\omega t_0 + \frac{2\pi}{3}) & \dots & \cos(n\omega t_{m-1} + \frac{2\pi}{3}) \\ \sin(n\omega t_0 + \frac{2\pi}{3}) & \dots & \sin(n\omega t_{m-1} + \frac{2\pi}{3}) \\ \frac{1}{2} & \dots & \frac{1}{2} \end{bmatrix}$$

$$S(t) = [S_1(t) \quad S_2(t) \quad S_3(t)]$$

$$W_1(t) = \begin{bmatrix} w(t_0) \\ w(t_1) \\ \dots \\ w(t_{m-1}) \end{bmatrix} \quad W_2(t) = \begin{bmatrix} w(t_0) \\ w(t_1) \\ \dots \\ w(t_{m-1}) \end{bmatrix}$$

$$W_3(t) = \begin{bmatrix} w(t_0) \\ w(t_1) \\ \dots \\ w(t_{m-1}) \end{bmatrix} \quad W(t) = \begin{bmatrix} W_1(t) \\ W_2(t) \\ W_3(t) \end{bmatrix} \tag{17}$$

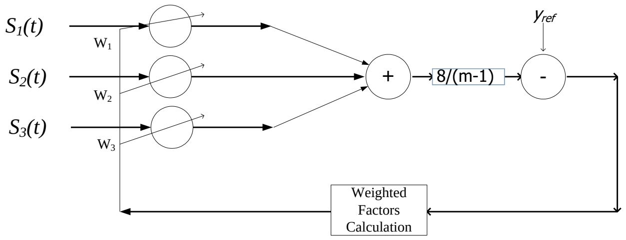


Figure 1. Block diagram of the proposed approach [2]

V. UNIFIED POWER QUALITY CONDITIONER

UPQC has composed of two inverters that are connected back to back. One of them is connected to the grid via a parallel transformer and can compensate the current problems. Another one is connected to the grid via a series transformer and can compensate the voltage problems. These inverters are controlled to inject compensator voltage and currents to the grid for improving of the power quality problems. Compensator voltage and current are difference between desired voltage and current by the source voltage and load current respectively as Equation (18). Figure 2 shows the general schematic of a UPQC.

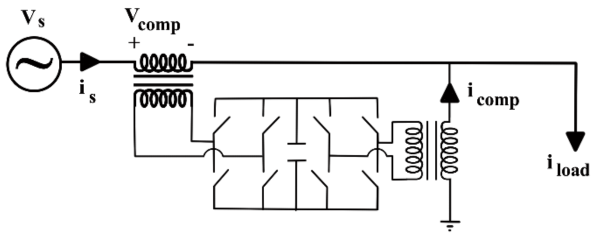


Figure 2. General schematic of a UPQC [1]

Figure 3 shows a simple circuit model of the UPQC. In this paper, the series APF operates as a controlled voltage source arranging the load voltage sinusoidal and at a predetermined constant voltage level. But the shunt APF operates as a controlled current source arranging the source current sinusoidal. Related Kirchhoff's current and voltage lows are as Equation (18).

$$\begin{aligned} i_{sh} &= i_L - i_s \\ v_{comp} &= v_s - v_{Load} \end{aligned} \tag{18}$$

where, i_s is the desired current signal and v_{Load}, is the desired voltage signal. This signals were determined based on power quality compensation principles.

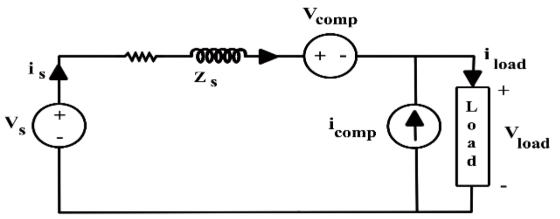


Figure 3. Circuit model of the UPQC [1]

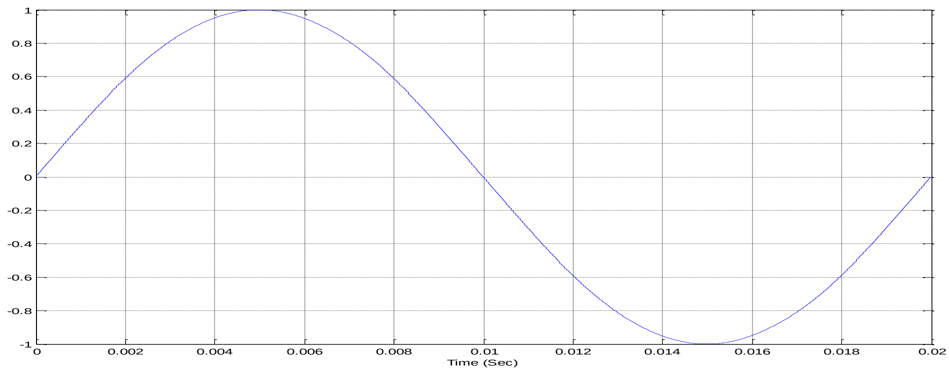
VI. SIMULATION RESULTS

For the validity investigation of the mentioned control strategy three different desired signals have been derived from the proposed approach have been shown in Figure 4. Also for power quality compensation of a distribution system as an applicable example, simulation of the test circuit of Figure 2 has been done in MATLAB software. Related equations of the controlled system have been compiled in MATLAB software via M-file.

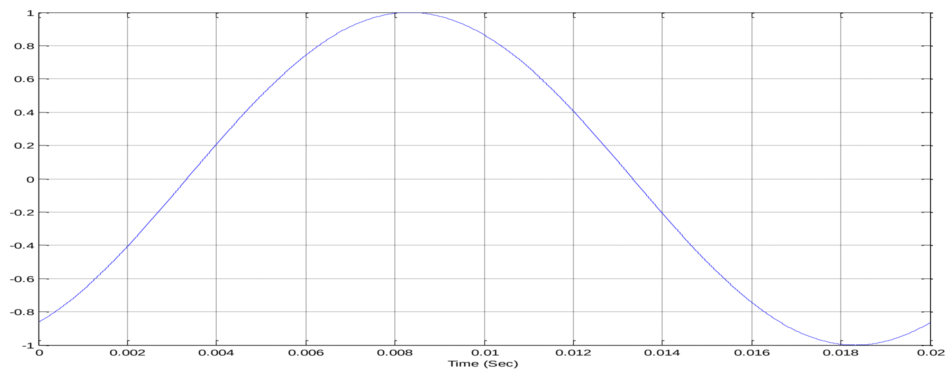
Desired values of a_1 and b_1 for voltage and current are used in the proposed algorithm for extraction of the reference signals waveforms.

The power system consists of a three phase 380 V (RMS, L-L), 50 Hz utility which its magnitude has been decreased and a nonlinear load.
A number of selected results will be showed further.

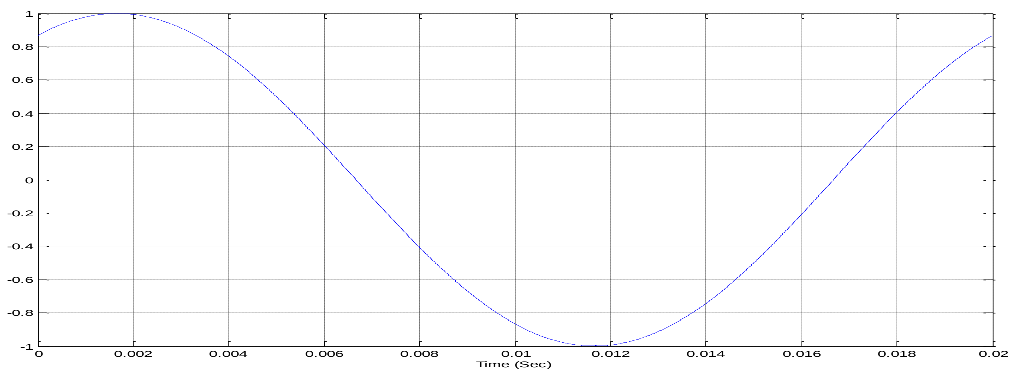
Figure 5 shows the source side voltage. Figure 6 shows the compensator voltage. Figure 7 shows load side voltage. Figure 8 shows the load side current. Figure 9 shows the compensator current. Finally, Figure 10 shows the source side current.



a



b



c

Figure 4. Sampled reference signals, a: $a_1 = 0, b_1 = 1$, b: $a_1 = \frac{-\sqrt{3}}{2}, b_1 = \frac{1}{2}$, c: $a_1 = \frac{\sqrt{3}}{2}, b_1 = \frac{1}{2}$

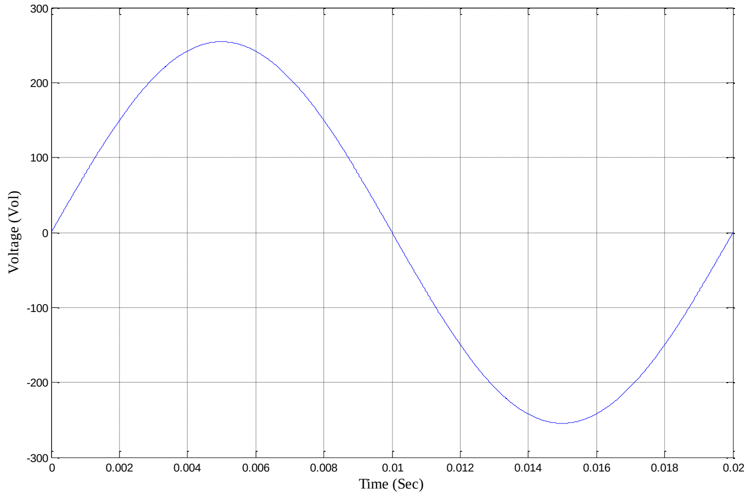


Figure 5. Source side voltage (This is figure of source voltage V_s, which is sinusoidal with magnitude of 253 volt. This is uncompensated voltage.)

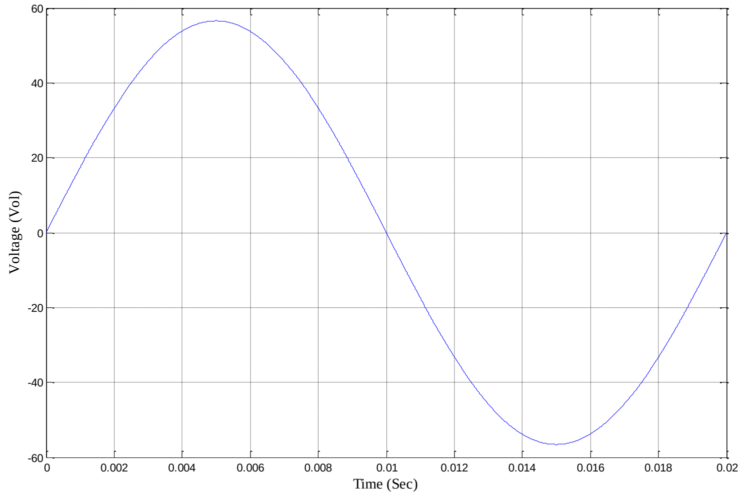


Figure 6. Compensator voltage (This is figure of the compensator voltage V_{comp}, which is for compensation of reduced magnitude of source voltage. Compensator voltage is summed by source voltage to generation of sinusoidal load voltage.)

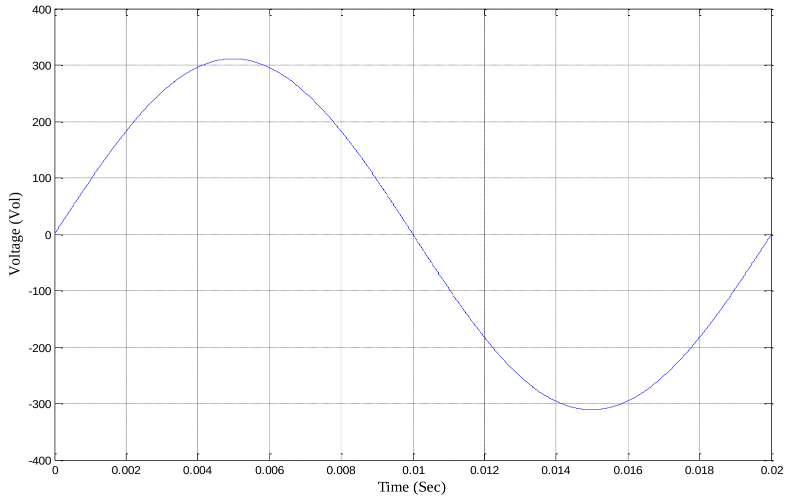


Figure 7. Load side voltage (This is figure of the load voltage V_{Load}, which is sinusoidal with magnitude of 310 volt. This is desired voltage.)

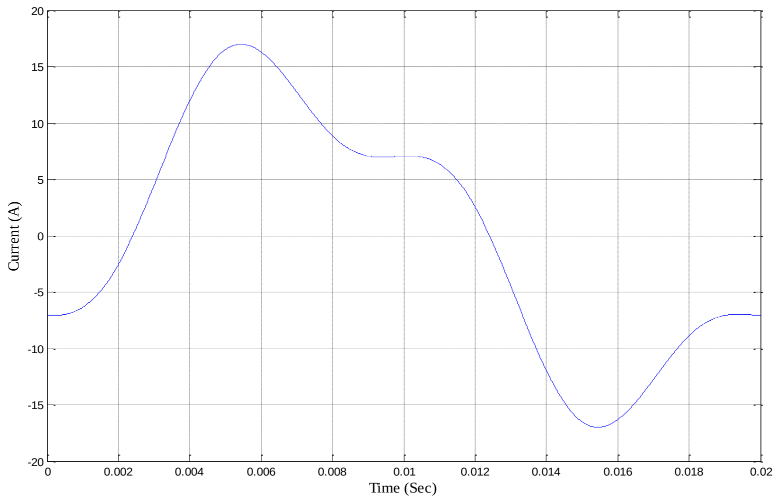


Figure 8. Load side current (This is figure of the load current I_{Load}, which is nonsinusoidal. This is uncompensated current.)

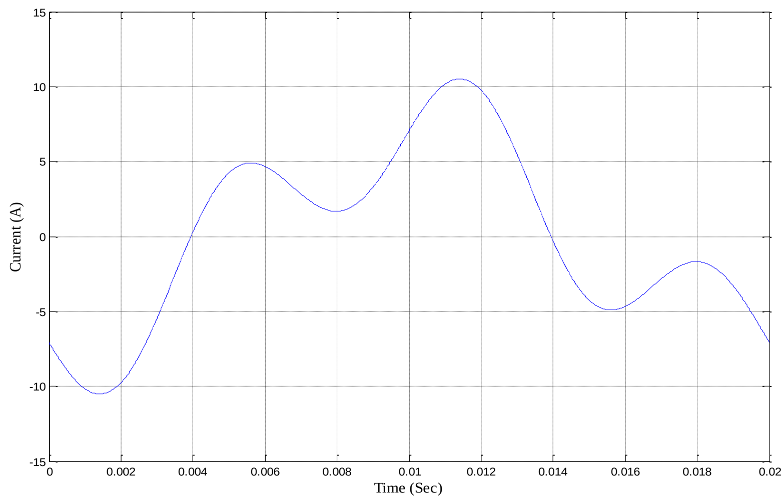


Figure 9. Compensator current (This is figure of the compensator current I_{comp}, which is for compensation of nonsinusoidal load current. Compensator current is summed by load current to generation of sinusoidal source current.)

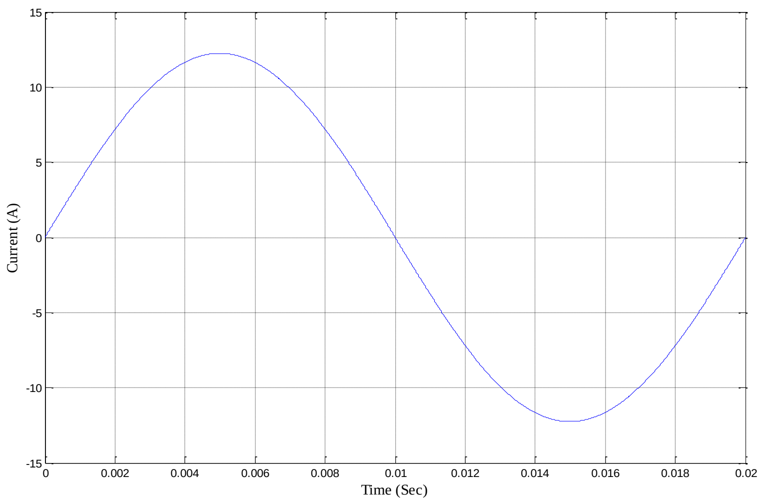


Figure 10. Source side current (This is figure of the source current I_s, which is sinusoidal. This is desired current.)

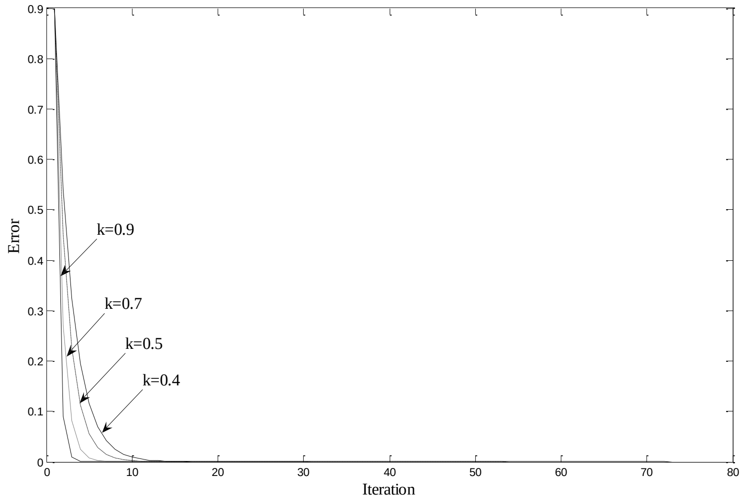


Figure 11. Error curve based on different k factors (This figure shows effect of the convergence factor in amount of error.)

VII. CONCLUSION

It is known that the proposed VFFT approach could reduce integral limit to one twelveth of a signal period. Composition of the VFFT and MOADALINE approaches can be used for waveform generation of different desired Fourier coefficients easily and rapidly. The proposed approach was used in an applicable example of electrical engineering for desired signals waveform generation. In this example power quality compensation was done by the use of UPQC. The related proposed approach was compiled in MATLAB software via M-File. Voltage problems have been compensated by SAF of the UPQC and current problems have been compensated by PAF of the UPQC. Based on the results proposed strategy can generate pure sinusoidal reference source current and load voltage.

NOMENCLATURES

i_L : The load current

v_s : The source current

$S(t)$: $n \times m$ component matrix at time t

$W(t)$: $m \times 1$ vector of weighted coefficient

$e(t)$: The error between desired and actual signal

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