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A Novel Compensation Based on Pi and Fuzzy Logic Controller for Matrix Converter System with Distorted Input Voltage and Harmonics

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ABSTRACT

Matrix converter is a single stage converter, which directly connects a three phase supply to a three phase load without dc link. If any harmonic distortion and imbalance in input voltage, it directly reflects to the output of the matrix converter. In this paper two different controller based compensation are discussed to rectify this problem, under distorted input voltage with harmonics of matrix converter and its controlled method are analyzed with PI controller and fuzzy controller based compensation system to prevent effects of distorted input voltage. The proposed method based on the closed loop control of output currents, not only reduces the output harmonic contents but also maintains the load currents. Finally results for the two different compensation systems are discussed and comparison is given for the development.

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INTRODUCTION

Matrix converter is providing direct AC-AC power conversion for Matrix converters firstly introduced in the year 1976 and its performance and usage of matrix converter is improved after the papers proposed by (Venturini, 1980) and (Alesina and Venturini, 1989).

The matrix converter has received an increased amount of interest and has been studied intensely as an alternative to overcome conventional indirect power converter systems in recent, because it has lot of advantages is follows (Huber and Borojevic, 1995), (Casadei ed al.,1998) and (Wheeler ed al.,2002).

- Input and output currents are sinusoidal
- No bulky dc-link reactive elements
- Unity displacement factor for any kind load is possible
- Multi quadrant operation
- Design is simple and compact
- Regeneration capability.

These properties attract the researchers to study about the matrix converter. Here the load side of Matrix Converter is directly affected by the distorted input voltages due to the lack of DC intermediate link in the Matrix Converter. The distorted non sinusoidal input voltages may cause the undesirable harmonic currents. The performance of the load has varied, when it is exposed to the harmonic and non sinusoidal currents in load side. The effects of distorted input voltages are eliminated from Matrix Converter will increase the popularity of the Matrix Converter. Some methods to reduce the effect of distorted input voltages have been discussed (Wheeler ed al., 2002), (Nielsen ed al., 1996), (Karaca and Akkaya, 2008) and (Sun ed al., 2004).

In this paper PI and Fuzzy logic control (FLC) based compensation technique are presented to eliminate the desirable effects of distorted input voltages for matrix converter controlled with optimum Venturini modulation method. Since this technique improving the output performance of the Matrix Converter performs closed loop control of the output current, three phase output currents of the Matrix Converter must be measured and given as a feedback to control system. Proposed method reduces the output harmonic contents and also protects the system from over current and control the load current. In this paper simulation results for compensated system are discussed for the proposed compensation techniques.

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II. Matrix Converter:

The matrix converter is a single-stage converter, which is composed of an array of m x n bidirectional power switches, each connected between one phase of the input and one phase of the output. Theoretically, the number of input phases, m must be at least three, and the number of output phases, n can be chosen from one to infinity. The basic matrix converter topology which connects a three phase voltage source to a three phase load is shown in Fig. 1. A matrix converter is also called as frequency changer, which is generating output frequency of the system which is greater than or less than the input frequency of the converter.

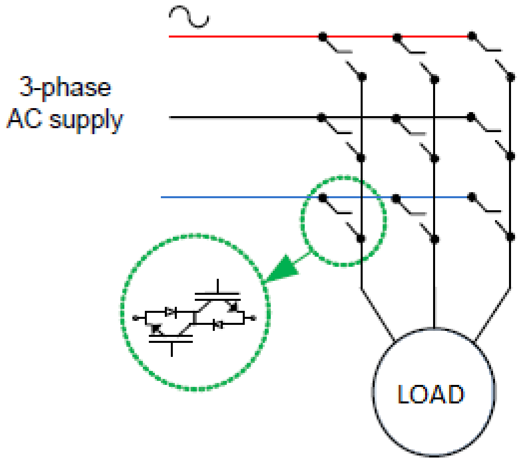

Fig. 1: Three phase matrix converter.

The two important things to be considered are input terminals should not be short circuited, because the Matrix Converter is fed by voltage source. Output phase must never be open circuited, owing to the fact that the absence of a path for the inductive load current leads to the over voltages(Alesina and Venturini, 1989),(Nielsen ed al ,1996). These constraints can be expressed by Eq. (1). When these rules are provided, the 3 x 3 matrix converter can allow only 27 different switching states among the possible 512 switching combinations (Casadei ed al.,1998), (Wheeler ed al.,2002), and (Sünter ed al., 2002).

$$\sum_{K=A,B,C} m_{Ka}(t) = \sum_{K=A,B,C} m_{Kb}(t) = \sum_{K=A,B,C} m_{Kc}(t) = 1 \qquad (1)$$

In this paper V_{sA},V_{sB},V_{sC} are source voltages , I_{sA},I_{sB},I_{sC} are source currents ,V_{jn} , j = {a, b, c} , are the load voltages with respect to the neutral point of the load n, and i_j , j = {a, b, c} , are the load currents. Additionally, other auxiliary variables have been defined to be used as a basis of the modulation and control strategies: V_i , i = {A,B,C} , are the MC input voltages, i_i , i = {A,B,C} , are the MC input currents, and V_{jN} , j = {a, b, c} , are the load voltages . Each switch S_{Kj} , K ={A, B,C}, j ={a, b, c} , can connect or disconnect phase K of the input stage to phase j of the load and, with a proper combination of the conduction states of these switches, arbitrary output voltages V_{jN} can be synthesized. Each switch is characterized by a switching function, defined as follows Eq. (2)

$$S_{ij}(t) = \begin{cases} 0 & \text{if switch } S_{Kj} \text{ is open} \\ 1 & \text{if switch } S_{Kj} \text{ is closed} \end{cases} \qquad (2)$$

Firing pulses for each of the nine bidirectional switches must be calculated to generate variable frequency and/or variable amplitude sinusoidal output voltage from the fixed frequency and the fixed amplitude input voltages. If it is defined as t_{Kj}, the time during which switch S_{Kj} is on, Ts: the sampling interval Eq. (3), duty cycle of switch S_{Kj}, modulation matrix is given in Eq. (4).

$$m_{Kj}(t) = \frac{t_{Kj}}{T_s} \qquad (3)$$

$$M(t) = \begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix} \qquad (4)$$

The sinusoidal input voltages of the matrix converter are given in Eq. (5)

$$\bar{v_i} = \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t - 2\pi/3) \\ \cos(\omega_i t + 2\pi/3) \end{bmatrix} \quad (5)$$

The sinusoidal output currents of the matrix converter can be given as in Eq. (6)

$$\bar{i_o} = \begin{bmatrix} \cos(\omega_o t + \varphi_o) \\ \cos(\omega_i t + \varphi_o - 2\pi/3) \\ \cos(\omega_i t + \varphi_o + 2\pi/3) \end{bmatrix} \quad (6)$$

Where φ_o is the output phase angle

In accordance with this, each output phase voltages can be expressed by Eq. (7).

$$[v_{jN}(t)] = [M(t)][v_i(t)] \quad (7)$$

In the same way, the input currents are in Eq. (8)

$$i_i(t) = [M(t)]^T [i_o(t)] \quad (8)$$

Where, $[M(t)]^T$ is the transpose matrix of [M (t)]. To obtain a maximum voltage transfer ratio is added common mode voltages to the target outputs voltages as shown in Eq. (9).

$$v_{jN}(t) = qV_{im} \begin{bmatrix} \cos(\omega_o t) - \frac{1}{6}(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t) \\ \cos\left(\omega_o t + \frac{2\pi}{3}\right) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t) \\ \cos\left(\omega_o t + \frac{4\pi}{3}\right) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t) \end{bmatrix} \quad (9)$$

Where, q is the voltage gain. The common mode voltages have no effect on the output line-to-line voltages, but allow the target outputs to fit within the input voltage envelope with a value of q up to 86.6%. It should be noted that a voltage ratio of 86.6% is the intrinsic maximum for any modulation method where the target output voltage equals the mean output voltage during each switching sequence (Wheeler ed al.,2002). The formal statement of the algorithm, including displacement factor control, in Venturini's method (Alesina and Venturini, 1989) is rather complex and appears unsuited for real time implementation. In fact, if unity input displacement factor is required, and then the algorithm is simpler. In the modeled system, firstly, the power circuit, including nine bidirectional switches was designed. Then, an input filter and a clamp circuit were modeled to smooth distortion of the input current and to prevent damaging of the power switches due to over voltages or over currents possibly occurring during commutation, respectively. Then, duty cycles of bidirectional switches were calculated according to Eq. (10).

$$t_{Kj} = T_s\left[\frac{1}{3} + \frac{2v_K v_j}{3V_{im}^2} + \frac{2q}{9q_m}\sin(\omega_i t + \beta_K)\sin(3\omega_i t)\right] \quad (10)$$

The switching functions ($S_{Kj}(t)$), will determine the turn on time of switches which is obtained according to the logic in eq. (11) by using duty cycles.

$$\begin{aligned} S_{Aj} &= (X) \\ S_{Bj} &= not(X)\ and\ (Y) \qquad j = \{a, b, c\} \\ S_{Cj} &= not(X)\ and\ not\ (Y) \end{aligned} \quad (11)$$

PI, FLC Compensation System:

Modulation algorithms used in the Matrix Converter have employed fixed switching patterns under the normal input voltage conditions. For certain frequency and/or amplitude values, duty cycles of the power switches are pre calculated and placed into the table. But the disturbance reflects the outputs of the converter under the distorted input voltage conditions, using the fixed switching patterns are not appropriate. Therefore, duty cycles for switching patterns must be calculated instantaneously by measuring the output currents at each sampling period (Filho ed al., 2006).

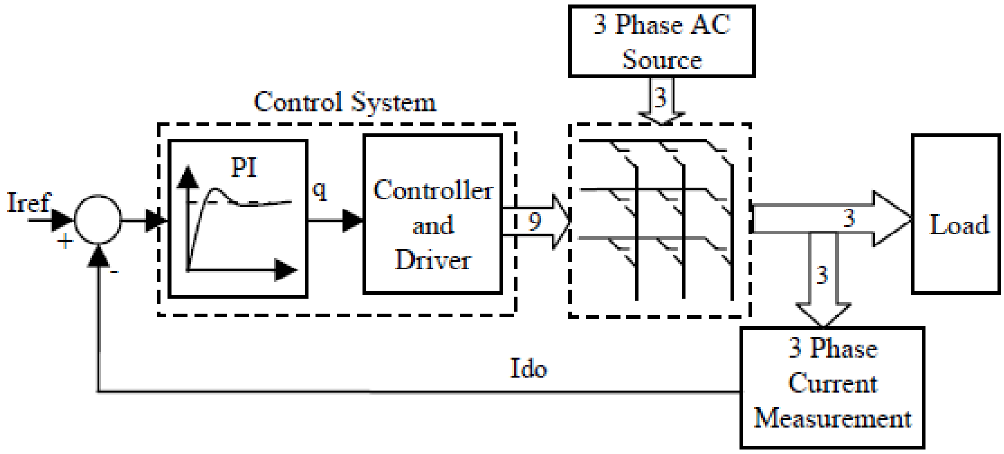

Fig. 2: PI Based Matrix converter System.

In the Matrix Converter, which is shown schematically in Fig. 2, the measured output currents are used to calculate the magnitude of the output current space vector (I_{do}) according to Eq. (12).

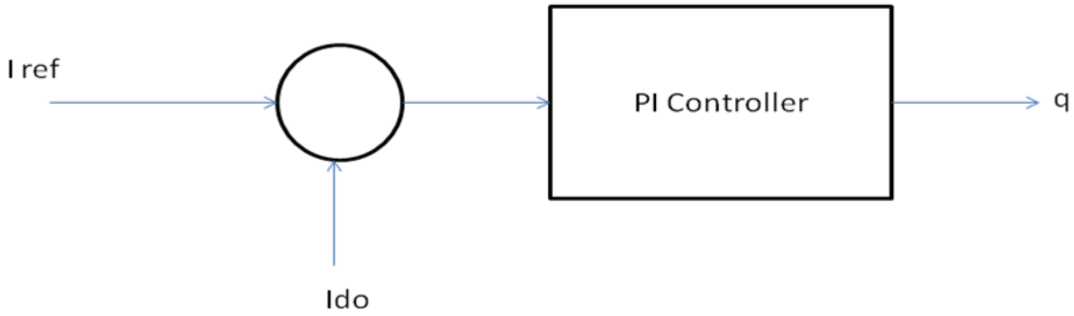

Fig. 3: PI Control System.

$$I_{do} = \sqrt{\frac{2}{3}\sum_{j=a,b,c} i_j^2(t)} \tag{12}$$

If the input voltages of the Matrix Converter are sinusoidal and balanced, the output currents will be sinusoidal, under this condition, I_{do} is constant. However, if the input voltages of the Matrix Converter are nonsinusoidal and unbalanced, I_{do} will be not constant due to the output harmonic currents (Filho *et al*., 2006), (Rodriguez *et al* ., 2005). If I_{do} is kept constant, the output of the converter is not affected by disturbances in the input voltages. The proposed compensation technique is based on this principle. Fig.3 PI controller, Fig.4 FLC controller are employed for this purpose. Accordingly, the fuzzy logic control system shown in Fig.5 is fed by the instantaneous error of I_{do} ($e(k)$) in Eq. (13) and the change of error ($\Delta e(k)$) in Eq. (14) and produces a variable voltage-gain q according to the disturbance of the input voltage.

$$e(k) = [I_{ref}(k) - I_{do}(k)] \tag{13}$$

$$\Delta\, e(k) = [e(k) - e(k-1)] \tag{14}$$

The instantaneous value of the error can be calculated by subtracting I_{ref} from the current space vector obtained by the measured three-phase output current. The change of error is the difference between present and previous values of the error.

The output of the FLC system is the change of voltage gain (Δq) and its value is between -1 and +1 according to rule base. Actual voltage gain is calculated by adding the previous value and the change of the voltage gain, as seen in Eq. (15). A saturation block has been supplemented, due to the magnitude of q cannot exceed 0.866 and cannot be negative. Totally there are 49 rules developed for the fuzzy control systems.

$$q(k) = [q(k-1) + \Delta q(k)] \tag{15}$$

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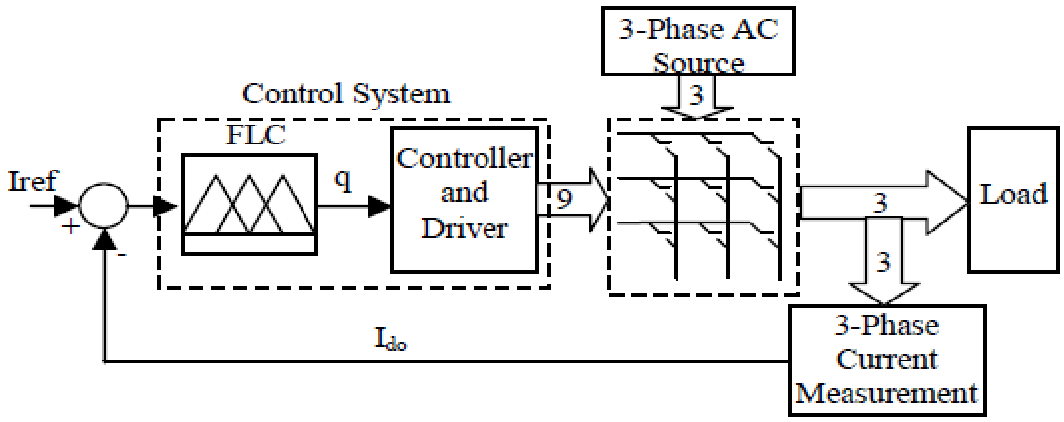

Fig. 4: FLC Based Matrix converter System.

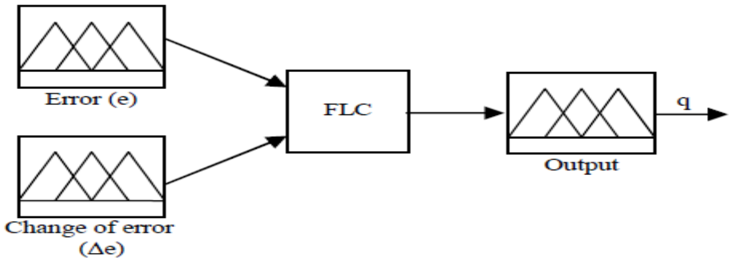

Fig. 5: Fuzzy logic control.

Simulation Results:

Simulation results for the matrix converter based system is given for the input voltage of 440 V and 50 Hz supply frequency with bridge rectifier, simulation done by the input voltage with fifth order harmonics are represented in Fig.6 ,output voltage before compensation is shown in Fig.7,output voltage after compensation(PI controller) is given in fig.8. Output voltage after compensation (FLC controller) is given in fig.9.

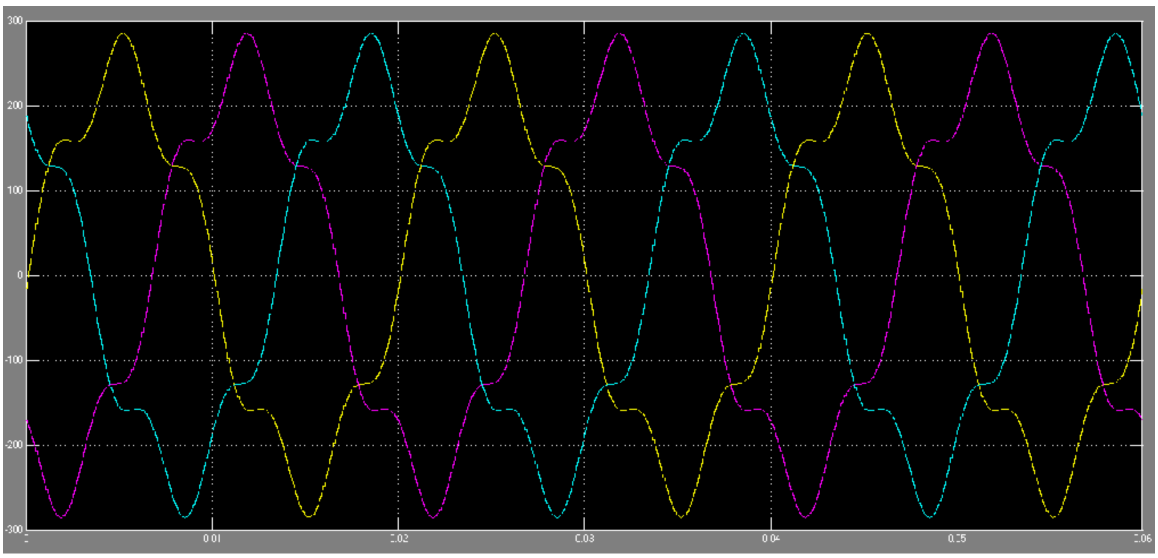

Fig. 6: Distorted input voltages waveform.

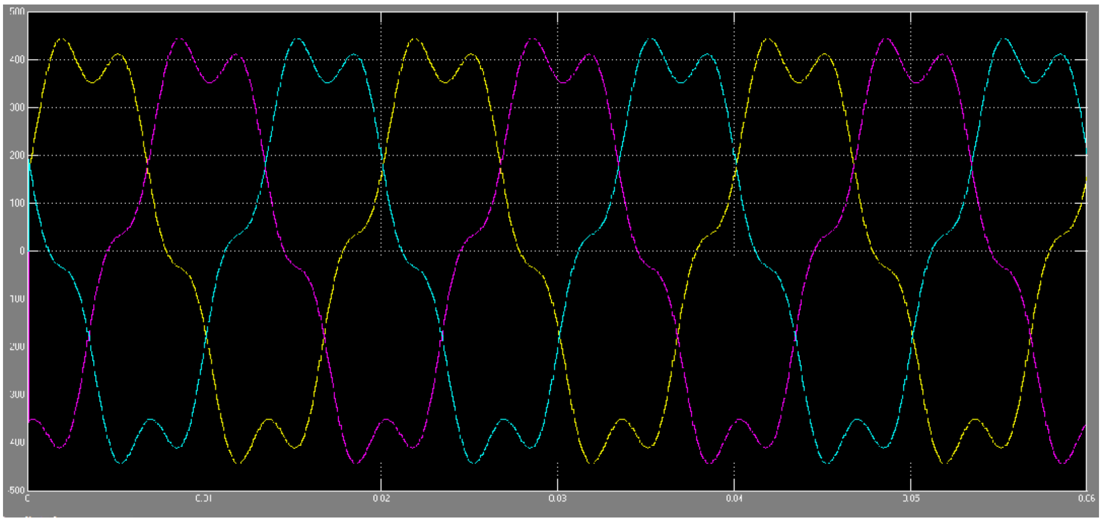

Fig. 7: Output voltage before compensation.

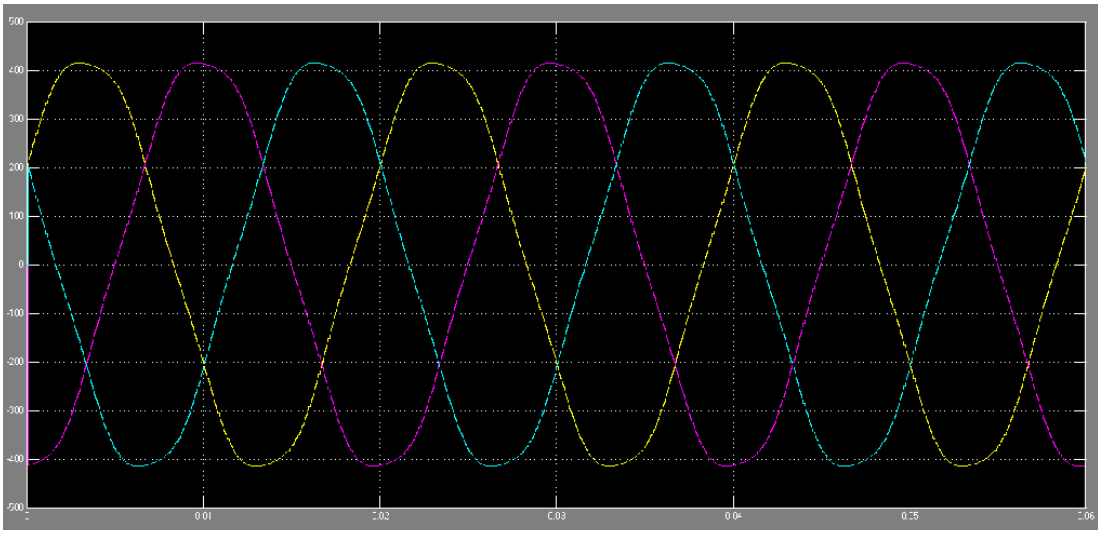

Fig. 8: Output voltage for PI controller system (compensated).

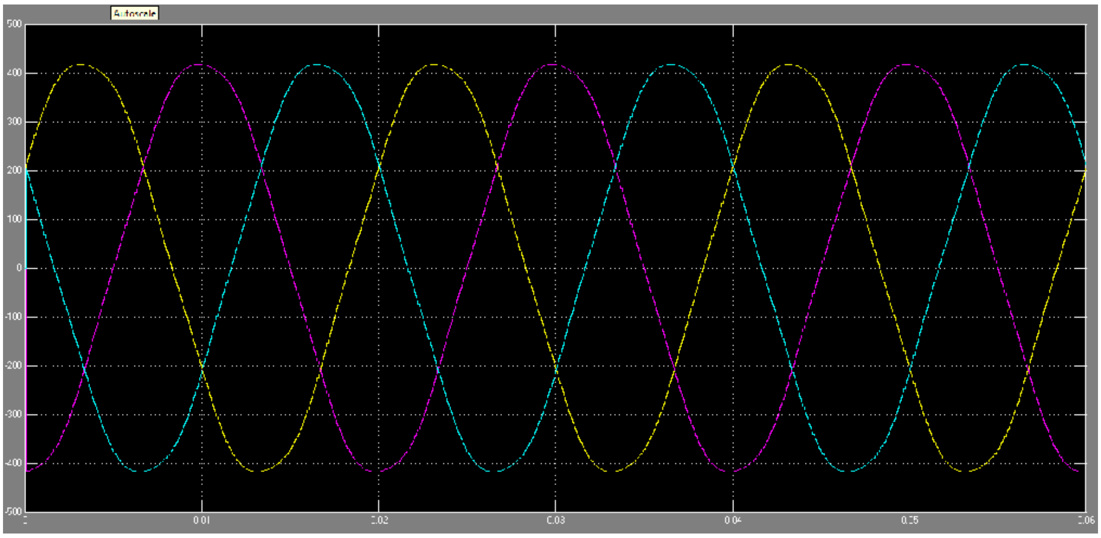

Fig. 9: Output voltage for FLC controller system (compensated).

Total harmonic distortion for input voltages 16.6% for (uncompensated), 3.05% is the total harmonics distortion (PI controller) and 2.23% THD (fuzzy logic controller). As it is shown, if the input voltage of the Matrix Converter is distorted and low order harmonics occur, the output voltage and current of proposed system eliminates the distorted voltage and current.

RESULTS AND DISCUSSION

In this paper, PI and FLC based compensation system are proposed which perform the close loop control of the output current to improve the output performance of the Matrix Converter. The proposed method has eliminated harmonics from the output currents and voltages under the distorted input voltage conditions. This method reduces output harmonic contents and also control of the load current within the allowable limit. Simulation results show that this compensation scheme is effectively reducing the harmonics of output voltage and current.

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