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Harmonics Reduction Using ANFIS Controller Based Matrix Converter System

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Abstract: Matrix converter allows the direct ac/ac power conversion without dc energy storage links, in this study matrix converter and its working principles with harmonics in input side is analyzed. A model is proposed to represent the matrix converter, power semiconductors are modeled as ideal bidirectional switches and the matrix converter is controlled using ANFIS (Adaptive Neuro-Fuzzy Inference System) combine with optimum Venturini Modulation Method. The study deals the method to be utilized to eliminate the harmonics which is present in input supply side of matrix converter. Simulation for Matrix Converter System which shows the effectiness of proposed compensation scheme is discussed with MATLAB simulation results.

Key words: Matrix converter, ANFIS, ac-ac converter, optimum, supply

INTRODUCTION

The matrix converter is an array of bidirectional switches functioning as the main power elements. It interconnects directly the three phase power supply to a three phase load without using any dc link or large energy storage elements. The most important characteristics of MCs are as follows (Venturini, 1980; Rodriguez *et al*., 2005): a simple and compact power circuit, generation of load voltage with arbitrary amplitude and frequency, sinusoidal input and output currents, operation with unity power factor and regeneration capability. These highly attractive characteristics are the reason for the tremendous interest in this topology.

The development of this converter starts with the early research by Venturini (1980). They presented the power circuit of the converter as a matrix of bidirectional power switches and they introduced the name matrix converter. In their modulation method also known as the direct transfer function approach, the output voltages are obtained by the multiplication of the modulation matrix with the input voltages. A conceptually different control technique using the 'fictitious dc link' idea was introduced (Alesina and Venturini, 1989).

In this study, ANFIS based compensation technique are presented to eliminate the effects of harmonics in input voltages for matrix converter controlled by 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 study, simulation results for compensated system are discussed for the proposed compensation techniques.

MATRIX CONVERTER CONTROL METHOD

The matrix converter is a single stage direct ac-ac converter which has an array of m×n bi-directional power switches that can directly connect an m-phase voltage source to an n phase load as by Zuckerberger *et al.* (1997) and Wheeler *et al.* (2002). A three phase matrix converter consists of 3×3 switches arranged in matrix form. The arrangement of bidirectional switches is such that any of the input phases A, B, C is connected to any of the output phases a, b, c. The switches are controlled in such a way that the average output voltage is sinusoidal of desired frequency with desired amplitude. The 3×3 switches give 512 combinations of switching States. under the consideration of two rules: input phase should not be short circuited and output current should not be interrupted due to this constrain only 27 switching combination can be done in three phase to three phase matrix converter. This constraints is given in Eq. 1.

Figure 1 shows the three phase matrix converter, 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

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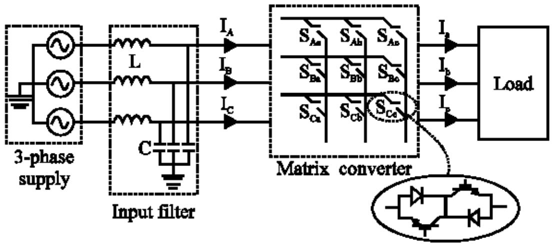

Fig. 1: Three phase matrix converter

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 in Eq. 2:

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

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

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, T_s: the sampling interval Eq. 3, duty cycle of switch S_{Kj}, modulation matrix is given in Eq. 4:

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

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

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

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

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

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

where, φ_o is the output phase angle. In accordance with this, each output phase voltages can be expressed by Eq. 7:

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

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

$$I_i(t) = [M(t)]^T [I_o(t)] \tag{8}$$

where, $[M(t)]^T$ is the transpose matrix of [M(t)]. To obtain a maximum voltage transfer ratio is added common mode voltages (Huber and Borojevic, 1995) to the target outputs voltages as shown in Eq. 9:

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

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 *et al*., 2002). The formal statement of the algorithm including displacement factor control by Venturini (1980)'s Method 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 (Casadei *et al*., 1998) and to prevent damaging of the power switches due to over voltages or over currents possibly occurring during commutation (Wheeler *et al*., 2002), respectively. Then, duty cycles of bidirectional switches were calculated according to Eq. 10:

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

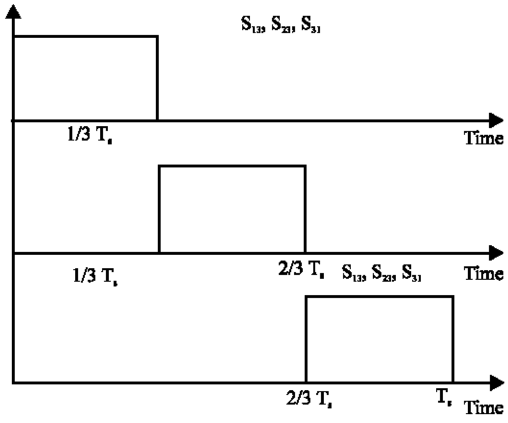

Fig. 2: Switching pattern of matrix converter

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. Figure 2 represents the simple switching pattern for matrix converter (Huber and Borojevic, 1995):

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

ANFIS BASED CONTROL SYSTEM

This method introduces the basics of ANFIS network architecture and its hybrid learning rule by combining a idea of fuzzy logic inference procedure on a feed forward network structure (Wheeler *et al*., 2002), proposed an Adaptive Network based Fuzzy Inference System (ANFIS), Adaptive Neural Fuzzy Inference System with matrix converter system is shown in Fig. 3. ANFIS architecture can be employed to eliminate the input harmonics which is present in the system.

It is a hybrid neuro-fuzzy technique that brings learning capabilities of neural networks to fuzzy inference systems (Jang, 1993). The Learning algorithm tunes the membership functions of a Fuzzy Inference System using the training input-output data. The ANFIS is from the topology point of view, an implementation of a representative fuzzy inference system using a Back Propagation (BP) neural network like structure (Nielsen *et al*., 1996).

In the matrix converter which is shown schematically in Fig. 3, the measured output currents are used to calculate the magnitude of the output current space vector (I_{do}) according to Eq. 12. Figure 4 shows the ANFIS based compensation is working to correct the harmonic content which is present in the input side of the matrix converter:

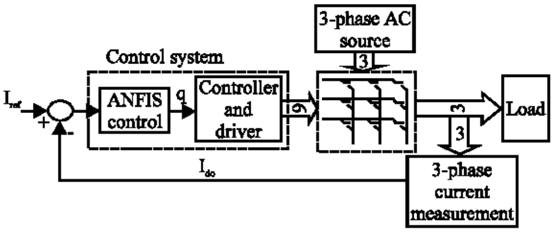

Fig. 3: Matrix converter system with ANFIS controller

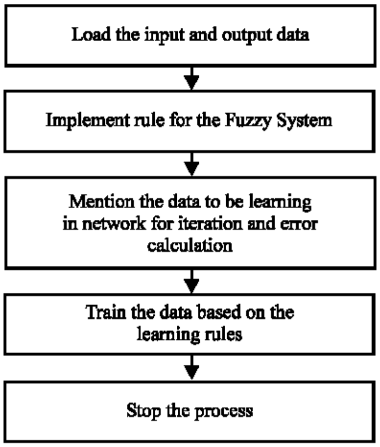

Fig. 4: ANFIS algorithm flowchart

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

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

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

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

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 in Eq. 12. The output of the ANFIS System is the change of voltage gain (Δq) and its value is according to rules. 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 implemented to maintain the magnitude of q cannot exceed 0.866 and below zero.

SIMULATION RESULTS

The input and output data pairs for training the ANFIS were generated. ANFIS structures with Fuzzy

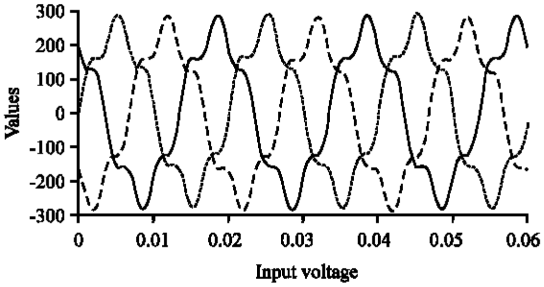

Fig. 5: Input voltage waveform with harmonics

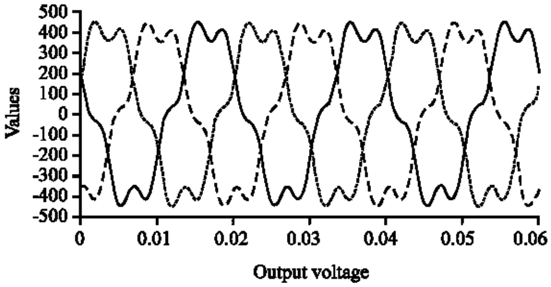

Fig. 6: Output voltage before compensation

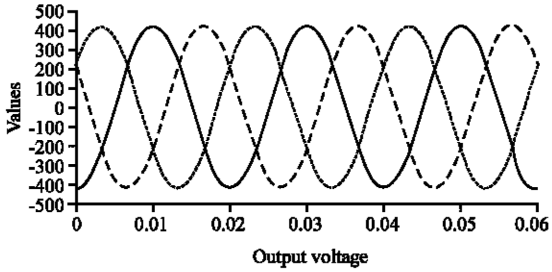

Fig. 7: Output voltage after compensation

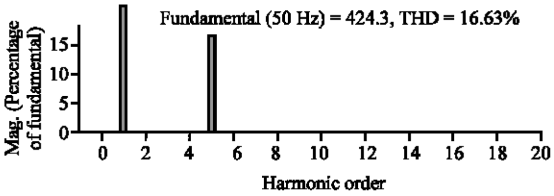

Fig. 8: Total harmonics distortion for input voltage

Model containing 25 rules have been considered. The proposed controller is generated by ANFIS training according to a given input and output data. Figure 5 shows the 440 V, 50 Hz, three phase input supply with 5th order harmonics, output voltage for matrix converter system without compensation is represented in Fig. 6. ANFIS based compensation system output voltage with eliminated harmonics wave is in Fig. 7. Total harmonic distortion for input voltages 16.63% for (uncompensated)

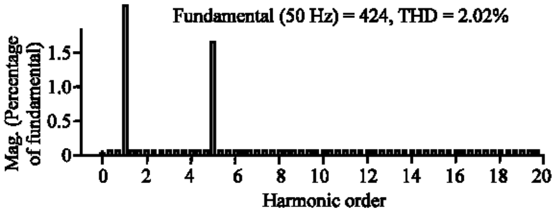

Fig. 9: Total harmonics distortion for output voltage (compensated system)

is in Fig. 8, 2.02% is the total harmonics distortion for the compensated system as it is shown in Fig. 9 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.

CONCLUSION

In this study, ANFIS based compensation system is proposed which perform control the input voltage of the matrix converter system with 5th harmonics to improve the output performance of the matrix converter. This proposed method has eliminated the harmonics from output currents and voltages under distorted/harmonic 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 to reduce the harmonic voltage and current in its limit. So, this proposed system is effectively control to achieve sinusoidal voltage and current.

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