Fuzzy Logic Control Based Matrix Converter for Improvement Output Current Waveforms based Wind Turbine System

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Abstract-With the rise of climate change problems, the use of clean energy sources becomes a priority. In this context, the evolution of wind farms is very recognized in the this new trend. The converters currently are an essential means in the performance of the wind turbine system, doubly-fed induction generator (DFIG) and power electronic equipment. In order to improve the performance of the wind turbine systems, in this paper an associated linear RL load – matrix converter under supply voltage connected system is studied. The influence of disturbed input supply voltage on output current waveforms has been discussed. We aim to extract sinusoidal output current waveforms, the conventional PWM methods and the optimum Venturini method with fuzzy logic control approach can be applied for controlling the matrix converter. Finally, Simulations results will be presented and interpreted, and a special attention is given to suppressing harmonic pollutions using total harmonic distortion evaluation.

Keywords Renewables energy, Wind turbine; DFIG; Matrix converter; Fuzzy logic control; PWM; power quality.

1. Introduction

In the last years, we can observe very fast development of new electrical power sources named renewable sources, like solar, wind and water flow, biogas, biomass….etc. Using a doubly-fed induction generator based wind turbine system, which converts mechanical power to electricity [1], offers the following advantages: possible at variable rotor speed, optimization at power generated, elimination of sudden variations in the rotor torque and generator output power, generation of electrical power at lower wind speeds of rotor, and the control of the power factor in order to obtain power factor at unity.

The paper proposes a novel wind energy generation scheme, which is based on an direct three phase matrix converter(MC) and a doubly-fed induction generator (DFIG), fig.1.

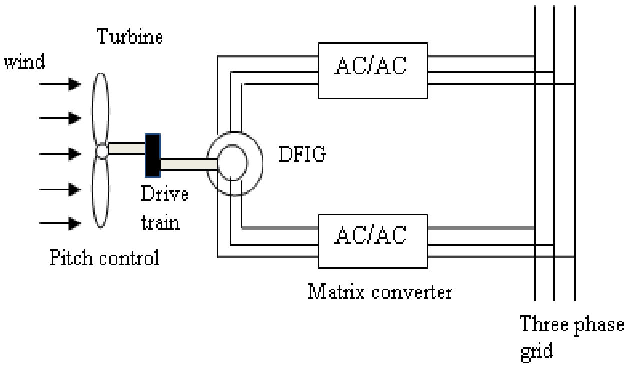

Fig.1. System Diagram of a DFIG-and matrix converter Based Wind Turbine System

The three phase matrix converter (TMC) is a important solution for the most appropriate remediation at both the AC-AC conversion [2]. The general concept of them is a single-stage converter, constructed by nine bidirectional power switches. Its structure topology was first described in 1976 Gyugyi [3], This converter allows both absorbance sinusoidal current networks, low consumption of reactive power, high power density, high capacity and potentially high reliability [4,5].

With the aim to clean up the networks and ensure good quality of energy conversion electric. This paper presents a model containing a linear passive RL load connected to the grid supply voltage via a three phase matrix converter (TMC).Objective of the work to improve power quality produced by wind turbines, to obtain essentially sinusoidal output current waveforms, shown as fig. 2.

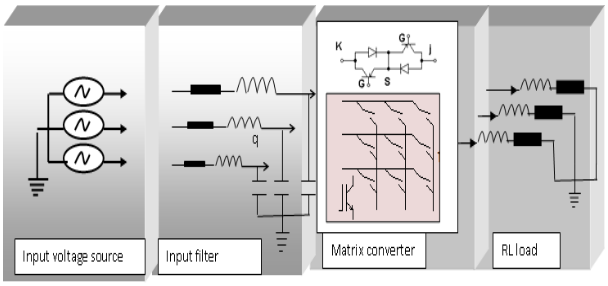

Fig. 2. Simplified representation of a matrix converter – three phase grid connected system

2. Three phase matrix converter

Three phase matrix converter (TMC) is a single stage direct AC/AC conversion, which perform is an array of controlled semiconductor switches that directly connect each input phase to each output phase, without any intermediate DC link. The nine bidirectional power switches (usually IGBT transistors with anti parallel diode) [4,5,6], connected to a passive input filter (RLC) to entry used in order to reduce the input harmonics current pollution [7,8]. The development studied of TMC started when Alesina and Venturini proposed the basic principles of operation in the early 1980's [7,8]. It has received an increased amount of interest and has been studied intensely as an alternative to conventional AC/DC/AC indirect power converter systems for many power supply applications.

The main advantage of TMC, because it allows not only, sinusoidal current absorbance from the network, but also zeros consumption of reactive power, it has high frequency operation, high power density, high capacity and potentially high reliability[5,9,10].

The input voltage of matrix converter is given by:

$$v_i(t) = \begin{cases} v_{AN}(t) = v_{im}\cos(\omega_i t) \\ v_{BN}(t) = v_{im}\cos(\omega_i t - \frac{2\pi}{3}) \\ v_{CN}(t) = v_{im}\cos(\omega_i t - \frac{4\pi}{3}) \end{cases} \tag{1}$$

The input current of matrix converter is given by:

$$i_i(t) = \begin{cases} i_A(t) = i_{im}\cos(\omega_i t + \varphi_i) \\ i_B(t) = i_{im}\cos(\omega_i t - \frac{2\pi}{3} + \varphi_i) \\ i_C(t) = i_{im}\cos(\omega_i t - \frac{4\pi}{3} + \varphi_i) \end{cases} \tag{2}$$

The effective approach to obtain sinusoidal output voltage and currents determined respectively by following equations:

$$v_j(t) = \begin{cases} v_{aN}(t) = v_{om}\cos(\omega_o t) \\ v_{aN}(t) = v_{om}\cos(\omega_o t - \frac{2\pi}{3}) \\ v_{cN}(t) = v_{om}\cos(\omega_o t - \frac{4\pi}{3}) \end{cases} \tag{3}$$

$$i_j(t) = \begin{cases} i_a(t) = i_{om}\cos(\omega_o t + \varphi_o) \\ i_b(t) = i_{om}\cos(\omega_o t - \frac{2\pi}{3} + \varphi_o) \\ i_c(t) = i_{om}\cos(\omega_o t - \frac{4\pi}{3} + \varphi_o) \end{cases} \tag{4}$$

The nine switches Sij of matrix converter are constructed a connection function Sij (t) defined by the following equations [5,6,11] :

$$S_{ij}(t) = \begin{cases} 0 \quad \textit{if} \text{ switch } S_{ij} \ \textit{open} \\ 1 \quad \textit{if} \text{ switch } S_{ij} \ \textit{closed} \end{cases} \tag{5}$$

With i = A, B, C and j = a, b, c

We define the nine average value $m_{ij}(t)$ of the connection function $S_{ij}(t)$ generation function of the nine switches S_{ij} defined by :

$$m_{ij}(t) = \frac{1}{T_p}\int_0^T S_{ij}(t)dt \quad with \quad 0 < m_{ij}(t) > 1 \tag{6}$$

T_p : period of switching

$$\begin{cases} m_{Aa}(t) + m_{Ba}(t) + m_{Ca}(t) = 1 \\ m_{Ab}(t) + m_{Bb}(t) + m_{Cb}(t) = 1 \\ m_{Ac}(t) + m_{Bc}(t) + m_{Cc}(t) = 1 \end{cases} \tag{7}$$

All the generation functions form a matrix called modulation matrix M (t) as:

$$M(t) = \begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix} \tag{8}$$

The conversion matrix of MC connects the electrical as follows:

$$v_j(t) = M(t) \cdot v_i(t) \tag{9}$$

$$i_i(t) = M(t)^T \cdot i_j(t) \tag{10}$$

Where, $M(t)$ and $M(t)^T$ are modulation matrix and its transposed.

3. Using optimum venturini method

In the optimum Venturini method to obtain the transfer ratio maximum voltage ‘’q’’ of the output voltage and input voltage of matrix converter it’s necessary to added a third harmonic frequency in the input and output voltage as given [7,8,11] :

$$v_j(t) = \begin{cases} v_{aN}(t) = qv_{im}(\cos(\omega_o t) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t)) \\ v_{bN}(t) = qv_{im}(\cos(\omega_o t + \frac{2\pi}{3}) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t)) \\ v_{cN}(t) = qv_{im}(\cos(\omega_o t + \frac{4\pi}{3}) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t)) \end{cases} \tag{11}$$

when, ‘’q ’’ is the transfer ratio voltage between the output v_{jm} and input voltage v_{im}, determinate by the flowing equation :

$$q = \frac{v_{jm}}{v_{im}} \quad with \quad 0 < q \geq 0.86 \tag{12}$$

Similarly, The modulations function according to the optimal amplitude according are given by[9]:

$$m_{ij}(t) = \frac{1}{3} \cdot \begin{vmatrix} 1 + \frac{2v_i v_j}{v^2_{im}} + \frac{4q}{3.\sqrt{3}}\sin(\omega_i t)\sin(3\omega_i t) \\ 1 + \frac{2v_i v_j}{v^2_{im}} + \frac{4q}{3.\sqrt{3}}\sin(\omega_i t + \frac{2\pi}{3})\sin(3\omega_i t) \\ 1 + \frac{2v_i v_j}{v^2_{im}} + \frac{4q}{3\sqrt{3}}\sin(\omega_i t + \frac{4\pi}{3})\sin(3\omega_i t) \end{vmatrix} \tag{13}$$

when the switching time were calculated according to equation:

$$t_{ij}(t) = \frac{m_{ij}(t)}{T_p} \tag{14}$$

The carrier signal is tooth an equation defined by:

$$u_p(t) = \frac{1}{T_p} t \qquad 0 \leq t \geq T_p \tag{15}$$

Finally, the nine impulsion switches of matrix converter are obtained by using a simple logic binary:

$$\begin{cases} G_{Aj} = X_j \\ G_{Bj} = \bar{X}_j \ \ et \ \ Y_j \\ G_{Cj} = \bar{X}_j \ \ et \ \ \bar{Y}_j \end{cases} \tag{16}$$

j = a, b, c

The sequence algorithm of control switches for matrix converter, as shown in Fig. 3.

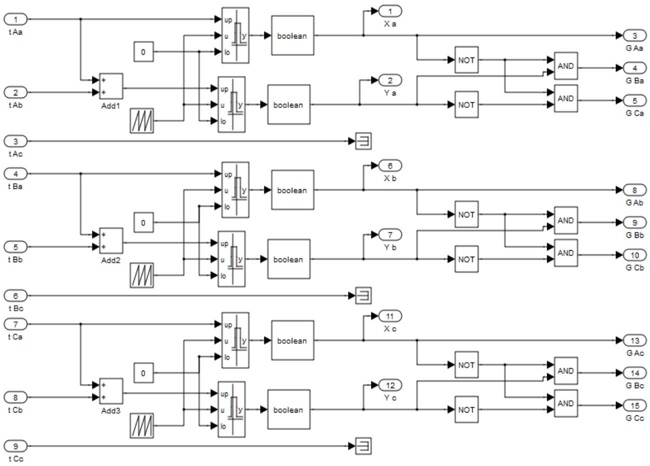

Fig. 3. Sequence algorithm of control switches

4. Control of Output Currents waveforms

The measured output currents are used to calculate the magnitude “id0’’ according to the following equation :

$$i_{do} = \sqrt{\frac{2}{3}(i_a{}^2(t) + i_b{}^2(t) + i_c{}^2(t))} \tag{16}$$

The maximum value of the reference of ‘’ id0’’ is obtained by:

$$i_{doref\_\max} = \frac{q \cdot v_{im}}{\sqrt{(R^2 + (L\omega)^2}} \tag{17}$$

By keeping ‘’id0 ‘’ constant, the output of the converter is not affected by disturbances harmonics in the input voltages. We propose, the use of a fuzzy logic controller [10-13], for controlling the magnitude of the output current via the control of the voltage transfer ratio “q”

The instantaneous error e(k) between ido and its reference is given by :

$$e(k) = (id_o(k)_{ref} - id_{oref}(k)) \cdot \alpha \tag{18}$$

The change of the error can be calculated by:

$$\Delta e(k) = (e(k) - e(k-1)) \cdot \beta \tag{19}$$

α and β are the normalization coefficients [11].

The proposed FLC is based on rule base given in Tabale.1.

Table1. The Fuzzy control rules

e(k) $\Delta e(k)$	N	Z	P
N	PB	PM	PB
Z	PB	PS	PB
P	PB	PM	PB

The bloc diagram of FLC is illustrated in figure.3. The output of the fuzzy regulator gives the voltage transfer ratio, so the actual value of q is obtained by adding the previous value q(k-1) and the change of the voltage transfer ratio $\Delta q(k)$, according to equation :

$$q(k) = q(k-1) + \Delta q(k) \tag{20}$$

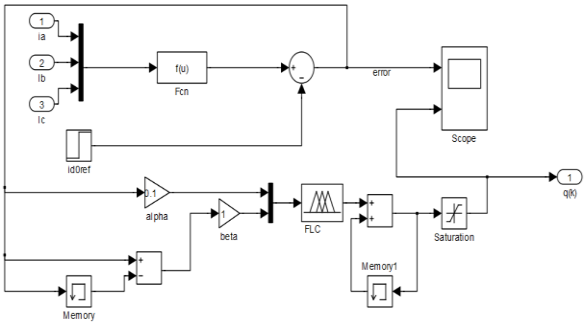

Fig.4. Block diagram to obtain the voltage transfer ratio

5. RL passive load model

The RL load model is represented by the following equations:

$$\begin{cases} v_a(t) = R \cdot i_a(t) + L \dfrac{di_a(t)}{dt} \\ v_b(t) = R \cdot i_b(t) + L \dfrac{di_b(t)}{dt} \\ v_c(t) = R \cdot i_c(t) + L \dfrac{di_c(t)}{dt} \end{cases} \tag{21}$$

6. Simulation results

The schema blocs of simulations is made utilizing MATLAB/SIMULINK. This software represents all the switches as ideal switches. The PWM signal, output current and output voltage waveforms are obtained to test the feasibility of proposed control method. The parameters of the converter for the MATLAB simulation are : Input voltage RMS V=220 V, frequency f i = 50Hz, Switching frequency: fs = 10 kHz, Linear RL Load: L = 30 mH, R =10 Ω,

6.1. In the normal input grid voltage

This first simulation was performed with purely sinusoidal input voltage. In order to test the robustness of the studied system, we have changed the ido reference form 10A to 6 A at t= 0.1s. Figures 5,6 and 6, show successfully the waveforms of input voltage, line to line output voltage of TMC
And simple output voltage of MC. Figure 7 and Figure 8 presents the output currents waveforms, spectrum harmonics analysis of a single phase input currents respectively. Finally, figure 9 and 10 gives respectively the evolution of ido (with its reference) and the voltage transfer ratio.

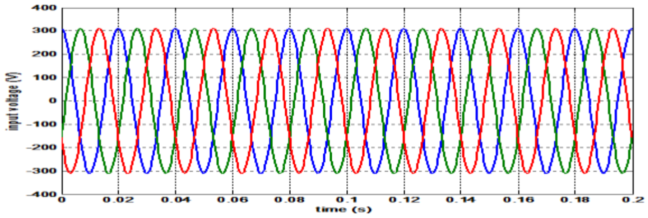

Fig. 5. Input voltage

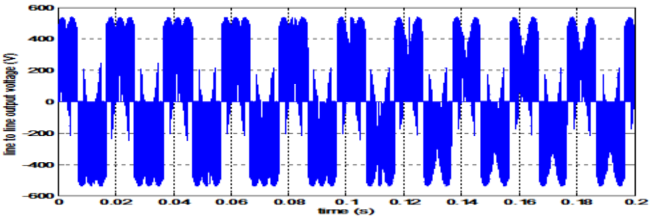

Fig. 6. Line to line output voltage

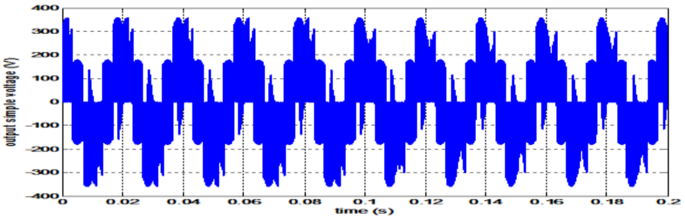

Fig. 7. Simple output voltage

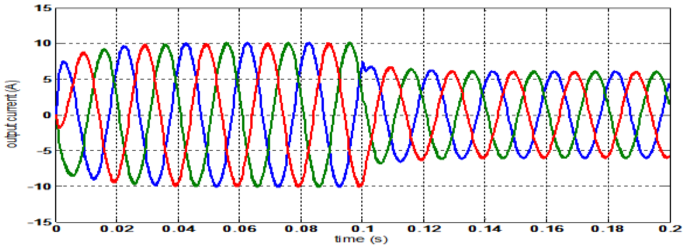

Fig. 8. Output currents waveforms

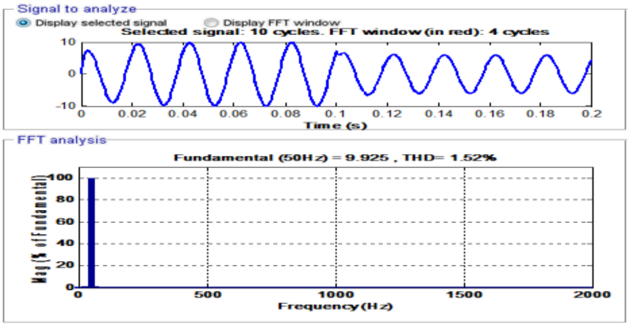

Fig. 9. Spectrum harmonics analysis of a single phase output current

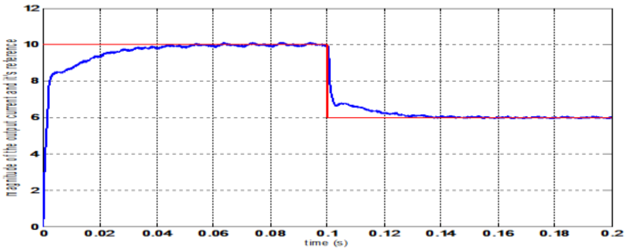

Fig. 10. Magnitude of the output current and it's reference

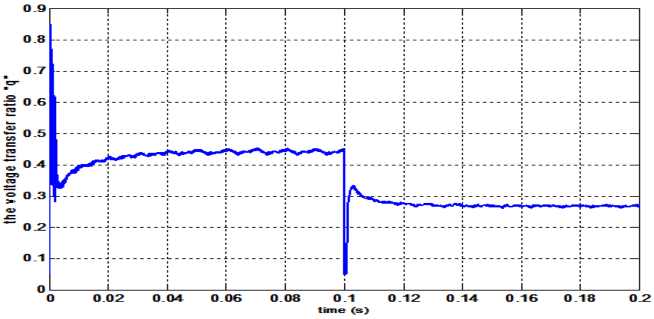

Fig. 11. Voltage transfer ratio

Simulation results show clearly the effectiveness of the proposed FLC witch forces the ido to follow perfectly its reference. It was also verified that both output currents waveforms of MC are nearly sinusoidal and they respect international standards IEEE 512-1992 [14].

6.2. In abnormal input grid voltage

In this case, input voltages are disturbed by adding the 5th , 7th , 9th , and 11th harmonics . Similarly to the previous simulation, a reference change of ido was realized: Figures 11 and 12 show successfully the waveforms of input voltage disturbed, spectrum harmonics analysis of a single phase input currents and spectrum harmonics analysis of a single phase input voltage respectively. The waveforms of the output currents of MC and spectrum harmonics analysis output currents are shown in Fig. 13 and 14 respectively. Finally figures 15 and 16 gives respectively the evolution of ido (with its reference) and the voltage transfer ratio.

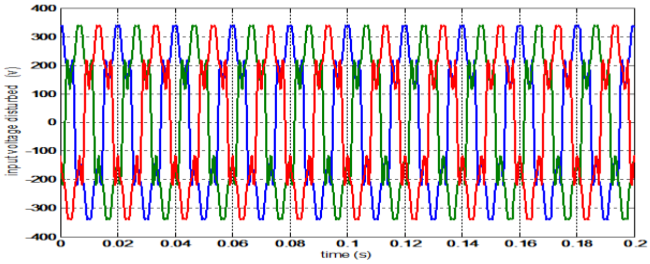

Fig. 12. Disturbed Input voltage grid

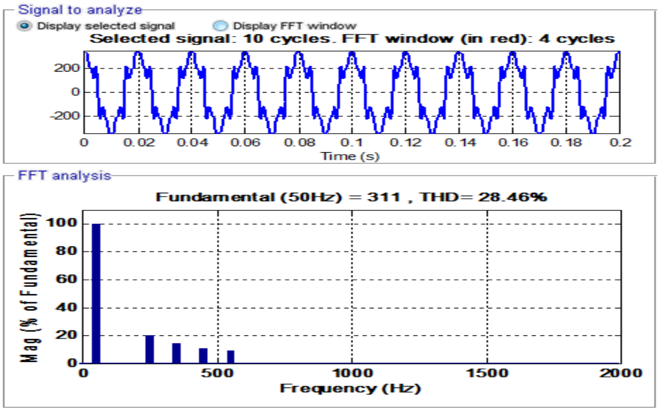
Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 10 cycles. FFT window (in red): 4 cycles
FFT analysis
Fundamental (50Hz) = 311 , THD= 28.46%

Fig. 13. Spectrum harmonics analysis of a single phase output voltage

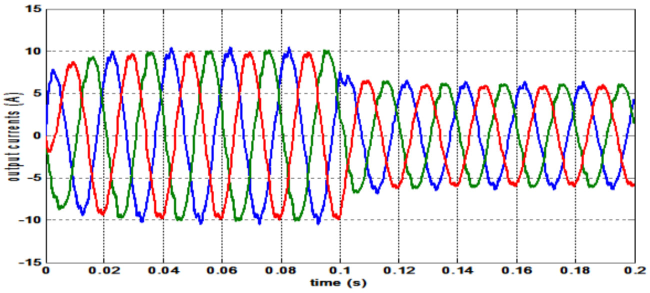

Fig. 14. Output composed voltage in linear load

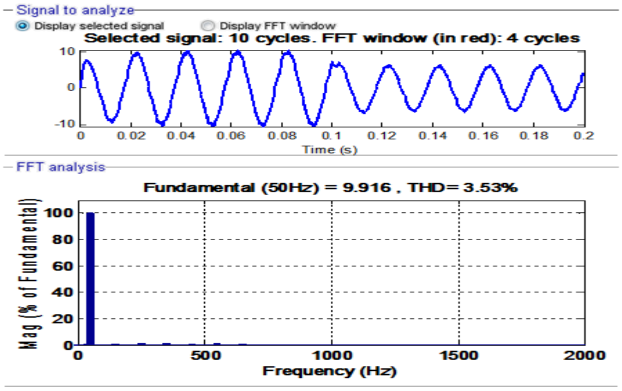
Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 10 cycles. FFT window (in red): 4 cycles
FFT analysis
Fundamental (50Hz) = 9.916 , THD= 3.53%

Fig. 15. Spectrum harmonics analysis of a single phase output currents

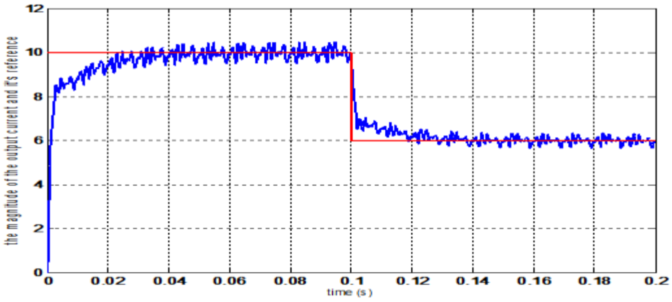

Fig. 16. Magnitude of the output current and it’s reference

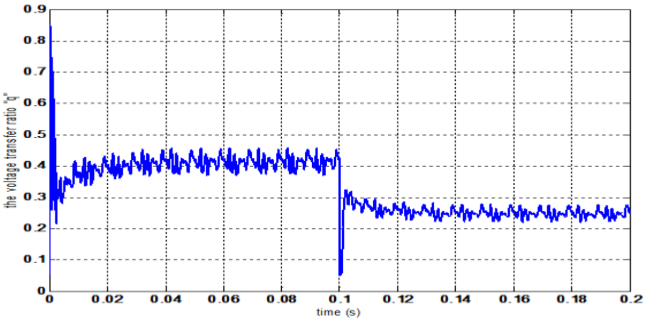

Fig. 17. Evaluation of voltage transfer ratio *q*

In this second case, the robustness of the FLC is another time proved; even under distorted grid voltage, the output currents of the MC are not affected and present nearly sinusoidal waveforms with a THD of 3.63 %. Other advantage of the proposed regulator is that it gives very good static and dynamic performances regardless of input voltage perturbation.

7. Conclusion

In order to develop renewable energy sources technology in power supply plants, it is necessary to research a new advanced solution, The optimal wind system depends on the particular meteorological characteristics of the site and on the control strategy of all system studied. In this paper containing a matrix converter feeding passive RL load under distorted supply voltage is proposed. To improve output current waveforms for a matrix with conventional PWM technique and optimum Venturini method based on fuzzy logic control approach is considered.

Simulation results obtained in this work that's clearly, using of the matrix converter give a better performance for AC/AC conversion applied to the wind conversion. The advanced control strategy of matrix converter can be applied for controlling the matrix converter and adjust the sizes electrical currents for three phase load against harmonic disturbances. Total harmonic distortion is reduced and respect international recommendation standards IEEE 512-1992. The matrix converter can be used in the wind turbines system and improved the power quality in this renewable energy source.

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