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EXPERIMENTAL INVESTIGATION ON STABILITY OF CLOSED LOOP VECTOR CONTROLLED MATRIX CONVERTER FED INDUCTION MOTOR DRIVE

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Abstract – In this paper, a state average model of the whole system, assuming a constant power load, is employed. The stability of the system is evaluated by analyzing the migration of eigenvalues of the system, which is linearized around the operating point. The approach allows the determination of relationships showing the maximum output power of the matrix converter as function of the parameters of power supply and input filter. The stability is evaluated by analyzing the migration of eigenvalues of the linearised state matrix. The approach allows the determination of the maximum voltage transfer ratio of the matrix converter, and then of the maximum output power, as function of the time constant of the digital lowpass input voltage filter. The transition from stable to unstable operation of the matrix converter has been verified by changing the operating conditions.
Keywords: closed loop control, matrix converter, stability.

1. INTRODUCTION

Stability issues of power converters and electrical drives have already been addressed. With reference to matrix converters, it is worth noting that the possibility of unstable behaviour is not inherent in matrix converter operation, but rather related to the control algorithm implementation [1].it is opportune to calculate the duty cycles of the switching configurations on the basis of the instantaneous values of the input voltages under unbalanced and distorted supply voltages. The feedforward action of this type of control is the main potential reason of the instability phenomena [2].

The use of matrix converter increases the stability problems, owing to the absence of an intermediate DC-link with energy storage capability and the presence of L–C input filters. Input filters are usually adopted in electrical drives to improve the input current quality and to reduce the input voltage distortion. These filters can determine instabilities, depending on the converter topology and the drive control strategy. This problem becomes evident if the converter is controlled with fast closed loops, as happens in controlled rectifiers, field-oriented control (FOC) and direct torque control (DTC) drives . The L–C filter is usually designed in order to satisfy EMC requirements rather than to guarantee system stability [3].

The effects introduced by digital controllers, such as the sample-and-hold circuit and the switching period delay, also affect the stability of matrix converters. The digital controller samples the input voltages at the beginning of the cycle period, then calculates the duty cycles of the switching configurations that will be applied at the beginning of the next cycle period, thus determining one cycle delay. It has long been known that a time delay can remarkably modify the stability of the drive system [4].

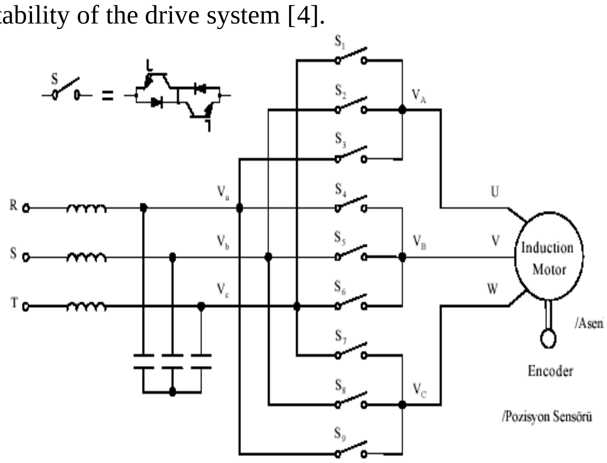

Fig. 1.1 Basic Matrix Converter Topology

It can be noted that matrix converters allow output power control with a degree of freedom, which is the phase angle between the input voltage and the input current space vectors. This degree of freedom can be used to define several input current modulation strategies, aimed at improving the performance of matrix converters in terms of input current quality, in the case of unbalanced and non-sinusoidal input voltages [5].

If the matrix converter is connected to a weak network, the filter inductance can be omitted because the grid inductance is sufficient for the filter requirements; it is then possible to avoid the presence of a bulky component. In this case the matrix converter stability can be improved only by using the digital lowpass filter applied to the voltages measured across the filter capacitors [6].

2. MATHEMATICAL MODEL FOR STABILITY ANALYSIS

The whole system, which comprises a power supply, a second-order input L–C filter and a matrix converter feeding a motor load, is represented in Fig. 2.1 In the following, the modeling is carried out neglecting the effects of the switching harmonics.

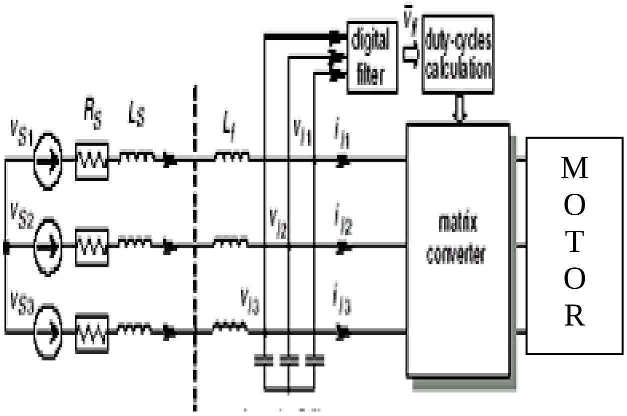

Fig. 2.1 Matrix Converter fed Cage Drive

The system equations, using the space vector notation, are

$$\bar{v}_S = R_S \bar{i}_S + L_T \frac{d\bar{i}_S}{dt} + \bar{v}_i \quad (1)$$

Where,

$$L_T = L_S + L_f.$$

$$\bar{i}_f = C_f \frac{d\bar{v}_i}{dt}$$

$$\bar{i}_S = \bar{i}_f + \bar{i}_i$$

$$\bar{i}_i = \frac{2/3 P\bar{\psi}}{\bar{v}_i \bullet \bar{\psi}} \quad (2)$$

$$\frac{3}{2}\bar{v}_i \bullet \bar{i}_i = P \quad (3)$$

$$\bar{i}_i \bullet j\bar{\psi} = 0. \quad (4)$$

arbitrary space vector is $\bar{\psi}$.

The nonlinear state space equations in a synchronous reference frame are

$$\frac{d\bar{i}_S}{dt} = -\left(\frac{R_S}{L_T} + j\omega\right)\bar{i}_S - \frac{1}{L_T}\bar{v}_i + \frac{1}{L_T}\bar{v}_S$$

$$\frac{d\bar{v}_i}{dt} = \frac{1}{C_f}\bar{i}_S - j\omega\bar{v}_i - \frac{1}{C_f}\frac{2/3 P\bar{\psi}}{\bar{v}_i \bullet \bar{\psi}} \quad (5)$$

being ω the supply angular frequency.

$$\frac{d\bar{v}_i}{dt} = \frac{1}{C_f}\bar{i}_S - j\omega\bar{v}_i - \frac{1}{C_f}\frac{2/3 P e^{-j\varphi}}{\bar{v}_i^{*} \cos\varphi} \quad (6)$$

This equation can be further simplified assuming φ = 0, which represents unity input power factor. In the synchronous reference frame and in steady-state conditions, the variables $\bar{v}_i, \bar{v}_S$ and $\bar{i}_S$ assume the corresponding values $\bar{V}_i, \bar{V}_S$ and $\bar{I}_S$. Therefore,

$$0 = -\left(\frac{R_S}{L_T} + j\omega\right)\bar{I}_S - \frac{1}{L_T}\bar{V}_i + \frac{1}{L_T}\bar{V}_S$$

$$0 = \frac{1}{C_f}\bar{I}_S - j\omega\bar{V}_i - \frac{2Pe^{-j\varphi}}{3C_f\bar{v}_i^* \cos\varphi}$$

These equations can be solved with respect to $\bar{I}_S$ and $\bar{V}_i$ it can be verified that the solution exists only if the output power P of the matrix converter satisfies the following inequality, written in the particular case of φ = 0

$P_{S1} < P < P_{S2}$.

where

$$P_{S1}.P_{S2} = \frac{3/4V_S^2}{\omega^2[L_T(1-\omega^2 L_T C_f) - R_S^2 C_f]^2} \left\{ - R_S \pm \sqrt{R_S^2 + \omega^2[1-\omega^2 L_T C_f) - R_S^2 C_f]^2} \right\} \quad (7)$$

The positive value P_{S2} refers to motor behavior, whereas the negative value P_{S1} represents a limit during regenerative braking.

3. STABILITY ANALYSIS OF MATRIX CONVERTER DRIVE

Resolving the above equations into d–q components, and assuming $\Delta\bar{\upsilon}_S$ = 0, leads to the following state equations:

$$dx/dt = Ax$$

where,

$$x = [\Delta i_{sd}\ \Delta i_{sq}\ \Delta v_{id}\ \Delta v_{id}\ \Delta v_{iq}\ \Delta i_{od}\ \Delta i_{oq}\ \Delta v_{ifd}\ \Delta v_{ifq}]^T$$

$$A = \begin{bmatrix} -R_s/L_\tau & \omega_i & -1/L_\tau & 0 & 0 & 0 & 0 & 0 \\ -\omega_i & -R_s/L_\tau & 0 & -1/L_\tau & 0 & 0 & 0 & 0 \\ 1/C_f & 0 & 0 & \omega_i & -q/C_f & 0 & K & 0 \\ 0 & 1/C_f & -\omega_i & 0 & 0 & 0 & 0 & -K \\ 0 & 0 & q/L_0 & 0 & -L_0/R_0 & \omega_0 & -q/L_0 & 0 \\ 0 & 0 & 0 & 0 & -\omega_0 & -R_0/L_0 & 0 & 0 \\ 0 & 0 & 1/\tau & 0 & 0 & 0 & -1/\tau & 0 \\ 0 & 0 & 0 & 1/\tau & 0 & 0 & 0 & -1/\tau \end{bmatrix}$$

where

$$K = \frac{q^2}{C_f} R_e \left[\frac{1}{Z_0}\right]$$

The stability limit of the matrix converter can be evaluated by analysing the eigenvalues of the state matrix **A** through a numerical approach [7].

4. RESULTS AND DISCUSSIONS

To experimentally verify the control method, comprehensive tests have been carried out on 250 VA, 230 V experimental setup illustrated in fig. 4.1. The equivalent circuit parameters of the test motor are obtained through light running and blocked rotor tests. Effect of saturation on magnetizing reactance has been found from zero slip test the test motor's name plate data is as given in Table 1.1.

Table-4.1 Test Motor Data

	In actual unit
Nominal line voltage	2 30 V
Nominal line current	0..8 Amps
Nominal output power at 50 Hz	186.5 W
Nominal speed	1400 RPM

Fig. 4.1 230-V, 250-VA laboratory prototype matrix converter

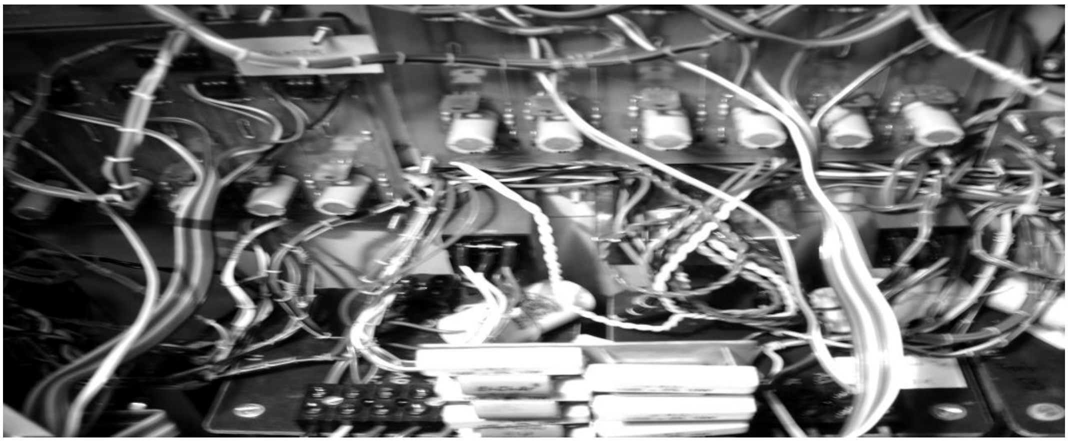

Fig. 4.2 Power-control-isolation module of the matrix converter

Response of the system, in terms of stability has been analysed for different value of the voltage transfer ratio(q) and time constant (τ)of the digital low pass filter The results obtained are presented in figs. 4.3. Figures 4.4 show steady-state waveforms of the I/O voltage & current for different voltage transfer ratio & time constant of digital filter. As can be seen, all the waveforms are practically sinusoidal & characterized by small ripple. Despite initial large oscillation, the waveform of the load current is also sinusoidal, as can be seen in figs. 4.5. Because of the fast adaption of the duty cycle, based on the online measurement of the input voltages, the system stability is enhanced.

The system behavior has been verified for sudden change in load and frequency. To visualize the effectiveness of the control strategy frequent step commands are applied at short interval. The system response is excellent which is evident from results depicted in figure 4.6. The ride through operation is also tested & the drive performance is found to be quite satisfactory as illustrated in the fig. 4.7. Fig. 4.8 shows the FFT of the output current. The harmonic components are practically negligible.

Harmonics, interactions between input current and input voltage, as well as digital implementation could all be potential instability contributors. It was revealed that the filtering on the input voltage angle component helps to improve the MC stability whereas the filtering on the input voltage magnitude component has less influence on it.

The strategy used, does not take into account the effect of the control delay and therefore it gives reliable results only for low values of the cycle period. Because the supply voltage is not ideal and is affected by unbalance, harmonics and parasitic notches, it is possible that the zero-crossing detection will give errors.

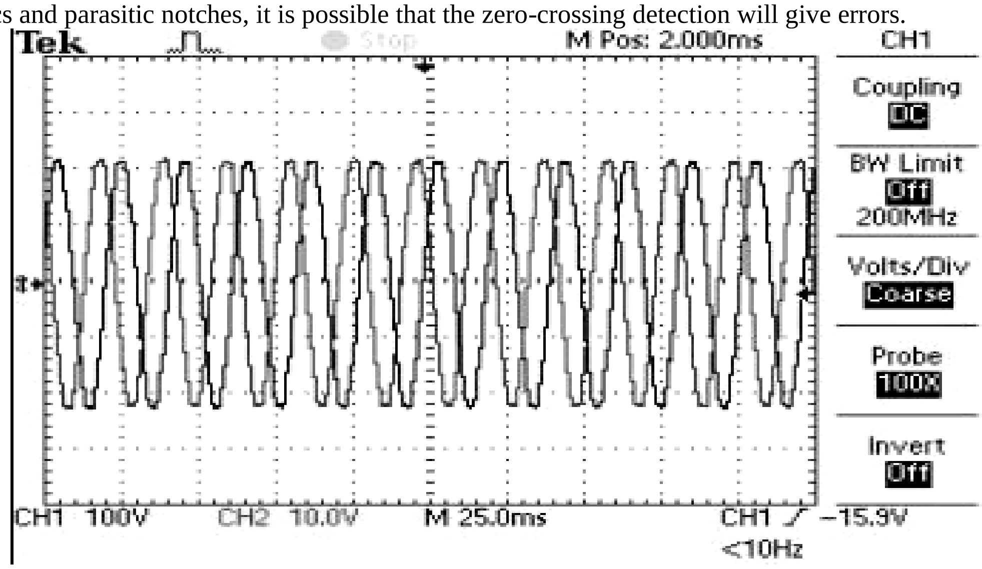

Fig. 4.3 Input voltage at no-load $\tau = 0.3ms$,q=.35

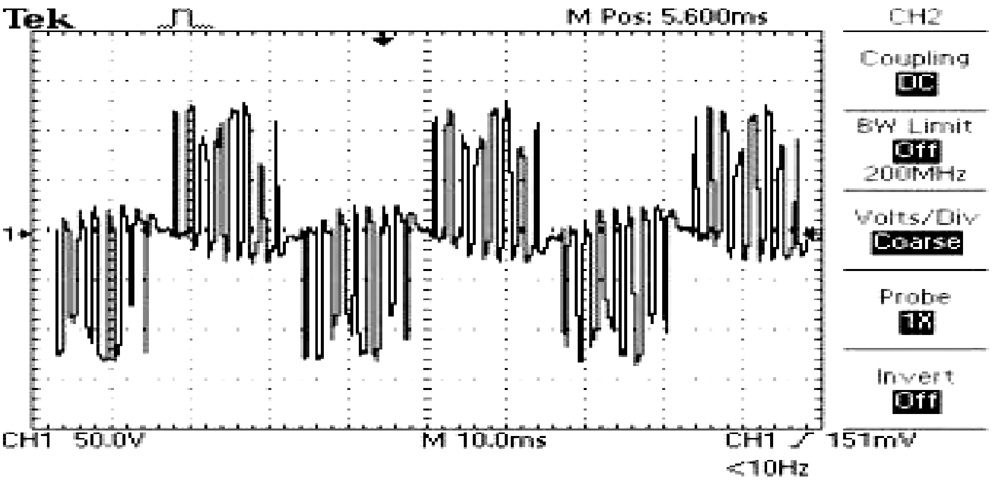

Fig. 4.4 Output voltage at 20 Hz $\tau = 0.3ms$,q=0.25

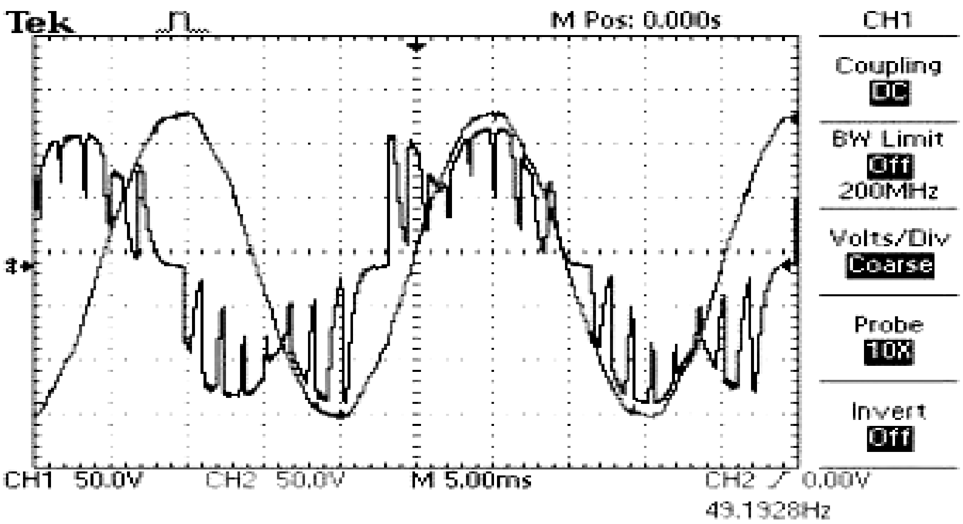

Fig. 4.5 Input & output phase voltage at 30 Hz, $\tau = 0.15ms$,q=0.15

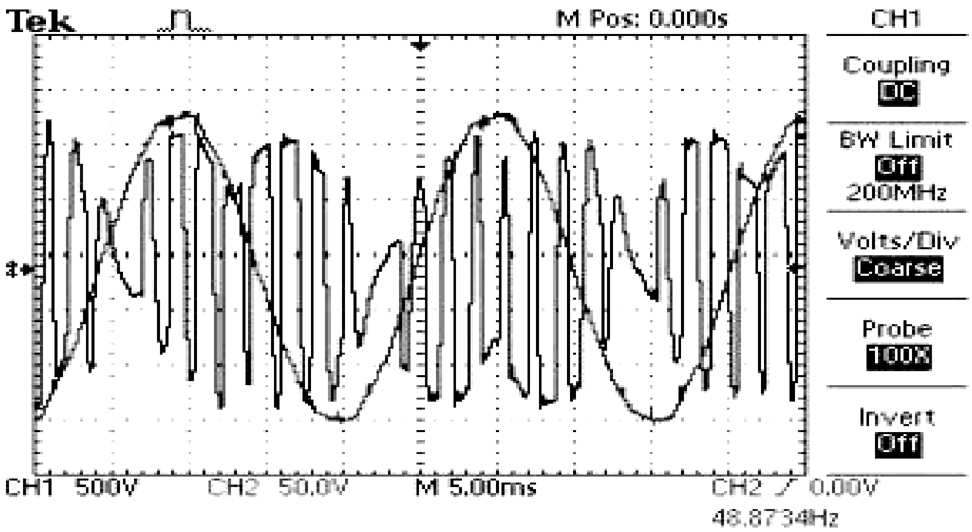

Fig. 4.6 Input & output voltage 40 Hz $\tau = 0.27ms$, q=0.33

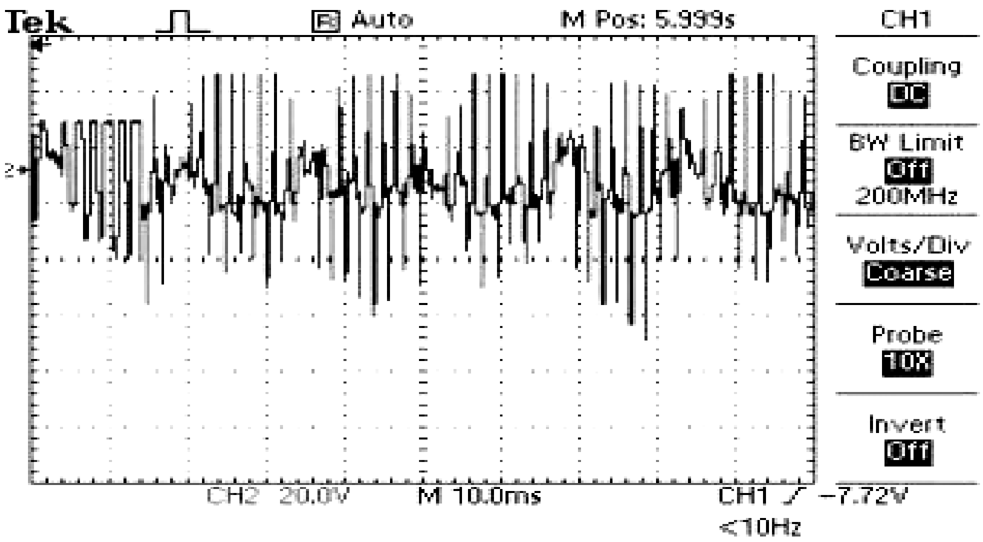

Fig. 4.7 Output Current at 45 Hz $\tau = 0.3ms$,q=0.20

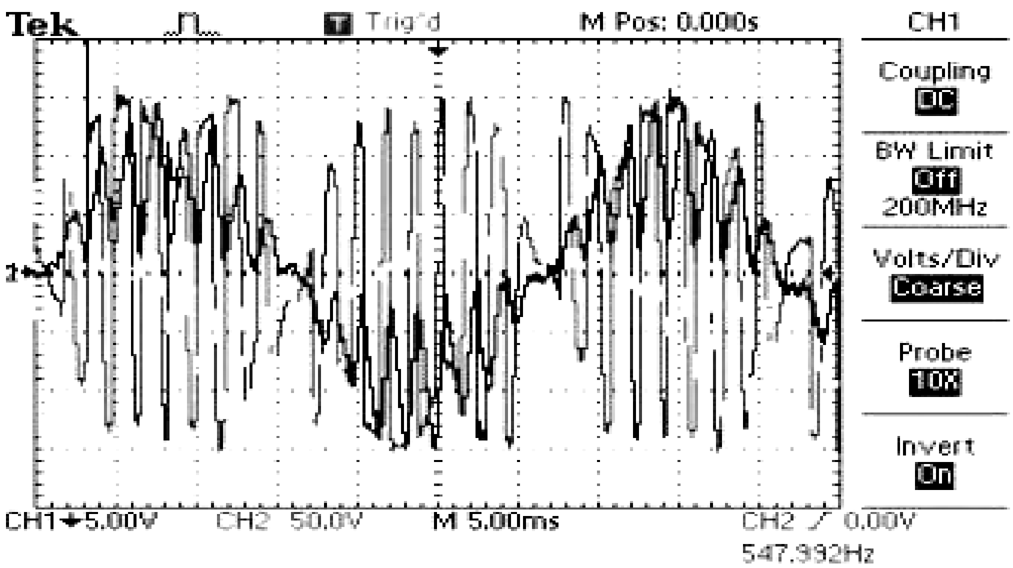

Fig. 4.8 Output voltage & current at55Hz $\tau = 0.15ms$,q=0.50

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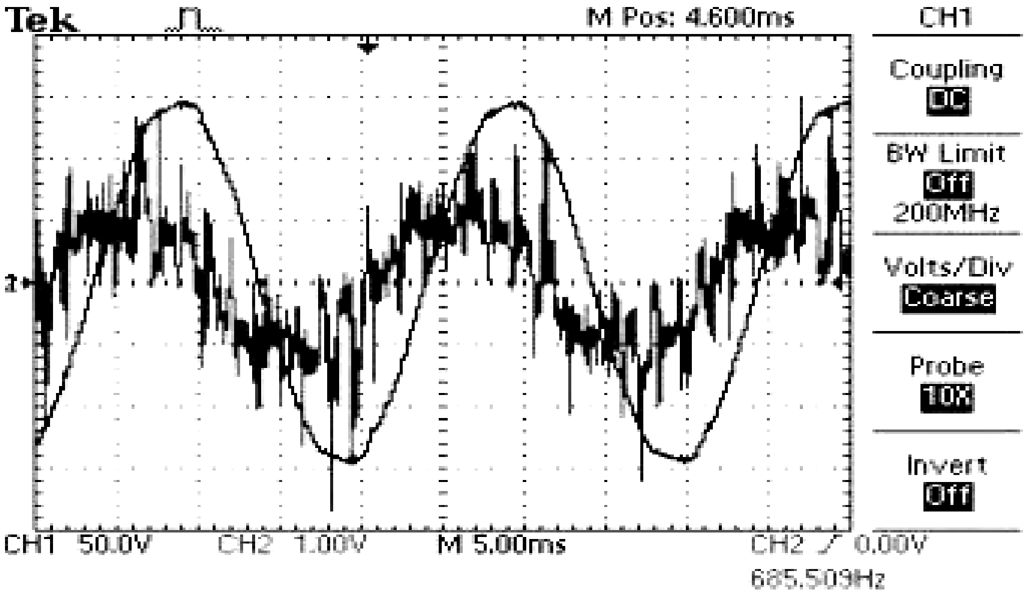

Fig. 4.9 Input & output voltage at 60 Hz $\tau = 0.15ms$**, q=0.25**

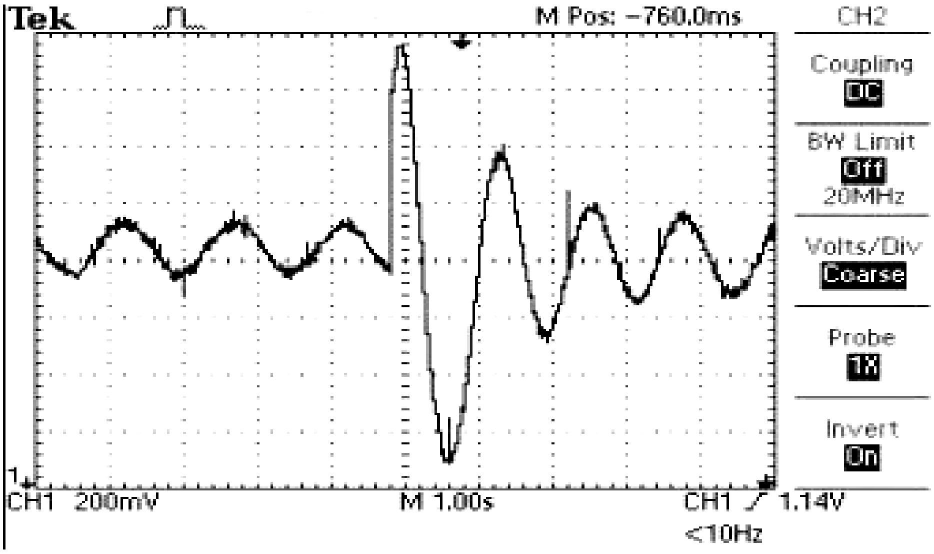

Fig. 4.10 Transients at step load $\tau = .4ms$ **,q=.45**

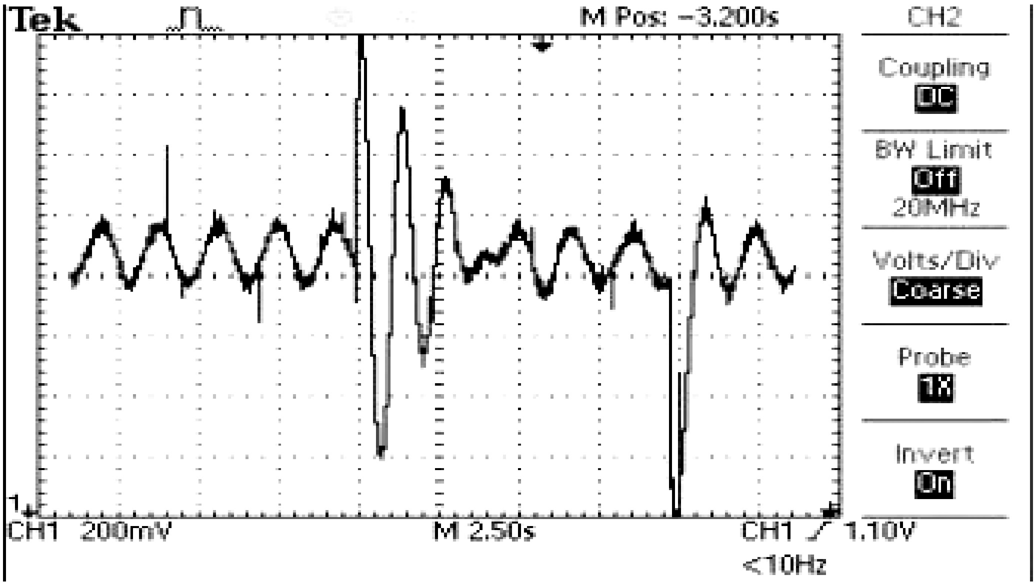

Fig. 4.11 Transients at frequent step load, q=0.55, $\tau = 0.4ms$

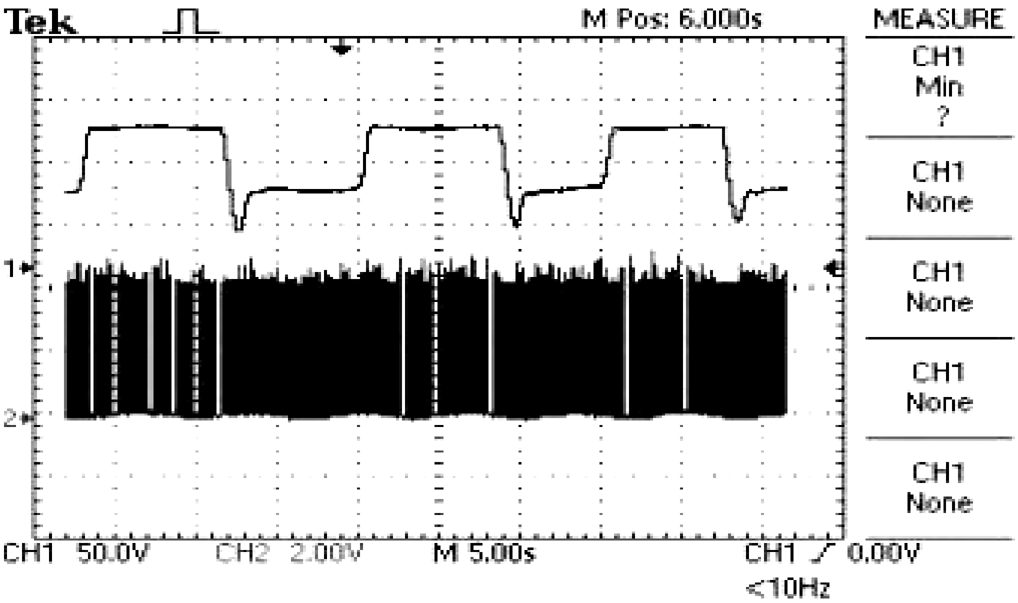

Fig. 4.12 Transients at repeated step frequency $\tau = 0.15ms$**, q=.25**

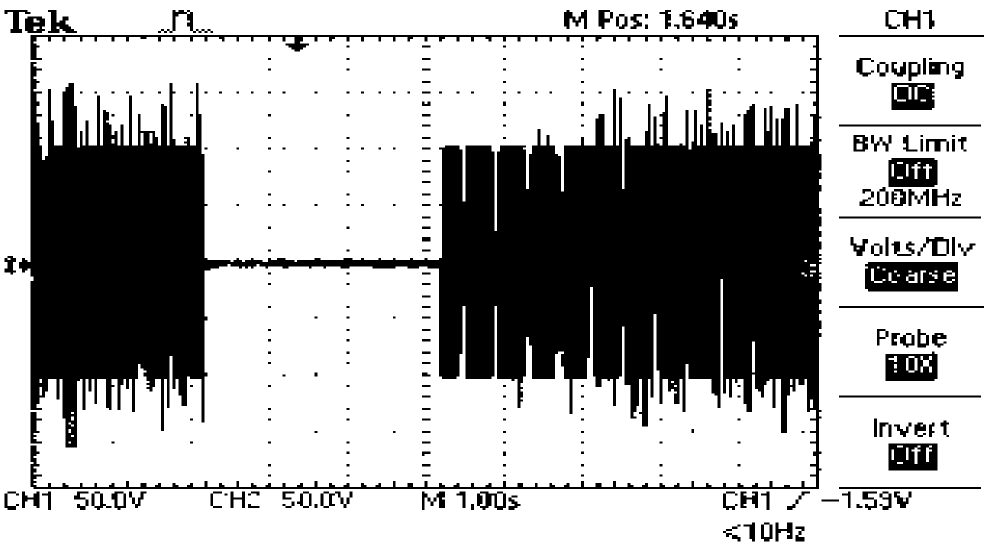

Fig. 4.13 Output voltage at ride through operation q=0.45, $\tau = 0.4ms$

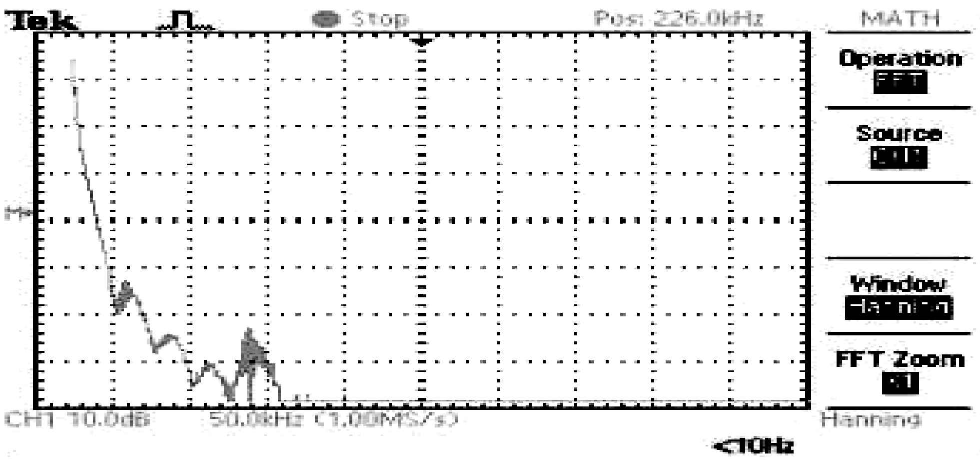

Fig. 4.14 FFT of output current at 30 Hz q=0.55, $\tau = 0.4ms$

CONCLUSION

The behaviour of the system, in terms of stability, has been analysed for different values of the voltage transfer ratio and of the time constant of the digital lowpass input filter. The results obtained are illustrated in Figs. 6–16.

These experimental results demonstrates the effectiveness of the control strategy in terms of stability It has been shown that, by applying a digital lowpass filter to the input voltages, and using these filtered voltages for calculating the duty cycles of the matrix converter switching configurations, it is possible to improve the system stability, with no additional hardware. . The strategy used, does not take into account the effect of the control delay and therefore it gives reliable results only for low values of the cycle period. Because the supply voltage is not ideal and is affected by unbalance, harmonics and parasitic notches, it is possible that the zero-crossing detection will give errors.

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