Vector Control of two five-phase induction Machines Connected in Series powered by Matrix Converter

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Abstract: *Drive system of two five-phase motor serial connected is available in the literature. The power supply of such system is considered as matrix converter (direct AC-AC converter) with three-phase input and five-phase output. The main advantages of such drive topology are the sinusoidal source side current with a controllable input side power factor. The decoupled control is achieved similar to the inverter based drive system. In this paper; we presented the decoupled control of two five-phase Induction Machine (IM) connected in series and powered by five-phase matrix converter. Analytical and simulation results are presented.*

Keywords: *Induction Machine, multi machines system, matrix converter and vector control.*

1. Introduction

Three-phase induction motors have well known advantages of simple construction, reliability, ruggedness, low maintenance, off the shelf availability and low cost which has led to their wide spread use in many industrial applications. However, with the advent of cheap and fast switching power electronics devices not only the control of induction machine became easier and flexible but also the number of phases of machine can be considered a design parameter that can be varied.

Multi-phase machines (more than three-phases) are investigated extensively in the literature and are found to possess several advantages over three-phase machines such as lower torque pulsation [1-2], higher torque density [3-4], fault tolerance [5-6], stability [7-8] and lower current ripple [9]. Thus multi-phase order machines are normally considered for niche application areas such as ship propulsion, 'more electric aircraft', electric/hybrid electric vehicles, robotics etc. Detailed reviews on the development in the research on multi-phase machines are presented in [10-11].

One of the applications of multi-phase machine is their series connection and or parallel connection. Such drive system is called series-connected/parallel-connected two-motor drive system. Such drive system is supplied from a variable frequency and variable voltage supply (most commonly a power electronic inverter) introduced in [12-13]. The drive system is such that the motors are controlled independently and can carry different loads, can run at different speeds without interfering each other. The type of machine being used in the drive topology is also not specific [14]. The machines are controlled using vector control approach.

Since vector control of any multi-phase machine requires only two stator current components, the additional stator current components are used to control other machines. It has been shown that, by connecting multi-phase stator windings in series [12-14] it is possible to control independently all the machines with supply coming from a single multi-phase voltage source inverter. One specific drive system, covered by this general concept, is the five-phase series/parallel connected two-motor drive, consisting of two five-phase machines and supplied from a single five-phase voltage source inverter. Such topology has been analyzed in a considerable depth in [12, 15, 16]. The multi-motor drive system discussed so far in the literature uses multi-phase voltage source inverter as their supply. In contrast this paper proposes a multi-phase matrix converter to supply such drive topology.

Thus this paper focuses on the feasibility study of using matrix converter for supplying series-connected five-phase two-motor drive. The performance of power electronic converters (AC to AC or AC-DC-AC) is highly dependent on their control algorithms. Thus a number of modulation schemes

Are developed for voltage source inverters for three-phase output [17] and multi-phase output [19]. Modulation methods of matrix converters are complex and are generally classified in two different groups, called direct and indirect. The direct PWM method developed by Alesina and Venturini [30] limits the output to half the input voltage. This limit was subsequently raised to 0.866 by taking advantage of third harmonic injection [31] and it was realized that this is maximum output that can be obtained from a three-to-three phase matrix converter in the linear modulation region. Motivated from the simple implementation, carrier-based PWM scheme is introduced recently for three to three phase matrix converter [20-21].

This paper presents the feasibility of driving five-phase series connected two-motor drive system with direct AC-DC converter or matrix converter. The novelty of the paper lies in the new solution of using matrix converter for feeding two motor drive topology. It is shown that the drive topology can be fed successfully using matrix converter. The advantage that is offered by this solution is sinusoidal source side current, no use of bulky dc link capacitors, controllable power factor and bidirectional power flow. The disadvantage of the scheme is the complex system with large number of bidirectional power semiconductor switches. The output voltage is lower compared to inverter based system. Analytical approach is used to develop and analyze the proposed modulation techniques and is further supported by simulation results.

The major aim of the modulation is to produce two fundamental frequency output from the matrix converter that can be used to control two series-connected five-phase machines.

2. Modeling of the five phase matrix converter

The power circuit topology of a 3 to 5 phase matrix converter is shown in Fig.1. The input is three-phase fixed voltage and fixed frequency supply from the grid system (50 Hz, 220 V RMS). The output is n-phase with variable voltage and variable frequency. A small filter is needed at the input source side and the switches are bidirectional for allowing regenerative operation of the load. The matrix converter is modulated both using carrier-based PWM [20]-[21] and space vector PWM [22]-[24].

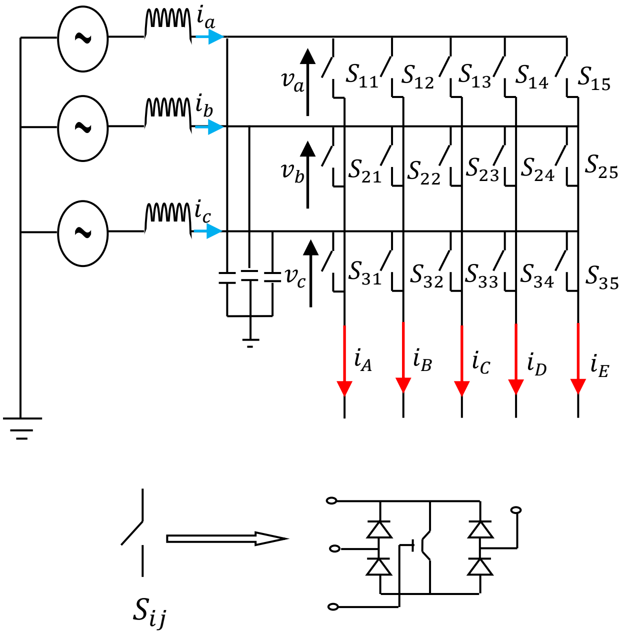

Fig.1 Principle diagram of the Pentaphasées matrix converter [22].

This paper presents simple carrier-based PWM scheme. Carrier-based PWM scheme presented in this section is derived in [23]. However, the load considered in was a simple R-L load. Since the input side is three-phase, the analytical treatment remains the same as that of [22]. However, the output is now increased to five and hence the analysis will be modified to suit the requisite output phase number. A balanced three-phase system is assumed at the input.

$$\begin{aligned} v_a &= |V| + \cos(\omega t) \\ v_b &= |V| + \cos(\omega t - 2\pi/3) \\ v_c &= |V| + \cos(\omega t - 4\pi/3) \end{aligned} \qquad (1)$$

Since the matrix converter outputs voltages with frequency decoupled from the input voltages, the duty ratios of the switches are to be calculated accordingly. The five-phase output voltage duty ratios should be calculated in such a way that output voltages remains independent of input frequency. In other words, the five-phase output voltages can be considered in synchronous reference frame and the three phase input voltages can be considered to be in stationary reference frame, so that the input frequency term will be absent in output voltages. Considering the above, a duty ratio of output phase j is chosen as:

$$\begin{aligned}\delta_{ai} &= k_i + \cos(\omega t - \rho)\\ \delta_{bi} &= k_i + \cos(\omega t - \tfrac{2\pi}{3} - \rho)\\ \delta_{ci} &= k_i + \cos(\omega t - \tfrac{4\pi}{3} - \rho)\end{aligned} \quad (2)$$

Where ρ is the phase shift at the input side? The input and output voltages are related as:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \end{bmatrix} = \begin{bmatrix} \delta_{aA} & \delta_{bA} & \delta_{cA} \\ \delta_{aB} & \delta_{bB} & \delta_{cB} \\ \delta_{aC} & \delta_{bC} & \delta_{cC} \\ \delta_{aD} & \delta_{bD} & \delta_{cD} \\ \delta_{aE} & \delta_{bE} & \delta_{cE} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (3)$$

Therefore the phase output voltage can be obtained by using the above duty ratios as:

$$V_A = k_A |V| [\cos(\omega t) * \cos(\omega t - \rho) + \cos(\omega t - 2\pi/3) * \cos(\omega t - 2\pi/3 - \rho) + \cos(\omega t - 4\pi/3) * \cos(\omega t - 4\pi/3 - \rho)] \quad (4)$$

$$V_A = \frac{3}{2} * k_A |V| \cos(\rho) \quad (5)$$

In equation (5), cos(ρ) term indicates that the output voltage is affected by ρ. The term $k_A$is defined in equation (18). Thus, the output voltage V_A is independent of the input frequency and only depends on the amplitude |V| of the input voltage and k_A is a reference output voltage time-varying modulating signal for the output phase A with the desired output frequency $\omega_{01} + \omega_{02}$, ω_{01} is the operating frequency of machine-1 or the first fundamental output frequency and ω_{02} is the operating frequency of machine-2 or the second fundamental output frequency. The fundamental output voltage magnitude corresponding to ω_{01}be given as m_1 and corresponding to ω_{02} is given as m_2. The five-phase reference output voltages can then be represented as:

$$\begin{aligned} k_{A1} &= m_1 \cos(\omega_{01} t)\\ k_{A1} &= m_1 \cos(\omega_{01} t - 2\pi/5)\\ k_{A1} &= m_1 \cos(\omega_{01} t - 4\pi/5)\\ k_{A1} &= m_1 \cos(\omega_{01} t - 6\pi/5)\\ k_{A1} &= m_1 \cos(\omega_{01} t - 8\pi/5)\end{aligned} \quad (6)$$

$$\begin{aligned} k_{A2} &= m_2 \cos(\omega_{02} t)\\ k_{A2} &= m_2 \cos(\omega_{02} t - 2\pi/5)\\ k_{A2} &= m_2 \cos(\omega_{02} t - 4\pi/5)\\ k_{A2} &= m_2 \cos(\omega_{02} t - 6\pi/5)\\ k_{A2} &= m_2 \cos(\omega_{02} t - 8\pi/5)\end{aligned} \quad (7)$$

And:

$$\begin{aligned} k_A &= k_{A1} + k_{A2}\\ k_B &= k_{B1} + k_{B2}\\ k_C &= k_{C1} + k_{C2}\\ k_D &= k_{D1} + k_{D2}\\ k_E &= k_{E1} + k_{E2}\end{aligned} \quad (8)$$

Therefore, from (5), the output voltages are obtained as:

$$\begin{cases} V_A = \left[\frac{3}{2} * k_{A1}|V| \cos(\rho)\right] \cos(\omega_{01} t) \\ \qquad + \left[\frac{3}{2} * k_{A2}|V| \cos(\rho)\right] \cos(\omega_{02} t) \\ V_B = \left[\frac{3}{2} * k_{B1}|V| \cos(\rho)\right] \cos\left(\omega_{01} t - \frac{2\pi}{5}\right) \\ \qquad + \left[\frac{3}{2} * k_{C2}|V| \cos(\rho)\right] \cos(\omega_{02} t - 4\pi/5) \\ V_C = \left[\frac{3}{2} * k_{C1}|V| \cos(\rho)\right] \cos\left(\omega_{01} t - \frac{4\pi}{5}\right) \\ \qquad + \left[\frac{3}{2} * k_{E2}|V| \cos(\rho)\right] \cos(\omega_{02} t - 8\pi/5) \\ V_D = \left[\frac{3}{2} * k_{D1}|V| \cos(\rho)\right] \cos\left(\omega_{01} t - \frac{6\pi}{5}\right) \\ \qquad + \left[\frac{3}{2} * k_{B2}|V| \cos(\rho)\right] \cos(\omega_{02} t - 2\pi/5) \\ V_E = \left[\frac{3}{2} * k_{E1}|V| \cos(\rho)\right] \cos\left(\omega_{01} t - \frac{8\pi}{5}\right) \\ \qquad + \left[\frac{3}{2} * k_{D2}|V| \cos(\rho)\right] \cos(\omega_{02} t - 6\pi/5) \end{cases} \quad (9)$$

The discussion on the common mode voltage addition and subsequent enhancement in the modulation index is presented in [37].

3. Five-phase series-connected two motor drive

The basic topology of a five-phase series-connected two motor drive system is shown in Fig. 1. The variable frequency (VF) source is supplying a five-phase induction machine (Motor 1) whose stator windings are connected to another five-phase induction machine (Motor 2) through appropriate phase transposition. The rotors of the two machines are independent and they are connected to different mechanical loads [25].

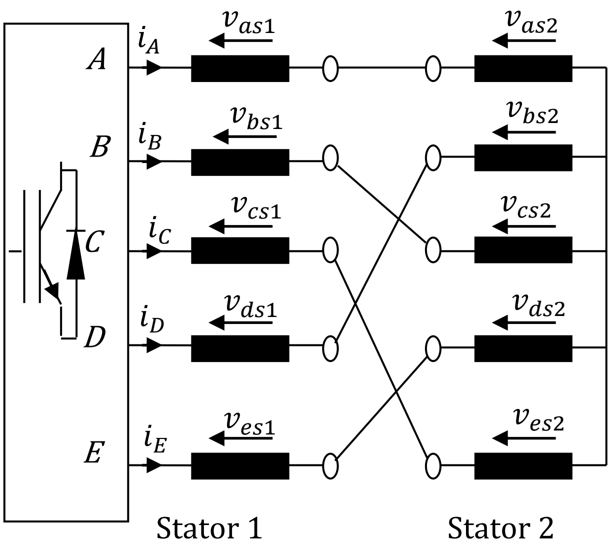

Fig.2 Representation of two five-phase IM in series with transposed stator phases

As a consequence of the phase transposition shown in Fig.2, inverter phase voltages are related to individual machine phase voltages through

$$\begin{aligned} v_A &= v_{as1} + v_{as2} \\ v_B &= v_{bs1} + v_{cs2} \\ v_C &= v_{cs1} + v_{es2} \\ v_D &= v_{ds1} + v_{bs2} \\ v_E &= v_{es1} + v_{ds2} \end{aligned} \qquad (10)$$

In a general case the two machines, although both five-phase, may be different and therefore may be with different parameters. Let the index ‘1’ denote induction machine directly connected to the five-phase inverter and let the index ‘2’ stand for the second induction machine, connected after the first machine through phase transposition.

Voltage equation for the complete system can be written in a compact matrix form as

$$\underline{v} = \underline{R} * \underline{i} + \frac{d(\underline{L} * \underline{i})}{dt} \qquad (11)$$

Where the system is of the 15th order and

$$\underline{v} = \begin{bmatrix} \underline{v}^{inv} \\ \underline{0} \\ \underline{0} \end{bmatrix}, \ \underline{i} = \begin{bmatrix} \underline{i}^{inv} \\ \underline{i}_{r1} \\ \underline{i}_{r2} \end{bmatrix}$$

$$\underline{v}^{inv} = [v_A \ v_B \ v_C \ v_D \ v_E]^T$$

$$\underline{i}^{inv} = [i_A \ i_B \ i_C \ i_D \ i_E]^T$$

$$\underline{i}_{r1} = [i_{ar1} \ i_{br1} \ i_{cr1} \ i_{dr1} \ i_{er1}]^T$$

$$\underline{i}_{r2} = [i_{ar2} \ i_{br2} \ i_{cr2} \ i_{dr2} \ i_{er2}]^T$$

In order to simplify the phase-domain model, the decoupling transformation is applied. The Clark’s decoupling transformation matrix in power invariant form is [26]:

$$[c] = \sqrt{\frac{2}{5}} \begin{bmatrix} 1 & \cos(\alpha) & \cos(2\alpha) & \cos(3\alpha) & \cos(4\alpha) \\ 0 & \sin(\alpha) & \sin(2\alpha) & \sin(3\alpha) & \sin(4\alpha) \\ 1 & \cos(2\alpha) & \cos(4\alpha) & \cos(6\alpha) & \cos(8\alpha) \\ 0 & \sin(2\alpha) & \sin(4\alpha) & \sin(6\alpha) & \sin(8\alpha) \\ \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} \end{bmatrix} \qquad (12)$$

By omitting the x-y and zero-sequence equation for rotor windings and the zero-sequence equation of the inverter, the complete d-q model in stationary reference frame for the two five-phase series-connected machines can be written in developed form as:

$$\begin{cases} V_d^{inv} = R_{s1} i_d^{inv} + L_{s1} \frac{di_d^{inv}}{dt} + L_{m1} \frac{di_{dr1}}{dt} \\ \qquad + R_{s2} i_d^{inv} + L_{s2} \frac{di_d^{inv}}{dt} \\ V_q^{inv} = R_{s1} i_q^{inv} + L_{s1} \frac{di_q^{inv}}{dt} + L_{m1} \frac{di_{qr1}}{dt} \\ \qquad + R_{s2} i_q^{inv} + L_{s2} \frac{di_q^{inv}}{dt} \\ V_x^{inv} = R_{s1} i_x^{inv} + L_{s1} \frac{di_x^{inv}}{dt} + R_{s2} i_x^{inv} \\ \qquad + L_{s2} \frac{di_x^{inv}}{dt} + L_{m2} \frac{di_{\alpha r2}}{dt} \\ V_y^{inv} = R_{s1} i_y^{inv} + L_{s1} \frac{di_y^{inv}}{dt} + R_{s2} i_y^{inv} \\ \qquad + L_{s2} \frac{di_y^{inv}}{dt} + L_{m2} \frac{di_{\beta r2}}{dt} \end{cases} \qquad (13)$$

Corresponding rotor equations are:

$$\begin{cases} 0 = R_{r1} i_{dr1} + L_{m1} \frac{di_d^{inv}}{dt} + (L_{r1} + L_{m1}) \frac{di_{dr1}}{dt} \\ \qquad + \omega_1 \left(L_{m1} i_q^{inv} + (L_{r1} + L_{m1}) i_{qr1} \right) \\ 0 = R_{r1} i_{qr1} + L_{m1} \frac{di_q^{inv}}{dt} + (L_{r1} + L_{m1}) \frac{di_{qr1}}{dt} \\ \qquad - \omega_1 (L_{m1} i_d^{inv} + (L_{r1} + L_{m1}) i_{dr1}) \\ 0 = R_{r2} i_{dr2} + L_{m2} \frac{di_x^{inv}}{dt} + (L_{r2} + L_{m2}) \frac{di_{dr2}}{dt} \\ \qquad + \omega_2 \left(L_{m2} i_y^{inv} + (L_{r2} + L_{m2}) i_{qr2} \right) \\ 0 = R_{r2} i_{qr2} + L_{m2} \frac{di_y^{inv}}{dt} + (L_{r2} + L_{m2}) \frac{di_{qr2}}{dt} \\ \qquad - \omega_2 (L_{m2} i_x^{inv} + (L_{r2} + L_{m2}) i_{dr2}) \end{cases} \qquad (14)$$

The electromagnetic torques is evaluated as:

$$\begin{cases} T_{r1} = P_1 L_{m1}(i_{dr1} i_q - i_d i_{qr1}) \\ T_{r2} = P_2 L_{m2}(i_{dr2} i_y - i_x i_{qr2}) \end{cases} \tag{15}$$

The mechanical equation of two machines is described as:

$$\begin{cases} J_{m1}\frac{d}{dt}\Omega_1 = T_{r1} - T_{L1} - f_{m1}\Omega_1 \\ J_{m2}\frac{d}{dt}\Omega_2 = T_{r2} - T_{L2} - f_{m2}\Omega_2 \end{cases} \tag{16}$$

4. Vector control of the two-motor drive

Since, according to (13)–(16), the phase transposition in series connection places the stator $d-q$ axis windings of the second machine in series with the $x-y$ windings of the first machine (i.e., into the x− y subspace of the inverter) and vice versa, the independent vector control of the two machines can be realized using standard indirect method of rotor flux oriented (RFO) control. The indirect RFO controller for each of the two machines is of the same structure as for a three-phase machine or an asymmetrical six-phase machine [27] (the only difference is that five, rather than three, phase current references are created at the output) and is shown in Fig. 3. Two indirect RFO controllers operate in parallel and give at the output phase current references for the two machines ($k = \sqrt{2/5}$; references for x− y stator current components are, according to Fig. 3, zero for both machines).

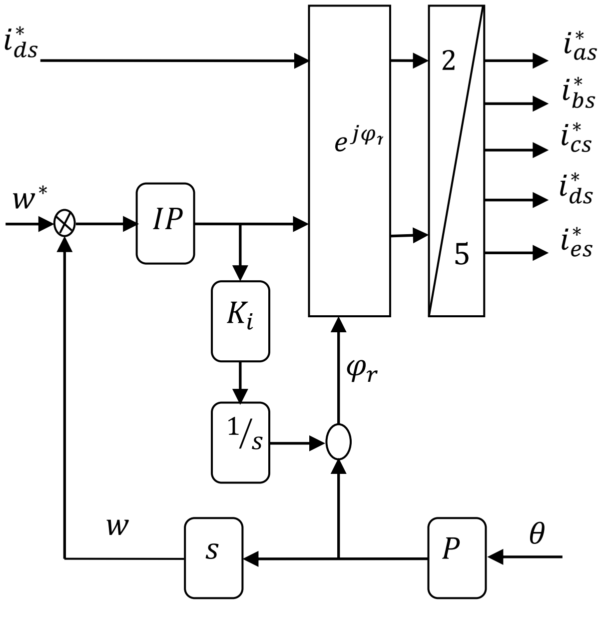

Fig.3 Indirect RFO controller for a five-phase induction machine ($k_1 = \frac{1}{T_r i^*_{ds}}$)

$$\begin{cases} i^*_{as1} = k\left(i^*_{ds1} cos\varphi_{r1} - i^*_{qs1} sin\varphi_{r1}\right) \\ i^*_{bs1} = k\left(i^*_{ds1}\, cos(\varphi_{r1} - \alpha) - i^*_{qs1} sin(\varphi_{r1} - \alpha)\right) \\ i^*_{cs1} = k\left(i^*_{ds1}\, cos(\varphi_{r1} - 2\alpha) - i^*_{qs1} sin(\varphi_{r1} - 2\alpha)\right) \\ i^*_{ds1} = k\left(i^*_{ds1}\, cos(\varphi_{r1} - 3\alpha) - i^*_{qs1} sin(\varphi_{r1} - 3\alpha)\right) \\ i^*_{es1} = k\left(i^*_{ds1}\, cos(\varphi_{r1} - 4\alpha) - i^*_{qs1} sin(\varphi_{r1} - 4\alpha)\right) \end{cases} \tag{17}$$

$$\begin{cases} i^*_{as2} = k\left(i^*_{ds2} cos\varphi_{r2} - i^*_{qs2} sin\varphi_{r2}\right) \\ i^*_{bs2} = k\left(i^*_{ds2} \cos(\varphi_{r2} - \alpha) - i^*_{qs2} sin(\varphi_{r2} - \alpha)\right) \\ i^*_{cs2} = k\left(i^*_{ds2} \cos(\varphi_{r2} - 2\alpha) - i^*_{qs2} sin(\varphi_{r2} - 2\alpha)\right) \\ i^*_{ds2} = k\left(i^*_{ds2} \cos(\varphi_{r2} - 3\alpha) - i^*_{qs2} sin(\varphi_{r2} - 3\alpha)\right) \\ i^*_{es2} = k\left(i^*_{ds2} \cos(\varphi_{r2} - 4\alpha) - i^*_{qs2} sin(\varphi_{r2} - 4\alpha)\right) \end{cases} \tag{18}$$

The currents in (17) and (18) are further summed, respecting the series connection with phase transposition of Fig. 3, in order to create the overall inverter current references:

$$\begin{aligned} i^*_A &= i^*_{as1} + i^*_{as2} \\ i^*_B &= i^*_{bs1} + i^*_{bs2} \\ i^*_c &= i^*_{cs1} + i^*_{cs2} \\ i^*_d &= i^*_{ds1} + i^*_{ds2} \\ i^*_E &= i^*_{es1} + i^*_{es2} \end{aligned} \tag{19}$$

Closed-loop phase current control in stationary reference frame is finally applied to force the actual inverter output currents of (2) to track the reference currents of (19). Assuming ideal current control, one has the equality of the reference inverter currents (19) with the actual inverter currents (2) so that actual machine currents are related with reference machine currents of (17) and (18) through

$$\begin{aligned} i_{as1} &= i_{as2} = i^*_{as1} + i^*_{as2} \\ i_{bs1} &= i_{cs2} = i^*_{bs1} + i^*_{bs2} \\ i_{cs1} &= i_{es2} = i^*_{cs1} + i^*_{cs2} \\ i_{ds1} &= i_{bs2} = i^*_{ds1} + i^*_{ds2} \\ i_{es1} &= i_{ds2} = i^*_{es1} + i^*_{es2} \end{aligned} \tag{20}$$

Since the right-hand side of (19) contains in steady state operation two sets of sinusoidal currents of, in general, different amplitudes and frequencies and these are summed according to the phase transposition in Fig. 3, it follows from (19) that each of the five phases of any of the two machines carries simultaneously two sinusoidal current components. One of these governs flux/torque producing $(\alpha - \beta)$ components while the other one is due to the other machine in series and therefore it determines parasitic $(x - y)$ current component.

5. Simulation results

The simulation model is developed in Matlab/Simulink for the whole drive system two five phase induction machines connected in series powered by matrix converter. Three-phase grid supply is assumed as 50 Hz 400 V RMS phase voltage. Five-phase reference voltage is chosen for the first motor and another set of five-phase reference is assumed for the second motor. The five-phase modulating signals are formulated by adding the two five-phase references according to the transposition rule (equation (7)).

The simulation condition is taken as;

The output voltage of the three to five phase matrix converters $V_a\ [V]$ presented in Fig 4.

Motor-1 operating at rated speed of 1500 rpm (reference frequency of 50 Hz) Motor-2 operating at half rated speed of 750 rpm (reference frequency of 50 Hz).

In the first test, the first machine runs at 1500 rpm then at -1500rpm at t=0.9s, while the speed reference of the second machine is 750 rpm. The load torque applied to the first machine and second machine is 100 % of the rated torque at $t_1 = [1 - 3]\ s$ and $t_2 = [1.5 - 3.5]\ s$ respetivments.

In the second test, the first machine runs at 1500 rpm then at -1500rpm at t=0.9s, while the speed reference of the second machine is 750 rpm. The load torque applied to the first machine is 100 % of the rated torque at $t_1 = [1 - 3]\ s$. And the first machine runs at 1500 rpm, while the speed reference of the second machine is 750 rpm then at -750 rpm at $t_2 = [1.5 - 3.5]\ s$. The load torque applied to the first and second machine is 100 % of the rated torque. It is evident from Figs.5-6-7-8-9-10 and Figs.11-12-13-14-15 that step loading of the second machine does not cause any disturbance in the first machine's speed and torque references traces.

In the third test, the first and second machine runs at 1500 rpm, Figs 16-17-18.

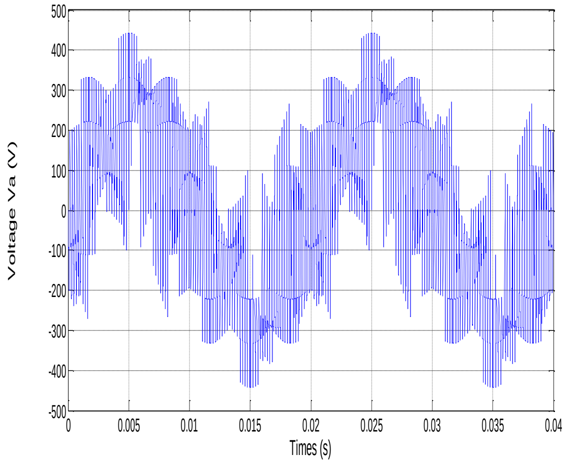

Fig. 4 Output voltage Va (V)

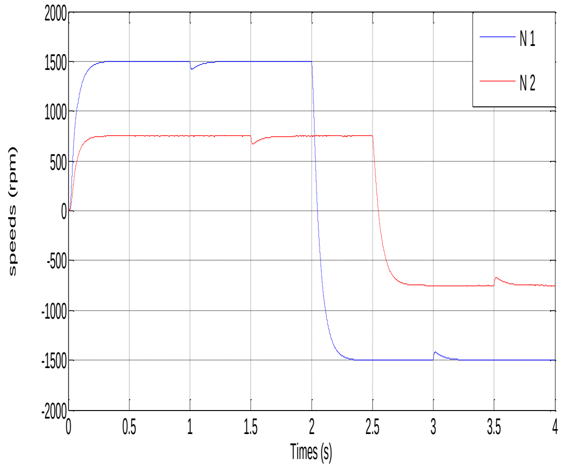

Fig. 5 Speeds of the first machine runs at 1500 rpm and -1500 rpm at t=2s, and speed second machine runs 750 rpm and -750rpm at t= 2.5s.

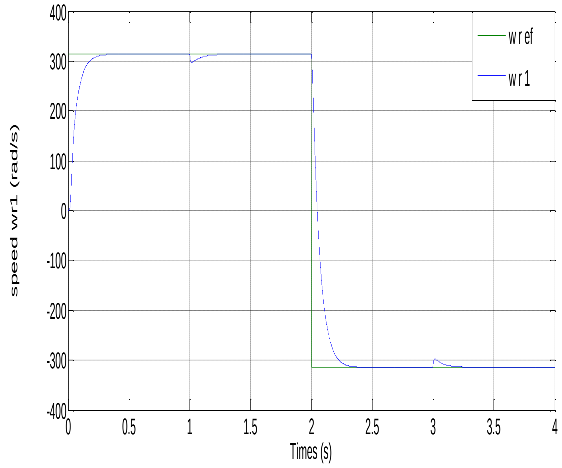

Fig. 6 Speeds of the first machine Vs its reference value

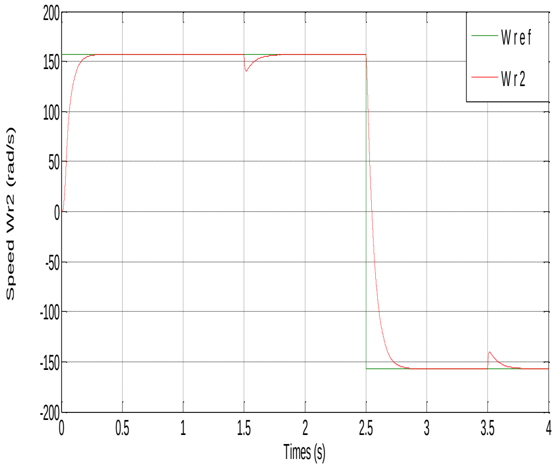

Fig. 7 Speeds of the second machine Vs its reference value

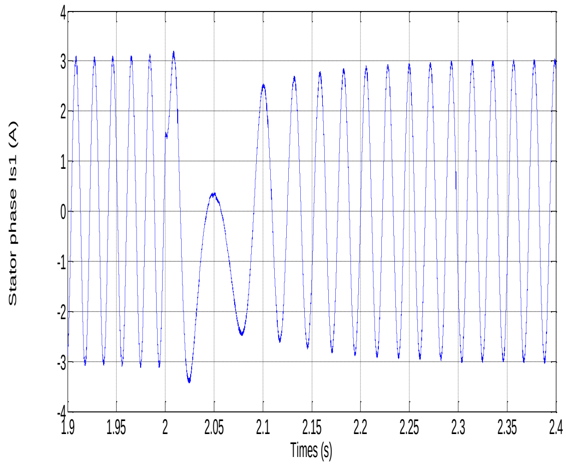

Fig. 10 Current in one phase of the first machine.

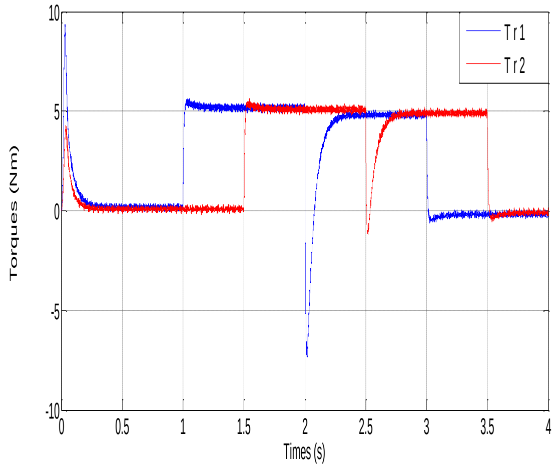

Fig. 8 Torques of the first and second machines.

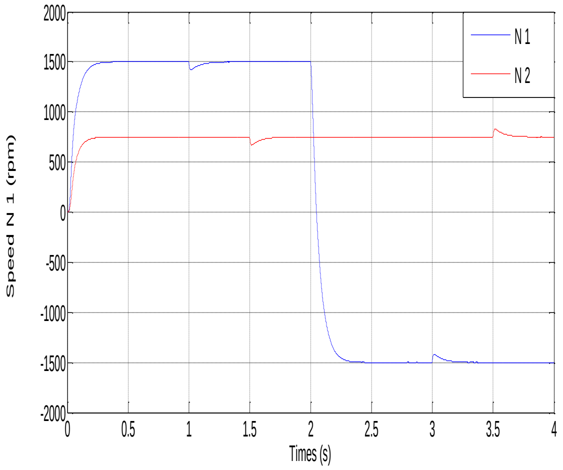

Fig. 11 Speeds of the first machine runs at 1500 rpm and -1500 rpm at t=2s, and speed second machine runs 750 rpm.

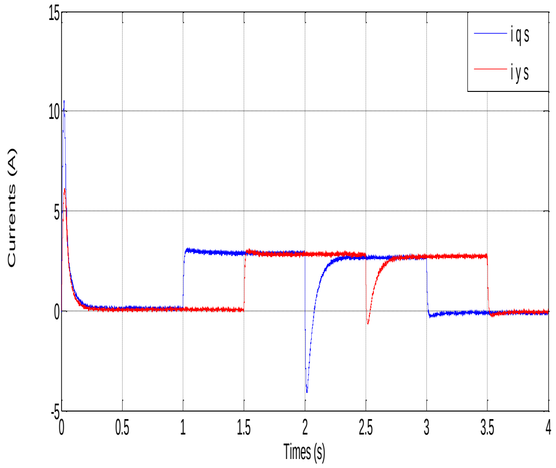

Fig. 9 Currents of the first and second machines.

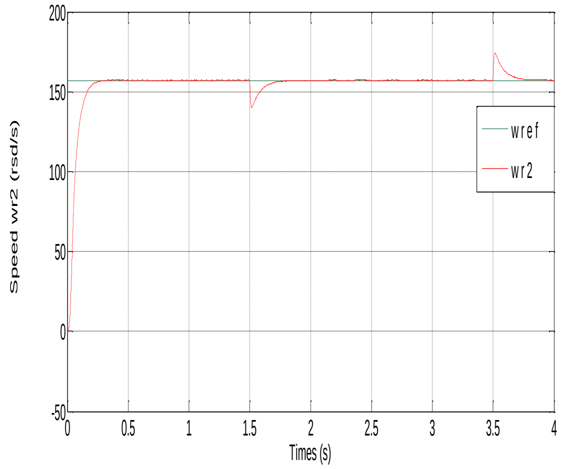

Fig. 12 Speeds of the second machine Vs its reference value

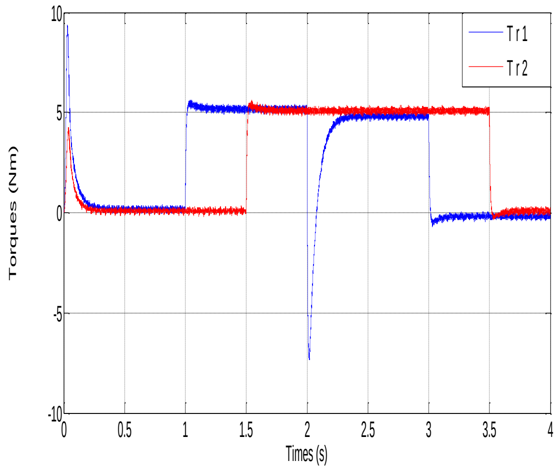

Fig. 13 Torques of the first and second machines.

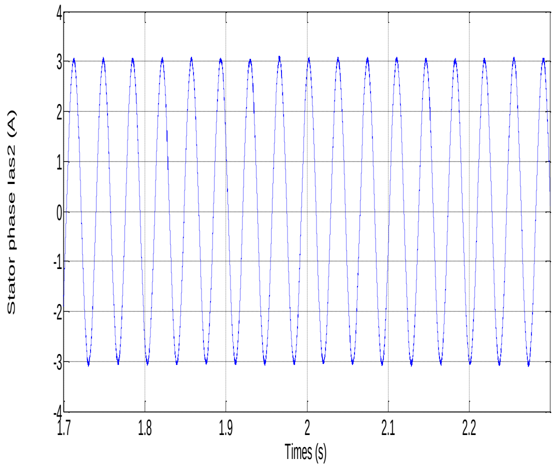

Fig. 14 Current in one phase of the second machine.

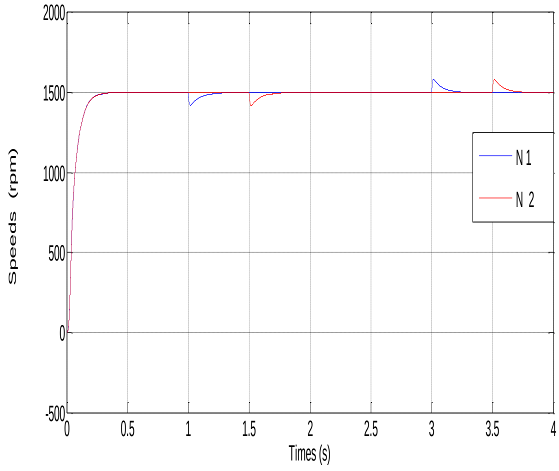

Fig. 15 Speeds of the first and second machine

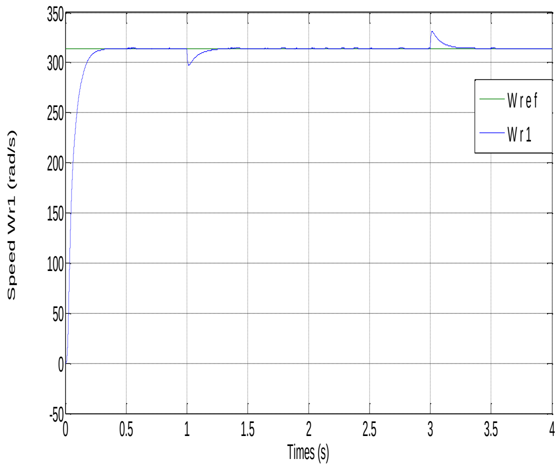

Fig. 16 Speeds of the first machine Vs its reference value

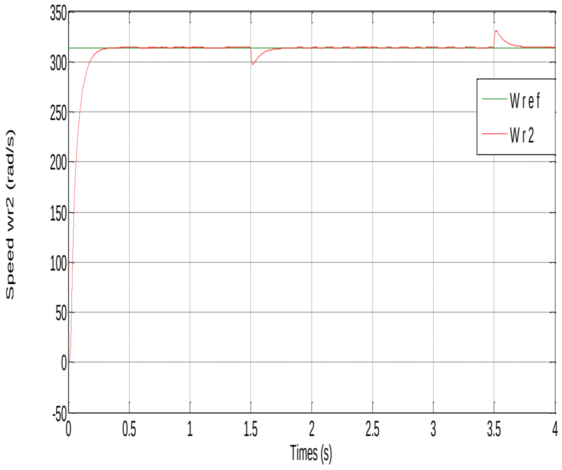

Fig. 17 Speeds of the second machine Vs its reference value

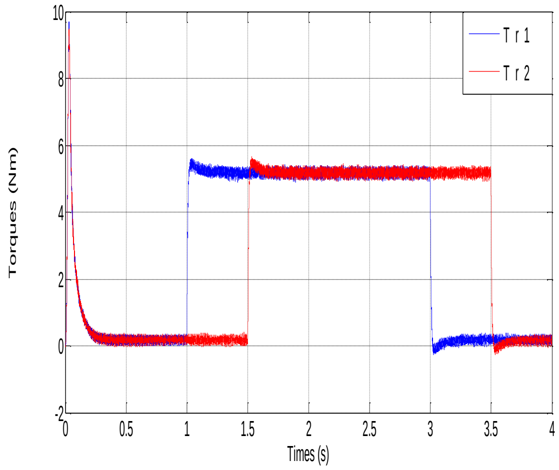

Fig. 18 Torques of the first and second machines.

6. CONCLUSIONS

A three to five phases matrix converter based five-phase series connected two-motor drive system is presented in this paper.

Simple carrier-based PWM technique is used to control the matrix converter. The matrix converters successfully drive two five-phase series-connected induction machines. This solution has advantage of higher power factor and sinusoidal source side current.

APPENDIXES

Simulation Parameters:

Parameters Name	Parameters Values
Source side resistance R_s	0.05 Ω
Source side inductance L_S	8 mH
DC link capacitor	2000 µF
Stator resistance	10 Ω
Stator leakage inductance	40 mH
Mutual inductance	420 mH
Inertia J_m	0.03 kgm^2
Number of Poles	4

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