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# Independent Control of a Dual Induction Motors Drives Control Based on Indirect Field Vector Oriented Method

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**Abstract**

To reduce the cost and the system complexity in power applications, voltage source five leg space vector pulse width modulation inverter (FLI) is designed to drive dual induction motors. This paper presents independent control of dual induction motor fed by five leg inverter. Indirect field oriented control is used separate by each motor. Two space vector pulse width modulator is utilized to generate the switching signal for FLI and a double zero sequence modulation technique (DZS) is employed to generate the modulation signals. Two motors operate under different operation condition where the result proven that dual induction motor can independently controlled by FLI.

**Key Words: Indirect Field Oriented Control, Five Leg Inverter, DZS, Dual IM**

## 1. Introduction

Recently, for Ac drive the power demand is increasing. The performance of machine drives is enhancing by decreasing the cost and size of the drives. Multi-Machine System (MMS) is one solution for that [1]. In many manufacturing fields such as electric trains, textile, paper making and mining, multiple motor drive systems (MMS) are demanded, in which two motors may be operate in parallel [2]. Generally, this system is required a lot of power switches and high performance control for the number of converter. As a result, will needed a large number of power electronic switches (IGBTs) semiconductor which is lead to complex of structure and high cost, for reducing this cost is utilized a common DC bus while each motor has its three phase inverter [3]. Probably, frequently, analyzed and reduced switch count topology for two-motor drives employing the five-leg (ten-switch) VSI. One phase of each motor is connected to the common leg of the five-leg VSI, while the remaining two phases of each machine are supplied independently, from the two pairs of inverter legs [4]. Five leg inverter fed drives are highly suitable for standalone applications like electric hybrid vehicles, aerospace applications and ship propulsion that require high levels of reliability and efficiency. The third harmonic in a five phase system can be used to effectively reduce the torque pulsations in the steady state operation and the percentage of the third harmonic included along with the fundamental can be altered by the switching algorithm itself [5]. In this paper the independent control of a dual induction motor drive system fed by a five-leg inverter is researching to make a good use of the five-leg inverter. In most, each induction motor is adopted indirect field oriented vector control, and using space vector pulse width modulation (SVPWM) for decreasing the switching count compared with the conventional PWM methods for the five-leg inverter (FLI). However, the structure of control is composed of four PI regulators for current loops and two PI regulators for speed, which is complex in the tuning of all regulators for optimizing performance of system. In addition, the common leg of inverter is shared by two induction motors and two inverter stages are modulated by SVPWM. The principle independent control of two three phase induction motor drive by five leg voltage source inverter is investigated.

## 2. Modeling of Three Phase Induction Motor Drive

The mathematical model of induction motor in stationary reference can be expresses in following equations [6]: The voltage of the stator winding given by

$$v_{qs}^{s} = \frac{2}{3} v_{as} - \frac{1}{3} v_{bs} - \frac{1}{3} v_{cs}$$

$$= \frac{2}{3} v_{ag} - \frac{1}{3} v_{bg} - \frac{1}{3} v_{cg} - v_{sg} \qquad (1)$$

$$v_{ds}^{s} = \frac{1}{\sqrt{3}}(v_{sc} - v_{bs}) = \frac{1}{\sqrt{3}}(v_{cg} - v_{bg}) \qquad (2)$$

The flux linkages as follows:

$$\psi_{qs}^{s} = \omega_b \int \left\{ v_{qs}^{s} + \frac{r_s}{x_{ls}} \left( \psi_{mq}^{s} - \psi_{mq}^{s} \right) \right\} dt \qquad (3)$$

$$\psi_{ds}^{s} = \omega_b \int \left\{ v_{ds}^{s} + \frac{r_s}{x_{ls}} \left( \psi_{mq}^{s} - \psi_{md}^{s} \right) \right\} dt \qquad (4)$$

$$\psi'^{s}_{qr} = \omega_b \int \left\{ \begin{matrix} v'^{s}_{qr} + \frac{\omega_r}{\omega_b} \psi'_{dr} \\ + \frac{r'_r}{x'_{lr}} \left( \psi_{mq}^{s} - \psi'^{s}_{qr} \right) \end{matrix} \right\} dt \qquad (5)$$

$$\psi'^{s}_{dr} = \omega_b \int \left\{ v'^{s}_{dr} + \frac{\omega_r}{\omega_b} \psi'_{qr} + \frac{r'_r}{x'_{lr}} \left( \psi_{md}^{s} - \psi'^{s}_{dr} \right) \right\} dt \qquad (6)$$

The electromagnetic torque is described by:

$$T_{em} = \frac{3}{2} \frac{P}{2\omega_b} \left( \psi_{ds}^{s} i_{qs}^{s} - \psi_{qs}^{s} i_{ds}^{s} \right) \qquad (7)$$

Where $v_{ag}, v_{bg}$, and $v_{cg}$ are the three applied voltage to the terminal of stator, and $v_{as}, v_{bs}$, and $v_{cs}$ are the three voltage of stator; $r_s, r'_r$, $\omega_r$, $\omega_b$ are stator resistance, rotor referred resistance, actual rotor speed, and the base electrical angular frequency, respectively. The mutual linkages flux is $\psi_{mq}^{s}$ and $p$ is the number of poles pairs. The stator and rotor windings leakage reactance are $x_{ls}$ and $x'_{lr}$, respectively.

## 3. Space Vector Pulse Width Modulation Technique SVPWM

The SVPWM technique is generally utilized in modern Ac drives, especially for three phase induction motor by calculating voltage vectors in sex sectors in order to generate switching signals for all switching in a circuit power. Figure (1) shows asymmetrical hexagon which represented eight voltage vector [7]. In SVPWM each desired position on the circular locus can be achieved by an average relationship between two neighboring active vectors. Zero state vectors are used to fill-up the gap to a constant sampling interval. An optimum space vector modulation is expected if the maximum deviation of the current vector for several switching states becomes as small as possible, and the cycle time is as short as possible [8].

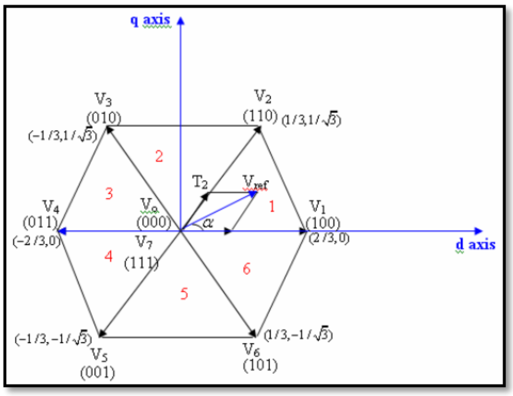



**Figure (1) Space vector**

## 4. Configuration of Five Leg Voltage Source Inverter System

### 4.1. Topology of Five Leg Drive System

The topology of five-leg VSI supplies dual -three phase induction machine drive shown in Figure (2), that will be saving two switches and lead to reduce in capital cost with respect to the standard configuration of dual three-phase voltage source inverter (VSI). In the five leg inverter topology, will used one leg as the common leg, where this leg is shared by two motors , leg $C$ is chosen to share by two machines. Legs $A$ and B of Inverter are connected to phases $a_1$ and $b_1$ directly, for machine 1. Legs $F$ and $E$ are connected to phases $a_2$ and $b_2$, respectively, of machine 2. $DC$ bus is of $V_{dc}$ rated value [9].

### 4.2. Modulation Methods of Five Leg Voltage Source Inverter

The Double Zero Sequence(DZS) is the best method where enables the DC link voltage to be an arbitrary distribution between two motors while its operation maintaining in constant switching frequency mode. Also, the DZS is easier to implement and show less complexity. This method is able to solve the drawbacks of previous PWMs such as the restriction voltage for one motor about 50% of the DC bus, sideband harmonics, underutilization of the switching state, asymmetrical switching frequency, high magnitude THD generation and their complexity problem [9]. The DZS method is using either carrier based or space vector PWM technique. A space vector double zero sequence DZS is shown in Figure (3) In this method, two standard identical SVPWM three- phase modulator are utilized to control each motor and it generating modulation signals for the five leg, where it is make able to assign either of the both machines any part of the DC bus voltage. For each machine respectively, voltage references become vector in d-q planes with complete arbitrary amplitude suitable to any the six sectors in d-q planes. Both modulators are operating in standard manner, where the total time of zero sequence is shared and equally among 111 and 000 space vectors, each reference space vector will have been realizing on average over the period of switching by adjusting two active space vector. Principally at first in the stationary frame setting is synthesized of the fundamental voltages in the 3-phase leg space vector modulator, then process will have repeated for setting modulator 2. The outputs of the SVPWM modulator is as assigned by duty cycle δ, to reduce the modulation signals from six to five will summed output signals of SVPWM machine1 and SVPWM machine 2 as an appropriate manner as shown in the block diagram configuration.

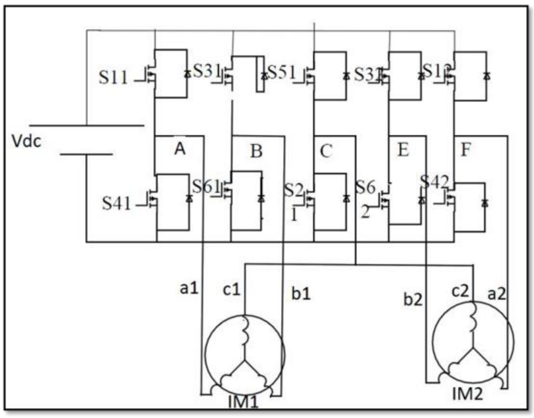



**Figure (2) Five-leg VSI supplies dual -three phase induction machine drive**

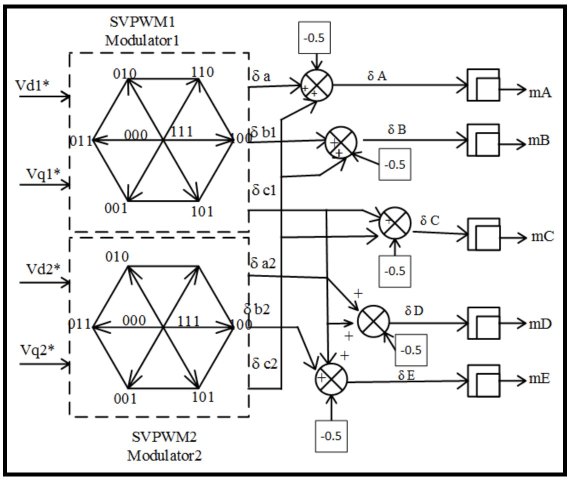



**Figure (3) A space vector double zero sequence DZS**

The output of five modulating signals for FLI are describe below [10]:

$$\delta_A = \delta_{a_1} + \delta_{c_2} \quad (8)$$

$$\delta_B = \delta_{b_1} + \delta_{c_2} \quad (9)$$

$$\delta_C = \delta_{c1} + \delta_{c2} \quad (10)$$

$$\delta_D = \delta_{a_2} + \delta_{c_1} \quad (11)$$

$$\delta_E = \delta_{b_2} + \delta_{c_1} \quad (12)$$

Where the $\delta_A$, $\delta_B$ ,$\delta_C$,$\delta_D$and $\delta_E$ denoted to the modulating signal which generated to FLI after compared with carrier signal. The placement of the zero Space Vector 111 will be in the middle of the switching pattern therefore the values of duty cycles will have equal to 0.5. After summation defined by Eqs. (8) to (12), the total duty cycles will be shifting between the rang 0.5 to1.5 between two motors (motor '1' and motor "2") shifted into the range (0.5: 1.5), where does not fit with the value of the switching period. therefore, however, the value of 0.5 make be continuously subtracted from the duty cycles, which calculated by using Eqs. (8) to (12). The net effect of the duty cycle summation is there distribution of the application times of the zero space vectors. From the first three equations above ,it is visible that the addition of the value of the duty cycle $\delta_{c2}$increases all three duty cycles, originally generated by the modulator1, in the same manner. Thus, the application time of the zero space vector 111 is effectively increased, and as a consequence application time of the zero space vector 000 is decreased (before shifting by –0.5), without affecting the application times of the two active space vectors. The same explanations apply to modulator2 on the basis of the last three equations above [11].

## 5. Control Strategy

### 5.1. Indirect Field Oriented Vector Control of Induction Motor Drive

In order to have better controllability and high performance, vector control is used where advanced control of IM is required an independent control of torque and magnetic flux like as $D_c$ machine [12]. Vector control is classified into two types depending on the way of calculating the field angle: direct oriented field FOC and indirect field oriented vector control IFOC. In direct vector control, the field angle is obtained from current and terminal voltage while in indirect field control the field angle is get using rotor poison calculating [13]. IFOC of IM drive is the widespread used in high performance of IM drive because of its advantages like high, efficiency, extremely rugged, good power factor, very simple, easy implementation, low cost and it does not require starting motor. IFOC motor drive is gaining greatly attention because of reduced machine parameter dependence and its less calculation complexity, it allows the decoupling of electromagnetic torque and rotor flux variables by means of nonlinear coordinate transformation and manipulating the field oriented quantities by using the vector components of direct and quadrature axis current by utilizing the unit vector [14].

### 5.2. Principle of Indirect Field Oriented Vector Control Method

In IFOC method, there is no needed to find the position of the rotor flux as in other type of vector control method (direct vector control), where a suitable value is applying to the slip frequency to adjusted appropriate position to the stator current of machine. After the estimation of the slip frequency, it will have summed with the actual rotor speed to obtain the stator angular frequency and integrated to obtain the electrical angular position [15]. Figure(4) shows the block diagram of an indirect field orient control induction motor drive component of stator current $i_{qs}$ and $i_{ds}$ consider constant in the rotor reference frame. The indirect vector control method is essentially same as the direct vector control except the unit vector is generated in an indirect manner using the measured speed $\omega_r$ and slip speed $\omega_{sl}$ [15]. The induction motor is fed by a SVPWM inverter, which operates in voltage control mode where the actual speed of motor $\omega_r$ is compared with the reference speed $\omega_r^*$ and will produced the error, which is fed to (PI or any intelligent controller)for the speed controller. The electromagnetic torque $T_e$ component of current $i_{qs}^*$ is the output of the speed controller [16]:

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{L_r}\left(\hat{\psi}_r\, i_{qs}\right) \qquad (13)$$

The electromagnetic torque reference $T_e^*$is used to calculate the quadrature -axis stator current reference $i_{qs}^*$ is calculated from[16].

$$i_{qs}^* = \left(\frac{2}{3}\right)\left(\frac{2}{p}\right)\left(\frac{L_r}{L_m}\right)\left(\frac{T_e^*}{\hat{\psi}_r}\right) \qquad (14)$$

Where

$$\hat{\psi}_r = \frac{L_m i_{ds}}{1+\tau_r s}$$

And

$\tau_r = \frac{L_r}{R_r}$, $\tau_r$ is the time constant of rotor.

The direct-axis current reference of stator $i_{ds}^*$ is obtained from reference rotor flux input $\psi_r^*$ as in the following equation:

$$i_{ds}^* = \frac{|\psi_r|^*}{L_m} \qquad (15)$$

The rotor flux position $\theta_e$ is obtained by added the feedback rotor speed to slip speed frequency $\omega_{sl}$,then the slip speed together with the speed of rotor is integrated.

$$\theta_e = \int \omega_e\, dt = \int(\omega_r + \omega_{sl}) \qquad (16)$$

The slip frequency $\omega_{sl}$ is generated by the stator reference current $i^*_{qs}$ and the parameters motor.

$$\omega_{sl} = \frac{L_m R_r}{\psi_r L_r} i^*_{qs} \qquad (17)$$

The two reference currents ($i^*_{ds}$ and $i^*_{qs}$) are compared with feedback current of motor through Park and Clark Transformation, the error from PI controllers is generated the voltage command signal which summed with decoupled voltage and these are converted to three phase voltage [17].

## 6. Design of Speed Control of Dual Induction Motors with FLI

The control strategy of vector control for dual independent three phase induction motor drive fed by five leg inverter is shown in Figure (5). The control strategy is based on two classical Indirect Field Oriented Control (IFOC aim is to decouple the torque and the flux control). This achieved by oriented the flux on the d-axis in the d-q frame.

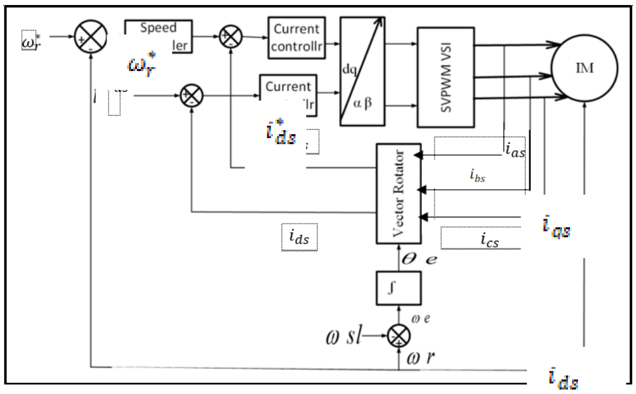



**Figure (4) The block diagram of an indirect field orient control IM drive**

The control system consists of two machines (IM1 and IM2), voltage source FLI, IFOC 1 for IM1 and IFOC 2 for IM2 and the double zero sequence modulation as shown in Figure (5). Where two speed controller PI and four current controllers PI is using. In the IFOC of IM1, the flux component and torque component of the stator current is going through coordinated transformation to supply the voltage amplitude, phase, and frequency. The speed demand is given as the speed reference $\omega^*_{r_1}$ or $\omega^*_{r_2}$ for IM1 and IM2, respectively. The speed demands are compared with the actual rotor speeds $\omega r_1$ and $\omega_{r2}$, the deviation is amplified in the speed control PI controller and the output of the speed controller serves as the reference input to the torque current loop. The reference torque current $i^*_{qs1}$ is compared with the actual torque current component, $i_{qs1}$ and results in the torque current error, the error is processed to generating the reference voltage torque component $V^*_{qs1}$. On the other hand, the current flux component, $i^*_{ds}$ which was earlier set to a constant value is compared with the actual values of the d axis- stator current of motor $i_{ds1}$. The error signal is applied to the PI controller to generate the command values of the flux voltage component, $V^*_{ds}$. The inverse Park transformation reference is using to transform the reference voltage to the stationary reference frame (αβ frame) coordinate. A similar principle is applied to the IFOC of IM2. Both signals after that synthesized using the DZS modulation to control the voltage supply required for the motors.

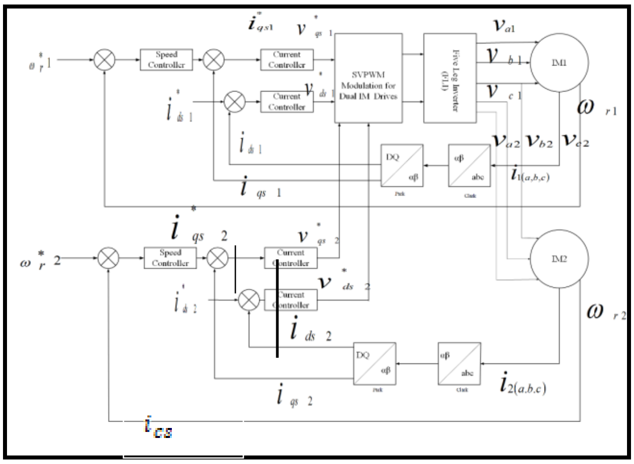
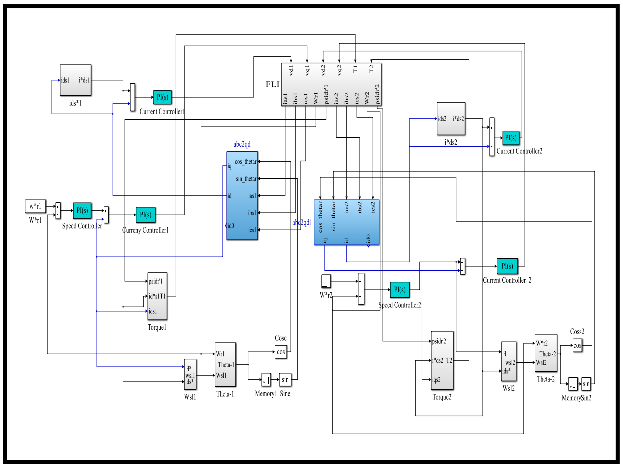



**Figure (5) The control strategy of vector control for dual independent three phase induction motor drive**

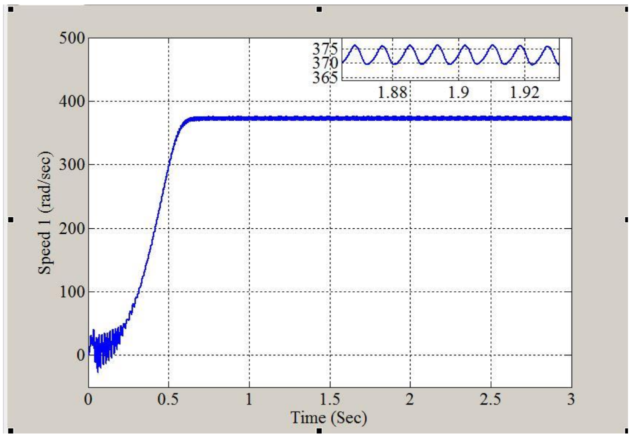


**fed by Five Leg Inverter**

### 6.1. Simulation Results of Dual IM Fed by FLI

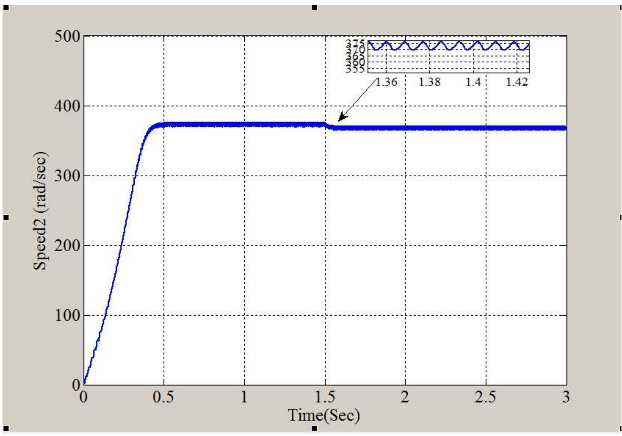
Figure (6) shows the simulation of IFOC method of dual IM using MATLAB/SIMULINK program. The Simulink model consist of two identical three phase induction motor both parameters are identical with 1hp 200V and 60Hz, and two independent IFOC method for each motor using single FLI which circuit consist of ten MOSFET and DC bus voltage, will used one leg as the common leg, where this leg is shared in two phases $c_1$ and $c_2$by two motors leg *C* is chosen to share by two machines. Legs A and B of Inverter are connected to phases $a_1$ and $b_1$ directly, for IM 1. Legs D and E are connected to phases $a_2$ and $b_2$, respectively. Two independent three phase space vector modulators are utilized to control the dual machines (IM1 and IM2), d–q rotating reference frame was referred as the voltage reference vector to dual motor. The performance of the system is obtained by two test. First test is shown in Figure (7). The IM1 is operated at no load condition. Figure (7a) shows the rotor speed of IM1 which starting and steady state at 0.6 sec, while the motor2 operate at no load and sudden load 2 N.m is applied at 1.5 sec, the rotor speed of IM2 is shown in Figure (7b), the torque for both motors is shown in Figures. (7c and 7d). Figures. (7e and 7f) are show the stator current of two motors. The next test illustrated in Figure (8)., the IM1 stay at no load and the IM2 is applied sequence load, full load at 3 Sec, half load at 6sec and quartier load at 8 Sec. The two motors motor is driven at the reference speed. Figure. (8a) shows the speed response of the IM1 and speed of IM2 is shown in Fig.8b during no load. The developed torque during no load and load condition is shown in Figures. (8c and 8d). The direct current of stator component given in Figures. (8e and 8f) respectively. From the results, it shown that the rotor speed of motor1 is steady state at 0.6sec and the rotor speed of motor2 is steady at 0.4sec and noted when motor1 is run at no load and the motor2 is loaded the two motor are independent control.

Figure (6) Simulink model of IFOC for Two Induction Motor.




**(a)**

**Figure (7) Dynamic Response of Dual IMs fed SVPWM FLI inverter (a)Speed, of IM1 (b)Speed of IM2, (c)Torque of IM1, (d) Torque of IM1, (e)iqs1, (f) iqs2.**

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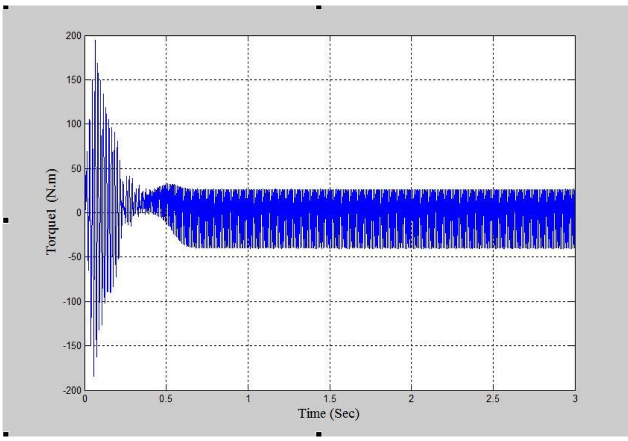

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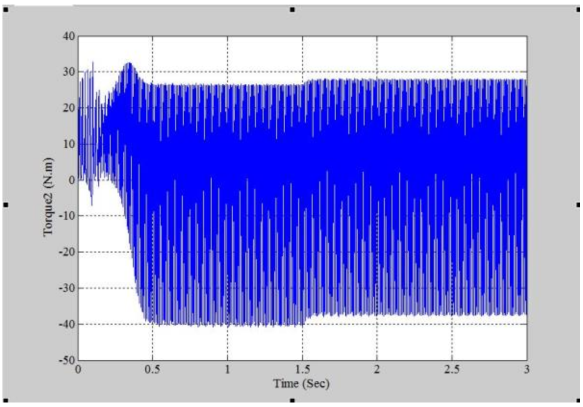
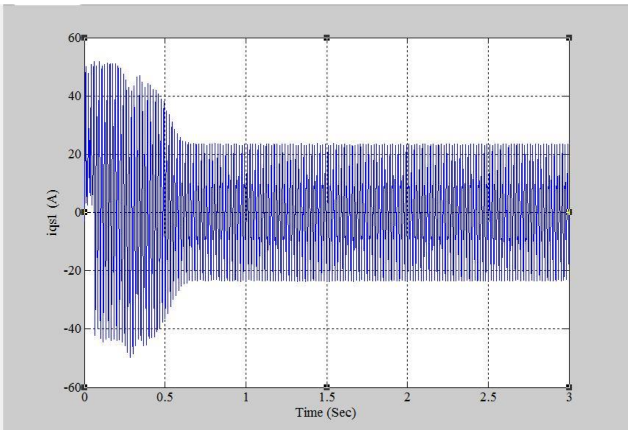



**(d)**

**Figure (7) Continued**

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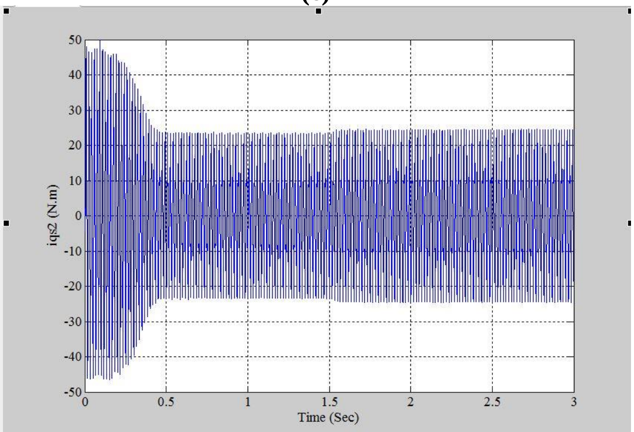
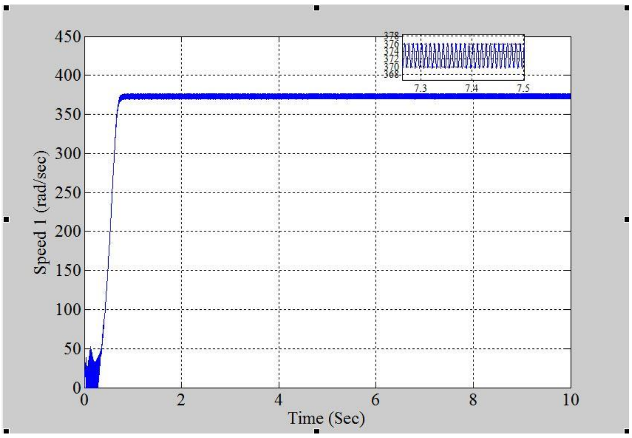


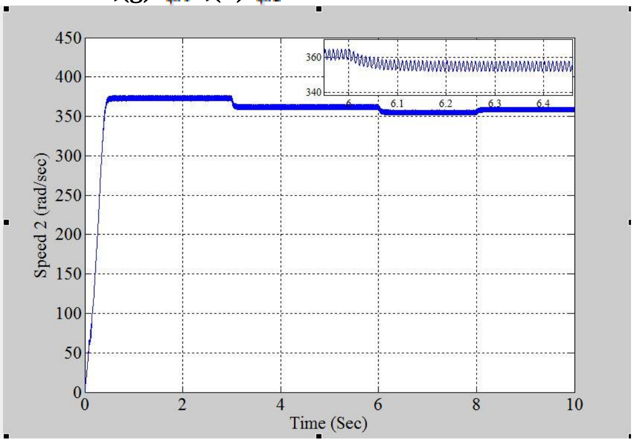

**(f)**

**Figure (7) Continued**




**(a)**

**Figure (8) Dynamic Response of Dual IMs fed SVPWM FLI inverter at second test. (a)Speed, of IM1 (b)Speed of IM2, (c)Torque of IM1, (d) Torque of IM1, (e)ids1, (f) ids2 ,(g) $i_{qs1}$ ,(h) $i_{qs2}$**

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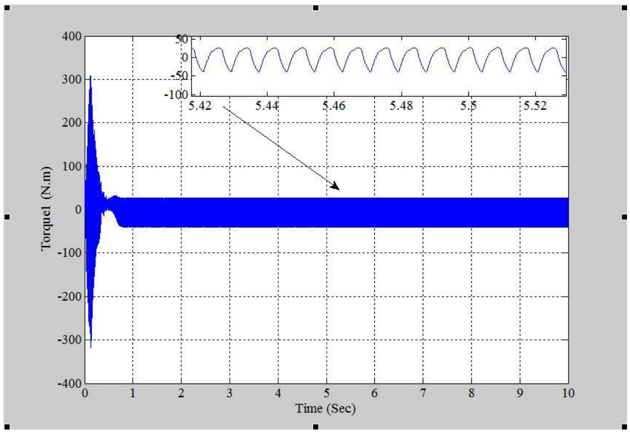


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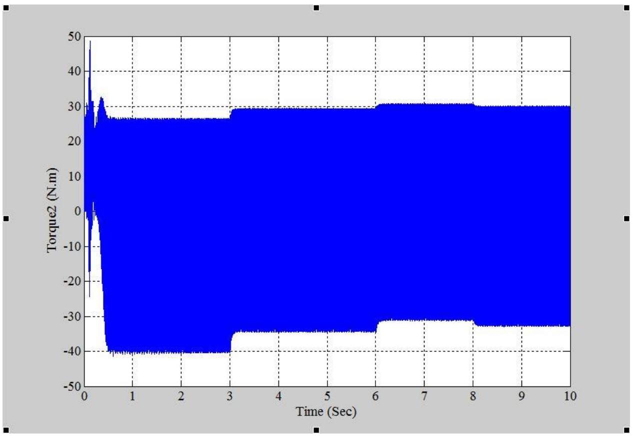
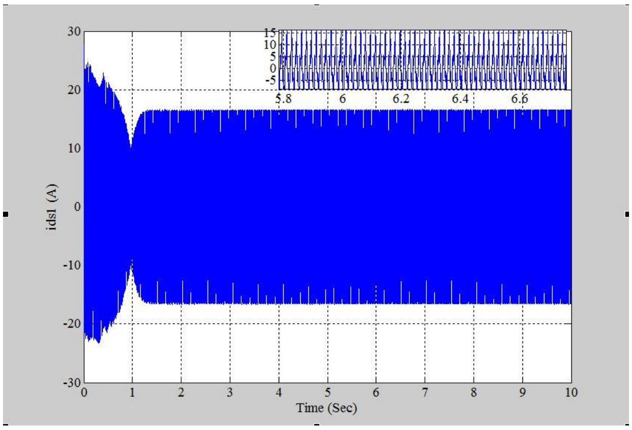



**(d)**
**Figure (8) Continued**

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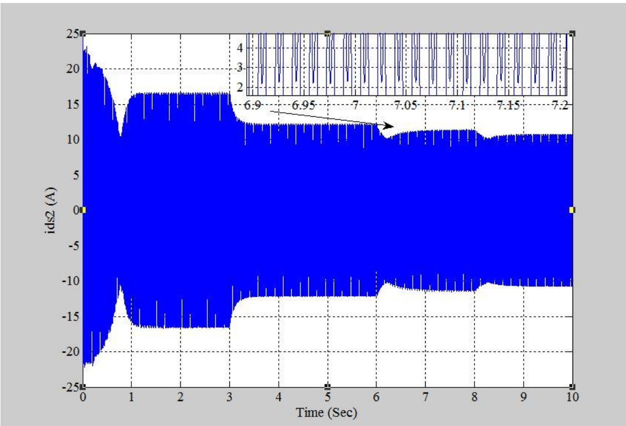
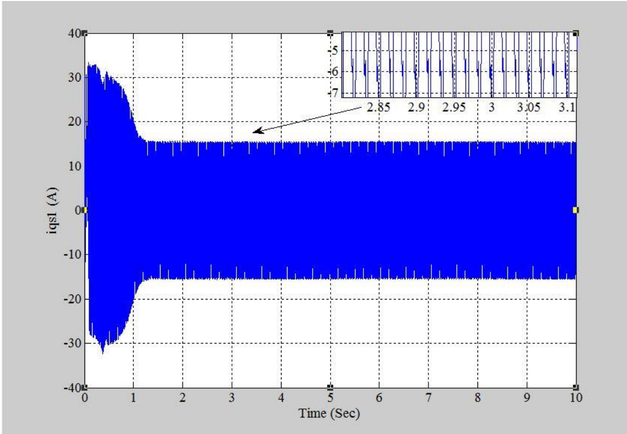



**(f)**
**Figure (8) Continued**

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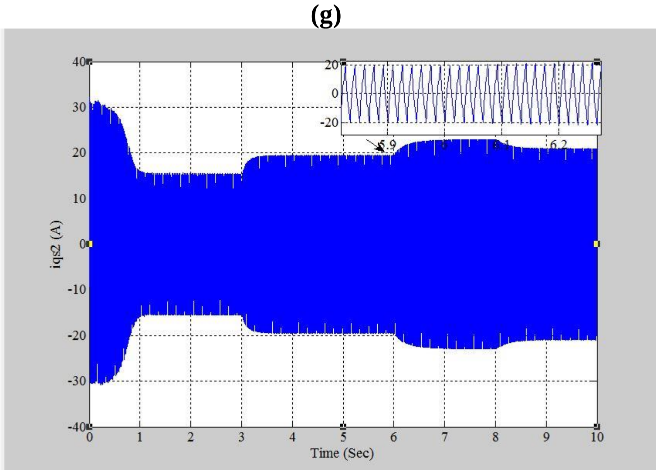


**(h)**
**Figure (8) Continued**

## 7. Conclusions

The model of the two IMs with its control circuit consist of, two IFOC vector controls for both motors are used. The simulated results show a robustness and stable of system, and prove that the topology of FLI is applicable to drive dual IM independently. The term independently refers to each motor that can be operated at different operating conditions such as different direction, speed, load torque and motors parameters. Here IM1 and IM2 work at different operation (here take with respect to load where one motor operates at no load and other motor at different load). It is showed that the five-leg VSI supplied two-motor drive is well suited to constant power applications, such as center-driven winders, where the motors are independently control.

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