

**DEVELOPMENT OF COMBINED VECTOR AND DIRECT TORQUE  
CONTROL METHODS FOR INDEPENDENT TWO INDUCTION MOTOR  
DRIVES**

**MD HAIRUL NIZAM BIN TALIB  
PROFESOR MADYA DR ZULKIFILIE BIN IBRAHIM  
N.A RAHIM  
N.M YAAKOP**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

# Development of Combined Vector and Direct Torque Control Methods for Independent Two Induction Motor Drives

M.H.N. Talib<sup>1</sup>, Z.Ibrahim<sup>2</sup>, N.A. Rahim<sup>3</sup>, N.M.Yaakop<sup>4</sup>

<sup>1,2</sup> Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka

<sup>3</sup> Faculty of Engineering, Universiti Malaya,

<sup>4</sup> Faculty of Engineering, University Kuala Lumpur Malaysian Spanish Institute,

<sup>1,2</sup> Melaka, Malaysia.

<sup>3,4</sup> Kuala Lumpur, Malaysia.

Email: hairulnizam@utem.edu.my, zulkifilie.ibrahim@utem.edu.my, nasrudin@um.edu.my, nurazlin@msi.unikl.edu.my

**Abstract**—Many applications use two or more motors operating in parallel configuration by using one variable speed drive. This system is able to control these multiple motors at the same desired motor speed operation which provide advantages in terms of components and cost reduction. However, the system is not able to control each motor separately if it is desired to operate at different speeds and it also cannot withstand the load disturbance. To address this problem, the design of combined Vector Control-Direct Torque Control (DTC) methods is proposed and their performance is investigated for the case of independent controlled two induction motors fed by single Five Leg Inverter (FLI) method. Double Zero Sequence (DZS) Injection Method Space Vector Pulse Width Modulation (SVPWM) scheme is used for the FLI. Simulation results from the Simulink/Matlab that verify the validity of the method are also included. The results show the ability of the proposed method to control motor speed independently under forward-reverse step speed command and load disturbance condition.

**Keywords** —Two Induction Motor Drive; Five Leg Inverter; Double Zero Sequence (DZS) Injection Method; Field Oriented Control (FOC); Direct Torque Control (DTC)

## I. INTRODUCTION

Vector Control and Direct Torque Controls are becoming a choice for high performance induction motor drive system in industrial applications. Most of the research and studies focused on the vector control or direct torque control with a single three-phase motor and a single-three leg inverter drive system [1, 2]. There are many industrial manufacturing processes that require high performance control of a multi motor operation under different loads and speeds requirement. The multi motor operations under this condition encourage research on the multi motor drive system by using a single inverter. The research offers advantage of allowing independent control of the motors with cost reduction and space minimization. The independent control of two inductions can be realized by using Four Leg Inverter[3, 4], Five Leg Inverter (FLI)[5-9]or Nine Switched Inverter[10, 11]. This drive system offers cost reduction by reducing the numbers of power electronics switches devices, using only one DC bus supply, one DSP and less space. Many researches on the two motor control operation have discussed on the development of the inverter, motors connection, PWM strategy and performance analysis of the inverter. All of the system used vector control method for both motors. This paper focused on

the development of combined vector control and DTC methods with a single FLI system to operate two three phase induction motors independently.

One of the important components in independent control of two AC motor drive systems is the inverter control. Either in Four Leg Inverter, Five Leg Inverter (FLI) or Nine Switched Inverter, the PWM methods are used to control the switching gates to produce an appropriate output voltage to the motor. In the FLI topology, there are numerous PWM techniques [5, 7] such as Dual Voltage Modulation (DVM), Modulation Bock Method (MBM), Inversion Table Method (IVM), Double Zero Sequence Method (DZS) and Two Arm Modulation (TAM). The DZS is one of the best methods which enables an arbitrary distribution of the DC link voltage between the two motors and maintain to operate in constant switching frequency mode. DZS offer less complexity and easy to implement using standard DSP. This method is able to solve the drawback of previous PWM such as restriction of 50% of the DC bus voltage for one motor, asymmetrical switching frequency, underutilizing of the switching state, sideband harmonics, high magnitude THD generation and their complexity issue.

The vector control or DTC offers better dynamic performance of induction motor drives[12]. The vector control imitates the principle of separately excited DC motor. Independent control of both magnetic field and torque is achieved. The vector control concept implies that the current components supplied to the machine should be split into a flux component and a torque component. The flux component of the current is oriented in phase with the rotor flux vector, and the torque component is oriented in quadrature. This system applied the indirect field oriented control (IFOC) which only required correct alignment of rotating reference frame with rotor flux frame. The flux orientation can be achieved by imposing a slip frequency derived from rotor dynamic equation. Thus, its offers more easy implementation and cost saving compared to the direct field oriented control method (DFOC).

Direct Torque Control- Space Vector Modulation (DTC-SVM) method offers constant switching frequency and lower flux and torque ripple, reliable start up and low speed operation compared to the conventional method[1, 2, 13-15]. A-part from these advantages, the DTC- SVM is chosen because it is able to

work with the vector control to feed signal into the modulation of the FLI. Many research have been conducted to improve the DTC- SVM schemes introduced such as closed loop flux control, closed loop torque control and closed loop for flux and torque control. DTC scheme with closed loop and flux control is selected for this analysis because it offers better flux and torque components control.

This paper proposes a combined vector control and DTC methods for independent control of two induction motors fed by a single FLI. FOC vector control method is used to control motor 1 (M1) and DTC space vector modulation method is applied to the motor 2 (M2). The output of the stationary voltage demand of both methods is synthesized through the DZS SVPWM method to generate the required voltage to the FLI. The output voltage from the FLI is supplied to the three-phase induction motor accordingly.

## II. FIVE LEG INVERTER

### A. Five Leg Inverter (FLI) Configuration

The typical connection of the five leg voltage source inverter for two three-phase induction motors is shown in Figure 1. Each of the leg consists of two switches with a total number of ten switches altogether. Inverter legs A and B are connected to M1 meanwhile D and E legs are connected to M2. In the FLI topology, one leg is used as the common leg. This common leg is shared to the both motors. In this case, leg C is chosen as the common leg. All the legs are connected to the three-phase supply termination of the motors denoted as a1,b1,c1 and a2,b2,c2 to represent M1 and M2 termination respectively.

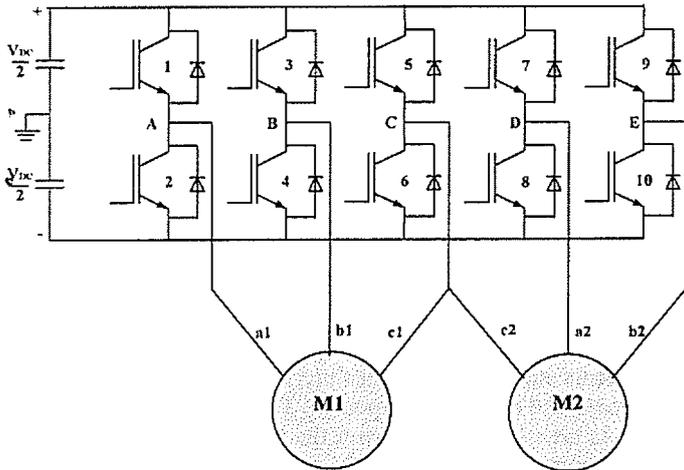


Figure 1 : Connection between five leg inverter and motors

### B. Double Zero Sequence (DZS) Injection Method Configuration

This simulation focused on the space vector PWM techniques applied using the DZS methods [5, 6, 16]. These methods are the best solution to the FLI issues nowadays. Even though this method faced the natural constrains of the FLI which requires the total voltage of the machines must not

exceed the DC bus voltage, it is able to utilize any portion of the DC bus voltage to be allocated to any of the two machines.

The space vector DZS block diagram is shown in Figure 2. This method utilizes the standard three-phase space vector modulator to generate modulation signals for the FLI.

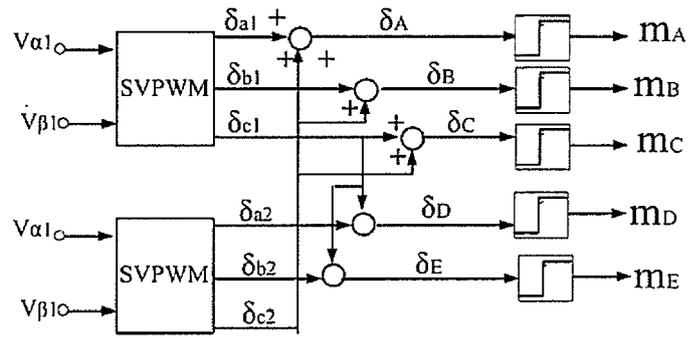


Figure 2 : Double Zero Sequence Injection Method block diagram.

Based on the principle, the first set of fundamental voltages in stationary frame is synthesized in the three-phase leg space vector modulator. This process is repeated for set 2. The output of the modulator is  $\delta$ , which can be considered as the duty cycle for each three leg. The output signals of set 1 and set 2 are then summed in an appropriate manner to reduce the number of modulation signals from six to five as presented in the block diagram configuration. The summed results of output set 1 and set 2 generate modulated signal for all the five legs of the inverter as equation below:

$$\begin{aligned}\delta_A &= \delta_{a1} + \delta_{c2} \\ \delta_B &= \delta_{b1} + \delta_{c2} \\ \delta_C &= \delta_{c1} + \delta_{c2} \\ \delta_D &= \delta_{a2} + \delta_{c1} \\ \delta_E &= \delta_{b2} + \delta_{c1}\end{aligned}\quad (1)$$

Finally, the modulation signals of the FLI which are noted as  $m_A, m_B, m_C, m_D$  and  $m_E$  respectively are compared to the carrier signal to generate output voltage of the FLI.

## III. THREE-PHASE INDUCTION MOTOR MODEL

The MATLAB/Simulink model of three-phase induction motor is developed based on the following equations in synchronous reference frame [12].

Stator voltage equations:

$$\begin{aligned}\bar{V}_{ds} &= R_s \bar{I}_{ds} + \frac{d\bar{\varphi}_{ds}}{dt} - \omega_s \bar{\varphi}_{qs} \\ \bar{V}_{qs} &= R_s \bar{I}_{qs} + \frac{d\bar{\varphi}_{qs}}{dt} - \omega_s \bar{\varphi}_{ds}\end{aligned}\quad (2)$$

Rotor Voltage equations:

$$\bar{V}_{dr} = 0 = R_s \bar{I}_{dr} + \frac{d\bar{\varphi}_{dr}}{dt} - (\omega_s - \omega_r) \bar{\varphi}_{qr}\quad (3)$$



$V_{sq}^*$ . The stator flux component,  $|\psi_s|$  is set to a constant value and compared with the estimated value for stator flux  $\hat{\psi}$  and is converted to direct axis voltage demand,  $V_d^*$ . Then, both voltage components in rotating reference frame are transformed to the stationary reference frame by dq to  $\alpha\beta$  transformation. The second set of reference voltage vector is synthesized through the modulation of the FLI.

## V. SIMULATION RESULT OF SPEED CONTROL OPERATION

### A. Parameter Set-up

Simulations have been carried out for the two motor controls for the FLI by using SVPWM method. A dedicated speed range and torque load is applied to understand the performances of the FOC and DTC method with the FLI through the motors performances. Two similar types of three-phase induction motors are used in the simulation studies and details about the motor parameters are shown in Table I below.

TABLE I. INDUCTION MOTOR PARAMETERS

Motor Specifications	Value
Rated Voltage	380 V
Rated Frequency	50 Hz
Poles	4
Rated Speed	1430 rpm
Stator Resistance	6.46 $\Omega$
Rotor Resistance	3.617 $\Omega$
Stator Inductance	0.34257 H
Rotor Inductance	0.32903 H
Magnetizing Inductance	0.3118 H
Inertia	0.008kgm <sup>2</sup>

Based on the two induction motor drives fed by a single inverter principle, the summed voltage requirement of both motors must be within the DC bus voltage supply. The FLI is supplied by using 537V DC supply and carrier frequency is set at 3kHz. Thus, this simulation is performed with a few speed ranges for forward and reverse operation by abiding to this principle in order to understand the speed behaviors. The analysis is limited to the half rated speed and half rated load for performance comparison. The motors are set to follow the speed operating demand and external torque load applied as follows:

- M1-400 rpm is applied from zero to 0.4s, then the speed is increased to 600rpm until it reaches 1s and suddenly step changed to -750rpm at 1s until it reaches 2s.
- Torque load 1(TL1): 3Nm external load torque is applied to the M1 from 0.6s to 1.5s
- M2-400 rpm is set from zero to 0.4s, then the speed is increased to 750rpm until it reaches 1s and suddenly step changed to -750rpm at 1s until it reaches 2s.
- Torque load 2(TL2): 5Nm external load torque is applied to M2 from 0.6s to 1.5s

By referring to the vector control block diagram in Figure 1, three PI controllers are used for the speed, torque and flux controlled for FOC and DTC. All the PI controllers are tuned manually to produce a periodic speed response with minimum settling time to the applications of 50% rated speed command under no load conditions with rated inertia. Table II shows the PI controller parameters for speed, torque and flux components.

TABLE II. SPEED, TORQUE AND FLUX CONTROLLER PARAMETERS

Motor Specifications	FOC PI Value	DTC PI Value
Speed Controller	$K_p=2.55$	$K_p=25$
	$K_i=80$	$K_i=50$
Torque Controller	$K_p=45$	$K_p=150$
	$K_i=90$	$K_i=5000$
Flux Controller	$K_p=25$	$K_p=440$
	$K_i=60$	$K_i=70000$

### B. M1 and M2 Simulation result

The performance investigation of the FOC and DTC method fed the FLI is conducted to understand the behavior of the motors under different speed command change, load disturbance, steady state stability and transient response.

Figure 4 shows the speed response for M1 and M2 motors based on FOC and DTC method respectively. Both motors are able to operate in forward and reverse direction. Different speed demand can be seen during 0.4s to 1s show the ability of the FLI to independently control the motors using combined FOC and DTC method. At -750rpm demand, the result shows the ability of the system to perform at 50% voltage utilization factor with FLI. Further analysis of the speed response during 400rpm speed and no load demand conclude that the DTC method produced lower percent overshoot (%OS) and faster speed response compared to FOC with about 1%OS and 8%OS respectively. Both methods are able to absorb different external loads applied with a minor speed drop at 0.6s to the motors and before recovering in a few milliseconds

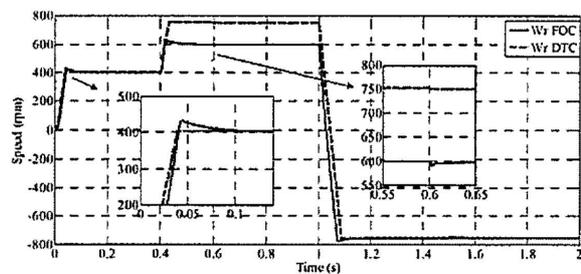


Figure 4 : M1 and M2 Speed Response

Based on the torque characteristics in Figure 5, DTC has experienced lower electrical torque response compared to the FOC which are about 12Nm and 16Nm respectively. In this case, the torque component is limited to 10Nm for DTC or 10A for FOC. In DTC, torque is directly controlled while in FOC the torque is controlled by the torque current component. The torque can be analyzed during no load condition at 400rpm,

DTC experienced 0.3Nm while FOC shows 0.5Nm. Overall, torque analysis has shown the FOC has a higher torque ripple compared to DTC.

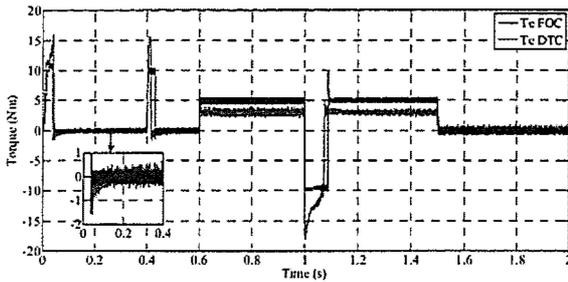


Figure 5 : M1 and M2 Torque Characteristic Performances

Figure 6 depicts phase A current of M1 and M2. Based on the current responses, the higher currents occurred during start up condition, during speed reversal and when external loads were applied. From the torque response, higher load condition experience higher stator current and vice versa. This is in line with the motor operation principle.

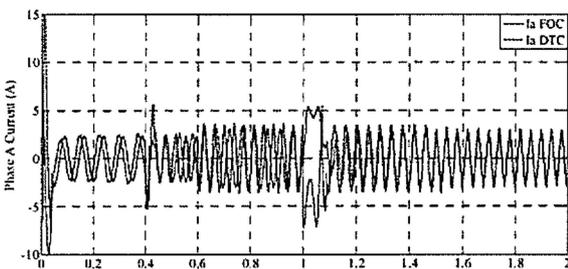
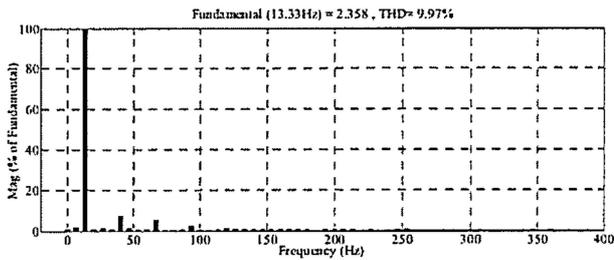
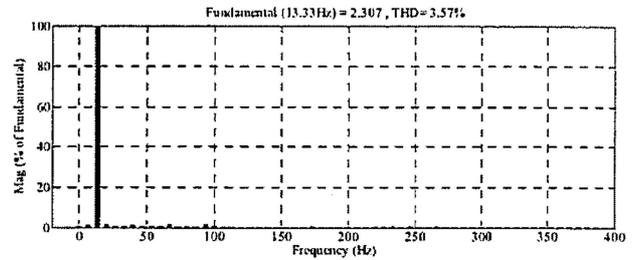


Figure 6 M1 and M2 Phase A stator current characteristic performances

Figure 7 shows %THD in phase A current at 400rpm for M1 and M2. The fundamental current for M1 is 2.358 and M2 is 2.307. Motor M1 produced higher THD content compared to M2 with 9.97% and 3.57% respectively. The presence of THD in the phase current becomes the main factor of electromagnetic torque ripple in the motors. Thus, FOC produces higher torque ripple compared to DTC in this system.



(a)



(b)

Figure 7 Phase A stator current at 400rpm (a) for M1 and (b) for M2

## VI. CONCLUSION

This paper presents the development of a combined vector control and DTC methods to independently control two induction motors fed by single FLI. The results show the ability of the proposed method to control motor speed independently under forward-reverse step speed command and load disturbance condition. The DZM SVPWM is able to combined vector control and DTC methods to generate switching pattern to the FLI according to the variation speed and load demand.

## VII. ACKNOWLEDGEMENT

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