

A Laboratory Platform for Plotting Speed-Torque Characteristics of a Vector Controlled Induction Motor

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ABSTRACT

This paper presents a platform for illustrating the speed- torque characteristics of a vector controlled three-phase induction motor. The methodology is based on acquiring the estimated torque and actual speed of a three-phase induction motor and plotting the speed-torque characteristic in real time. The platform contains a graphic interface to drive the motor and acquire the data, an induction motor, an AC drive, a communication protocol between the computer and the AC drive, and a loading system for the motor based on the claw pole alternator. LabVIEW has been used for designing the control interface. This control interface includes speed adjustment, stop command, direction of rotation, and drawing the speed-torque characteristic in real time to make the student able to notice the performance of the induction motor in the vector control mode.

Keywords: Vector Control, Ac Drive, Induction Motor, Speed-Torque Characteristic, Modbus, LabVIEW, claw pole alternator, encoder.

I. INTRODUCTION

The increase in the industrial need to adjust the torque of the induction motor has made the auto driving course an essential part in the engineering curricula for students of electrical machinery and industrial automation [1]. Vector control of the induction motor is one of the most widespread industrial applications, as it provides a good response in transient situations and gives full torque at low speeds, and it is one of the fields in which research is most published [2], but the separation between torque and flux components is still ambiguous for students so far [3] and this requires many educational experiments in this field. In order to clarify these concepts we need an educational platform that helps students to understand the principle of the vector control and shows the performance of the motor in this method with real-time monitoring of motor parameters.

In this paper, a control interface is designed by LabVIEW to drive a commercial vector drive [4] via Modbus. Although AC drive contains a software to drive the induction motor through the computer, but its options are limited and its cost might be high [5].

As for the loading system of the motor, it is the claw pole alternator, although there are many loading systems, this system was chosen because it is safer, more durable, costs less and is widely available in the local market [6]. This paper presents a scientific contribution to the algorithm used for data acquisition through an AC drive and also presents a new method for designing a low-cost real-time learning platform.

Unlike most researches in this field, vector control method has been simulated and also practical experiments have been presented by plotting the speed-torque characteristic of an induction motor at different loads and speeds.

For example in [7] an educational platform is performed for electrical machinery students that determines speed-torque characteristic of an induction motor driven by a conventional control method. In [8] and [2], the speed, torque and flux of the induction motor have been acquired, but the constant value of torque hasn't been calculated, and they recommended the design of a speed - torque control system of the induction motor. In [5] the researcher sent control commands from the LabVIEW software to the AC drive via Modbus, but the control loop remained open, he did not verify the validity and completeness of data transmission, and he recommended studying closed loop control. Also, the research [9] is a virtual platform, not practical experiments.

This article is directed to enhance the educational process of vector control method, in addition to the acquiring the data of AC drives via Modbus, and it supports the researches in the field of generation by using the claw pole alternator.

This paper is organized as follow: section 2 describes the vector control methodology with simulation in MATLAB, section 3 describes the platform equipment like the induction motor, AC drive, and loading system, section 4 describes the implementation of the communication system between LabVIEW and the AC drive, and sections 5, 6 describe the practical application and conclusions respectively.

II. VECTOR CONTROL METHOD

The vector control method is based on controlling the three-phase induction motor in a similar way of controlling DC motor where we can control the flux and torque separately [10].

The vector control method is based on transform the three fixed axes a, b, c into the $d^s - q^s$ coordinate system which has two fixed axes. This is by Clark transformation. If the d^s axis applies to the "a" axis, the voltage equations will be:

$$V_{ds}^s = \frac{2}{3}V_a - \frac{1}{3}V_b - \frac{1}{3}V_c \quad (1)$$

$$V_{qs}^s = \frac{1}{\sqrt{3}}V_b - \frac{1}{\sqrt{3}}V_c \quad (2)$$

Similarly, the equations of currents in the axis $d^s - q^s$ are:

$$i_{ds}^s = \frac{2}{3}i_a - \frac{1}{3}i_b - \frac{1}{3}i_c \quad (3)$$

$$i_{qs}^s = \frac{1}{\sqrt{3}}i_b - \frac{1}{\sqrt{3}}i_c \quad (4)$$

In order to convert from the fixed axes $d^s - q^s$ to the rotated axes $d^r - q^r$ we use the Park transformation and the equations of the currents is as follows:

$$i_{ds}^r = i_{ds}^s \cos \theta_e + i_{qs}^s \sin \theta_e \quad (5)$$

$$i_{ds}^r = -i_{ds}^s \sin \theta_e + i_{qs}^s \cos \theta_e \quad (6)$$

We calculate θ_e from the equation:

$$\theta_e = \int (w_r + w_m) \quad (7)$$

the variable w_r represents the slip speed and can be calculated from (8):

$$w_r = \frac{L_m * I_{qs}^r}{\tau_r * \psi_{dr}^r} \quad (8)$$

$$\tau_r = \frac{L_r}{R_r} \quad (9)$$

w_m can be calculated by multiplying the mechanical speed into the number of poles (10)

$$w_m = w_{mechanical} * p \quad (10)$$

ψ_{dr}^r can be calculated from the equation (11)

$$\psi_{dr}^r = i_{ds}^r * L_m \quad (11)$$

The torque equation will be as follow:

$$Te = \frac{3}{2} * p * \frac{l_m}{l_r} (i_{qs}^r * \psi_{dr}^r) \quad (12)$$

Based on the foregoing, a model was designed to convert the value of the current in the three axes into the rotating coordinate system $d^r - q^r$, shown in Figure 1. By changing the load torque on the motor, we notice that I_{qs}^r changes while I_{ds}^r remains almost constant, Table I. Based on that, we can say that the vector control system is similar to the control system of a DC motor.

TABLE I. THE CHANGE IN THE VALUES OF THE CURRENT COMPONENTS ON THE AXIS $d^r - q^r$ ACCORDING TO THE CHANGES IN THE LOAD TORQUE

T [Nm]	I_{qs}^r [A]	I_{ds}^r [A]
0	6.6	28
50	24.23	27.8
100	42	27.5
150	60	27
200	78.3	27

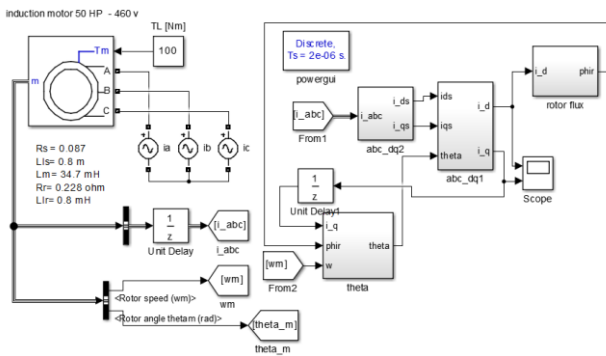


Figure 1. Model for acquiring current values of a vector-controlled three phase induction motor

III. DESCRIPTION OF THE PLATFORM

A. The Three Phase Induction Motor

The motor used is a squirrel cage three-phase induction motor, its specifications are shown in the table II.

TABLE II. SPECIFICATIONS OF THE INDUCTION MOTOR USED

Parameter	Specification
Power	0.75 Kw
Operational Voltage	220 V AC Delta / 380 V AC Star
Operational Frequency	50 Hz
Number of Poles	4
Speed	1370 rpm

B. The AC Drive

Also called Adjustable Speed Drive (ASD) or Variable Speed Drive (VSD) The AC drive uses vector control method to drive an induction motor, shown in Table III. It is based on controlling speed and torque, in addition to saving energy when decelerating [11]. In order to use the vector control method to drive the induction motor, you must enter the settings and set the drive system to be vector control. In order to use the LabVIEW to control the AC drive, the command receiving settings in

the AC drive must be set to RS485. In order to measure the speed accurately, we used an optical encoder, and the AC drive must be adjusted to obtain the speed from the Encoder, which is mounted on the motor shaft.

TABLE III. SPECIFICATIONS OF THE AC DRIVE

Parameter	Specification
Power	1.5 Kw
Operational Input Voltage	230 V AC / One Phase
Operational Output Voltage	230 V AC / Three Phase
Frequency	0.1 - 400 Hz
Communication Protocol	RS485

C. Claw Pole Alternator

There are many loading systems for the induction motors, in many studies Prony brake is used for loading, but this brake gives high temperature at high powers [10] and it is not possible to design a Prony brake at low cost. Therefore, the claw-pole alternator which belongs to salient pole machine, has low cost compared to other kinds of alternators [10], and it is widely used as an alternator in the vehicles. The claw-pole alternator contains internal poles, while the output is three-phase with a large number of pairs of poles. This alternator differs from salient pole machine in that it operates at higher speeds and is small in size [6]. This alternator contains a bridge rectifier so that the output becomes DC, and it also contains a voltage regulator feeds the excitation coils to maintain the alternator output at 24 volts [10].

In our project, we removed the voltage regulator to control the excitation current separately. Figure 2. shows the relation between the rotational speed and the output current. Since the nominal speed of the induction motor is 1370 rpm, we cannot connect the alternator with the motor directly, so we used pulleys to make the speed of the alternator becomes rpm 2740 when the motor rotates at synchronous speed.

TABLE IV. CLAW POLE ALTERNATOR ALT-T140

Parameter	Specification
Output Voltage	24 V DC
Operational Output Current	140 A

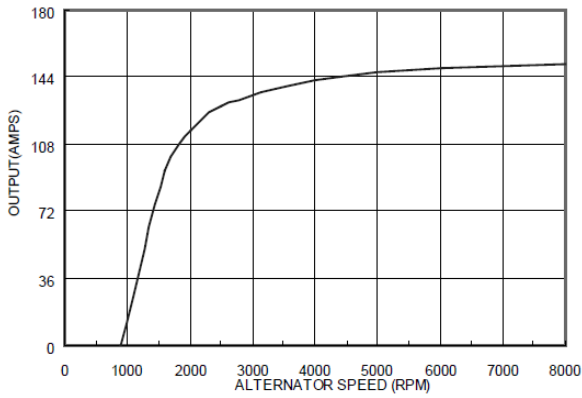


Figure 2. Relation between alternator speed and the output current

IV. COMMUNICATION SYSTEM BETWEEN LABVIEW AND AC DRIVE

1) Modbus

It is a serial communication system widely used to connect industrial electronic devices together and was developed for industrial applications. It uses RS485 in its physical layer. Modbus connects many electrical equipment called terminals (RTUs) with the supervising computer. There are three types of Modbus RS485, the first one is Modbus RTU, which uses a binary representation system for data and uses a CRC (Cyclic Redundancy Check) system for error checking in order to ensure the reliability of the data, and the second is Modbus ASCII which uses ASCII characters to transfer data, LRC (Longitudinal Redundancy Check) error detection [10]. Modbus ASCII messages begin with a colon (:) and end with a newline (CR/LF). The third type is Modbus Plus and AC drives do not support this system [11]. Modbus consists of the Application Data Unit (ADU) which contains the Protocol Data Unit (PDU).

ADU = Address + PDU + Error Check.

PDU = Function Code + Data.

2) Driving The AC Drive Via Modbus ASCII

First, the connection settings must be set to receive commands through Modbus ASCII and AC drive must be given a specific address (in this project number 1 is used) [11]. The PC which is connected to the AC drive through Modbus ASCII sends commands to the AC drive like: forward direction with specifying the required frequency, or sends reverse direction with specifying the required frequency. The code of each command shown in Table V, Table VI. shows the address of the registers associated with the parameters used in the project.

TABLE V. CMD

Command	Function Code
Read	03H
Write to one Register	06H
Write to Multi Registers	10H

TABLE VI. ADDRESSES USED IN THE PROJECT TO DRIVE THE AC DRIVE AND COLLECT DATA

Address	Function	Code
	Stop	0001H
	Run	0002H
2000H	Forward	H0012
	Reverse	0022H
2001H	Frequency Command	
210BH	Estimated Torque ratio	Read Only
210CH	Motor Speed (Hz)	

The program is based on sending the required speed with the direction of rotation, after that the AC drive returns the completion of the process of receiving the command. In order to obtain the speed and torque, the program sends a command to read the speed and torque registers, and the AC drive sends the value of both speed and torque to the computer. Figure 4 shows the user interface to drive the motor.

V. RESULTS AND DISCUSSION

Figure 4 illustrates the user interface for driving an AC drive to adjust the induction motor's speed, specify the direction of rotation, and pause data acquisition to change the load or speed, with displaying of torque value, actual speed, synchronization speed, and slip. Figures 5.6.7 show. The program for sending and receiving data from the AC drive. Figure 8 shows the speed-torque characteristic plotting code. The induction motor is engaged with the claw pole alternator. Excitation coils of the alternator are connected with a 24V DC source [10], and the stator coils are connected with a rheostat (0-34 Ohm) as shown in Fig. 9.

To plot the speed-torque characteristics, the speed is set at the value of 5 Hz and the load resistance at the value of 34 Ohm, and by pressing the Forward key, the motor rotates at the required speed and the interface starts plotting the speed-torque curve in real time, after that the value of the resistor is reduced gradually until reaching three times of the nominal torque. Then Pause key is pressed, resistance is returned to its maximum value, and speed is increased to 10 Hz. This procedure should be repeated. The result is shown in the figure. 10.

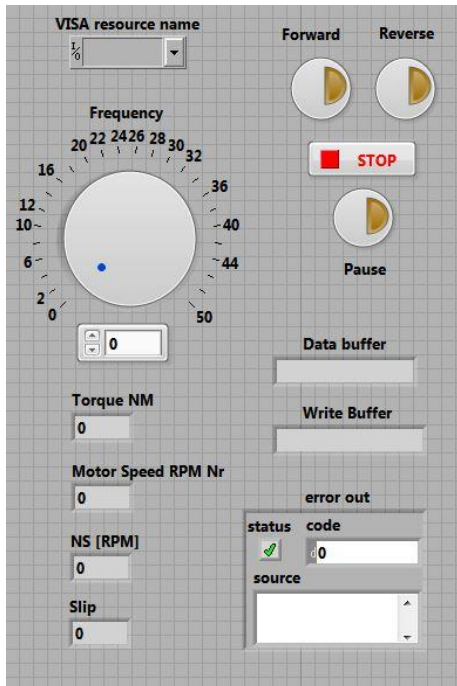


Fig.4: User interface for driving the AC drive

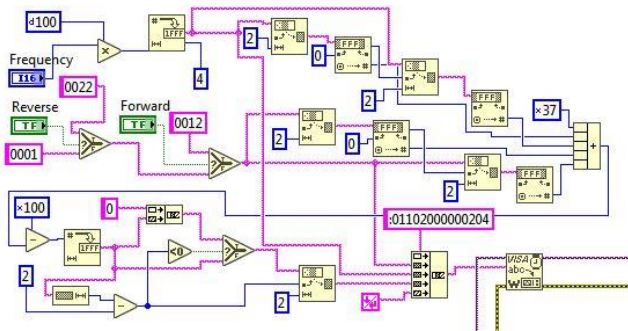


Figure 5. Sending the value of the speed and direction of rotation with the calculation of the value of the LRC

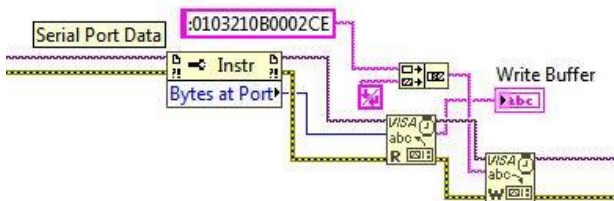


Figure 6. Receiving the response from AC drive and sending the command to read the torque and speed

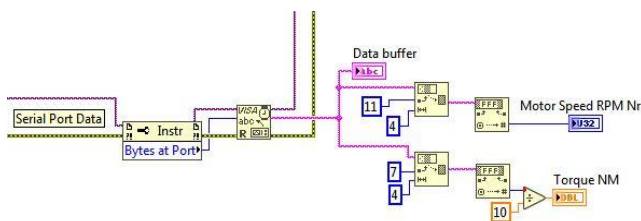


Figure 7. Acquiring the value of both speed and torque

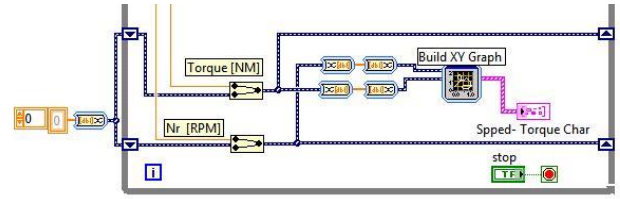


Figure 8. Speed-torque characteristic diagram of an induction motor

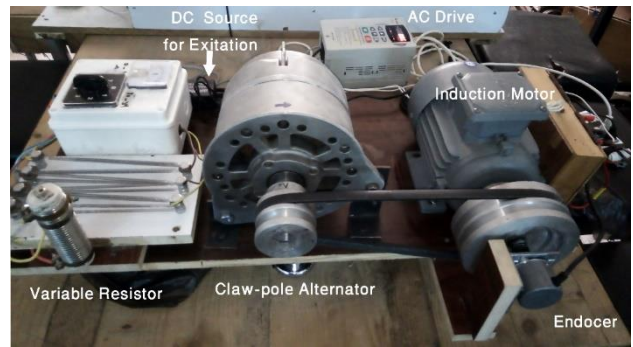


Fig.9 The full project

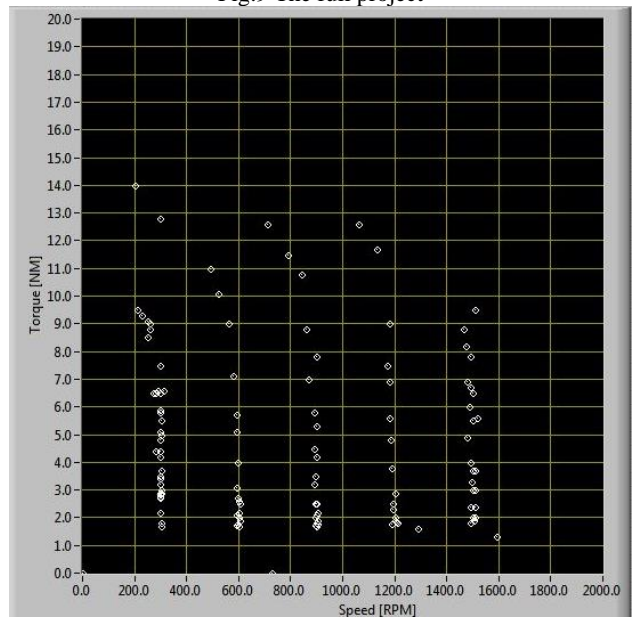


Figure 10. Speed-torque characteristic of a vector controlled induction motor

VI. CONCLUSION

This paper presents an educational platform and it uses LabVIEW to teach industrial automation students the vector control method by modelling a vector control system and plotting the speed-torque characteristic of a three-phase induction motor in real time, the curve showed motor stability at varying speeds and loads. The methodology used is based on utilizing the AC drive to drive an induction motor, acquiring the rated torque and

speed, and using the claw pole alternator to load the motor.

This platform costs less comparing with other vector control platforms, in addition to its ease of use. This helps students to understand the vector control system and its curves.

In future, the vector control system will be designed to fully drive an induction motor without using commercial AC drives.

VII. ACKNOWLEDGEMENT

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