

**Implementation of Vector Oriented Control for Induction Motor Using DS1104**Mr. Nimesh D. Smart<sup>1</sup>, Miss. Manisha M. Patel<sup>2</sup><sup>1</sup>Electrical Department, Vidhyadeep Institute of Engineering & Technology, Anita<sup>2</sup>Electrical Department, Mahavir Swami College of Engineering & Technology, Surat

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**Abstract** — Induction machines are universally used in industry because of their robustness, reliability, low price and high efficiency. The ability to control speed of induction motor is desired in industry. Besides for control of the processing procedure, efficient speed control strategies can reduce the operation cost. Several methods can be used to control the speed of induction motor. It includes scalar control and vector control. However, until recent times, it has been hard to control the torque of the induction motor. The objective of the thesis is to develop Simulink model of Vector Control of an Induction Motor by using Simulink/MATLAB to control motor torque and flux using dSPACE platform because it executes the model in real time application. This research paper describes the implementation of a field-oriented control for a squirrel cage induction motor. The control structure is programmed as a Simulink graphical model and can be implemented by Real-Time Interface (RTI) on the DS1104 R&D Controller Board.

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**Keywords-** dSPACE, Induction Motor, MATLAB/Simulink, Control Desk, Vector Oriented Control Method.

**I. INTRODUCTION**

An induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction, rather than a commutator or slip rings as in other types of motor. In certain texts, a machine with only amortisseur windings is called an induction machine. The distinguishing feature of an induction motor is that no DC field current is required to run the machine. These motors are widely used in industrial drives, particularly poly-phase induction motors, because they are rugged and have no brushes. Their speed is determined by the frequency of the supply voltage, so they are most widely used in constant-speed applications, although variable speed versions, using variable frequency drives are becoming more common. The most common type is the squirrel cage motor, and this term is sometimes used for induction motors generally. Although it is possible to use an induction machine as either a motor or a generator, it has many disadvantages as a generator and so is rarely used in that manner. For this reason, induction machines are usually referred to as induction motors. [1]

Squirrel-cage induction motors (IM) are the workhorse of industries for variable speed applications in a wide power range that covers from fractional watt to megawatts. However, the torque and speed control of these motors is difficult because of their nonlinear and complex structure. In the past five decades, a lot of advanced control schemes for IM drive appeared. First, in the 1960's, the principle of speed control was based on an induction motor model considered just for steady state. Therefore, the so-called "Scalar Control Methods" cannot achieve best performance during transients, which is their major drawback. Afterwards, in the 1970's, different control schemes were developed based on a dynamic model of the induction motor. Among these control strategies, the vector control which is included in the so-called Field Oriented Control (FOC) method is mentioned. The principle of vector control is to control independently the two Park components of the motor current, responsible for producing the torque and flux respectively. In that way, the induction motor drive operates like a separately excited dc motor drive (where the torque and the flux are controlled by two independent orthogonal variables: the armature and field currents, respectively). Since the 1980's, many researchers have worked on improvements of the FOC and vector control which have become the industry's standard for IM drives.

Moreover, these researches led to new control strategies such as Direct Self-Control (DSC) or Direct Torque Control (DTC). The principle of DTC is to control directly the stator flux and torque of the induction motor by applying the appropriate stator voltage space vector. With vector control, the major drawback of the scalar control is overcome because these control schemes are based on a model of the induction motor which is considered valid for transient conditions.

The objective of this research paper is neither to do an overview of an induction motor control method, nor to try to MATLAB for Engineers - Applications in Power, Electrical Engineering. Its aim is to present a powerful tool to help students to understand Induction motor control scheme, the vector control using a dSPACE platform and MATLAB/Simulink environment. First, the experimental system is presented. Then the Induction motor models used therein are described and the determination of the Induction motor parameters as well as the implementation of the control method is exposed using DS1104 R&D Controller Board. Finally, typical results are presented and the educational experience is discussed.

## II. INDUCTION MOTOR

An induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction, rather than a commutator or slip rings as in other types of motor. In certain texts, a machine with only amortisseur windings is called an induction machine. The distinguishing feature of an induction motor is that no DC field current is required to run the machine. These motors are widely used in industrial drives, particularly polyphase induction motors, because they are rugged and have no brushes. Their speed is determined by the frequency of the supply voltage, so they are most widely used in constant-speed applications, although variable speed versions, using variable frequency drives are becoming more common. The most common type is the squirrel cage motor, and this term is sometimes used for induction motors generally. Although it is possible to use an induction machine as either a motor or a generator, it has many disadvantages as a generator and so is rarely used in that manner. For this reason, induction machines are usually referred to as induction motors. [2]- [5]

Another classification of the control techniques for the induction machine depends on how the voltage-to-frequency ratio is implemented:

1. Scalar control.
  - a) Voltage/frequency (V/f) control.
  - b) Stator current control and slip frequency control.

These techniques are implemented through direct measurement of the machine parameters.

2. Vector Control.
  - a) Field orientation control.
    - i. Indirect Method
    - ii. Direct Method
  - b) Direct torque and stator flux vector control.

## III. VECTOR ORIENTED CONTROL (VOC) SCHEME FOR INDUCTION MOTOR

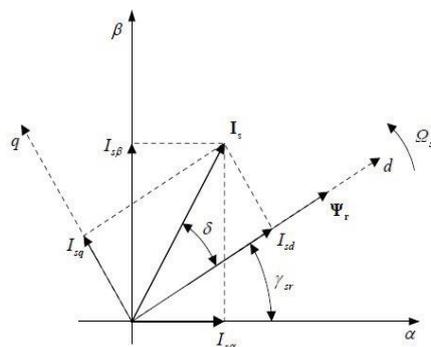
The Vector Controller Oriented (VOC) is also known as Field Controller Oriented (FOC) for induction motor. The main objective of this control method is to independently control torque and flux as in separately excited DC machines. This is done by choosing a d-q rotating reference frame synchronously with the rotor flux space vector. Once the orientation is correctly achieved, the torque is controlled by the torque producing current which is the q-component of the stator current space vector. At the same time flux is controlled by the flux producing current, which is the d-component of the stator current space vector.

### Basic Idea of Vector Oriented Control:

The idea behind vector oriented control is to control an induction motor in the similar way for dc motor control. In the so called "scalar control methods" for induction machines, the machine model is considered just for steady state. In "vector control methods," the motor model considered is valid for transient conditions. The reference frame used in the VOC is one whose real axis coincides with the rotor flux vector. This frame is not static and does not have a constant speed during transients. The great advantage of this "non-inertial" frame is that for impressed stator currents, this method allows independent flux and torque control.

### Principle of VOC:

The principle of the vector oriented control (VOC) is based on an analogy to the separately excited dc motor. In this motor flux and torque can be controlled independently. The control algorithm can be implemented using simple regulators, e.g. PI - regulators. In induction motor independent control of flux and torque is possible in the case of coordinate system is connected with rotor flux vector. A coordinate system d - q is rotating with the angular speed equal to rotor flux vector angular speed  $\Omega_k = \Omega_{sr}$ , which is defined as follows: The rotating coordinate system d - q is shown in Figure 1.



*Figure 1. Vector diagram of induction motor in stationary  $\alpha$ - $\beta$  and d - q co-ordinates.*

The voltage, current and flux complex space vector can be resolved into components d and q.

$$\Omega_{sr} = \frac{d\gamma_{sr}}{dt} \quad (3.1)$$

$$u_{sk} = u_{sd} + ju_{sq} \quad (3.2)$$

$$u_{sk} = u_{sd} + ju_{sq}, I_{rk} = I_{rd} + jI_{rq} \quad (3.3)$$

$$\varphi_{sk} = \varphi_{sd} + j\varphi_{sq}, \varphi_{rk} = \varphi_{rd} = \varphi \quad (3.4)$$

In d - q coordinate system the induction motor model equations can be written as follows:

$$u_{sd} = R_s I_{sd} + d \frac{\varphi_{sd}}{dt} - \Omega_{sr} \varphi_{sq} \quad (3.5)$$

$$u_{sq} = R_s I_{sq} + d \frac{\varphi_{sq}}{dt} - \Omega_{sr} \varphi_{sd} \quad (3.6)$$

$$0 = R_r I_{rd} + d \frac{\varphi_r}{dt} \quad (3.7)$$

$$0 = R_r I_{rq} + \varphi_r (\Omega_{sr} - p_b \Omega_m) \quad (3.8)$$

$$\varphi_{sd} = L_s I_{sd} + L_M I_{rd} \quad (3.9)$$

$$\varphi_{sq} = L_s I_{sq} + L_M I_{rq} \quad (3.10)$$

$$\varphi_r = L_r I_{rd} + L_M I_{sd} \quad (3.11)$$

$$0 = L_r I_{rq} + L_M I_{sq} \quad (3.12)$$

$$d \frac{\Omega_m}{dt} = \frac{1}{J} \left( p_b \frac{m_s}{2} \frac{L_M}{L_r} \varphi_r I_{sq} - M_L \right) \quad (3.13)$$

The equations 3.8 and 3.12 can be easy transformed to:

$$d \frac{\varphi_r}{dt} = \frac{L_M R_r}{L_r} I_{sd} - \frac{R_r}{L_r} \varphi_r \quad (3.14)$$

The motor torque can by express by rotor flux magnitude  $\psi_r$ , and stator current component  $I_{sq}$  as follows:

$$M_e = p_b \frac{m_s}{2} \frac{L_M}{L_r} \varphi_r I_{sq} \quad (3.15)$$

Equations 3.14 and 3.15 are used to construct a block diagram of the induction motor in d - q coordinate system, which is presented in Figure 2.

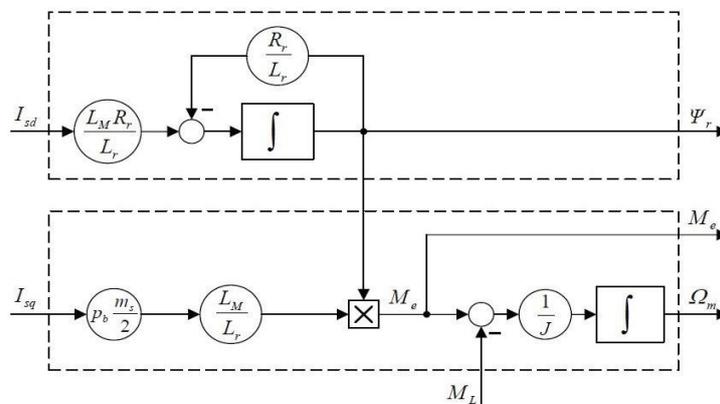


Figure 2. Block diagram of induction motor in d - q coordinate system.

The main feature of the vector oriented control (VOC) method is the coordinate transformation. The current vector is measured in stationary coordinate  $\alpha - \beta$ . Therefore, current components  $I_{s\alpha}, I_{s\beta}$  must be transformed to the rotating system  $d - q$ . Similarly, the reference stator voltage vector components  $U_{s\alpha}, U_{s\beta}$ , must be transformed from the system  $d - q$  to  $\alpha - \beta$ . These transformations requires a rotor flux angle  $\gamma_{sr}$ . Depending on calculations of this angle two different kind of field oriented control methods maybe considered.

#### IV. dSPACE DS1104 DSP CONTROLLER BOARD

The dSPACE control platform simplifies the programming task using library block set and interfacing of control algorithm to run on processor and on-chip peripherals. In the hardware part open loop simulation has been presented with real time simulation implementation. This is achieved by using digital signal processor controller. dSPACE and MATLAB interface is being made to achieve pulse generation. DS 1104 is used for PWM generation by SPWM technique. Description of DS1104 DSP Controller board is given below.

##### DS1104 R&D Controller Board

The DS1104 R&D Controller Board upgrades your PC to a powerful development system for rapid control prototyping ("R&D" stands for research & development). Real-Time Interface (RTI) provides Simulink® blocks for graphical I/O configuration. The board can be installed in virtually any PC with a free 5-V PCI slot. The real-time hardware based on PowerPC technology and its set of I/O interfaces make the controller board an ideal solution for developing controllers in various fields, such as drives, robotics, and aerospace. The board is used in many university laboratories.

##### Technical Specifications of the DS1104 Board

###### Main Processor

- MPC8240 processor with PPC 603e core, 250 MHz CPU clock
- 2 x 16 KB cache
- 64 bit floating-point processor

###### A/D Converter

- Resolution
  1. Multiplexed channels : 16-bit
  2. Parallel channels : 12-bit
- Input voltage range :  $\pm 10$  V
- Conversion Time
  1. Multiplexed channels : 2  $\mu$ s
  2. Parallel channels : 800 ns
- Signal-to-noise ratio
  1. Multiplexed channels :  $> 80$  dB
  2. Parallel channels :  $> 65$  dB

###### Digital I/O

- Channels : 20-bit parallel I/O
- Voltage range : TTL input/output levels
- $I_{out,max}$  :  $\pm 5$  mA

###### Serial Interface

- Single UART with FIFO
- RS232 / RS485 compatibility
- Baud Rate : Up to 115.2 kBd (RS232)
- Baud Rate : Up to 1 MBd (RS422/RS485)

###### Host Interface : Requires one 33 MHz / 32-bit 5V PCI slot

###### Timers

- 4 general purpose timers
- 1 sampling rate timer
- 1 time base counter

###### Memory

- Global memory, 32 MB DSRAM
- Flash memory, 8 MB

###### D/A Converter

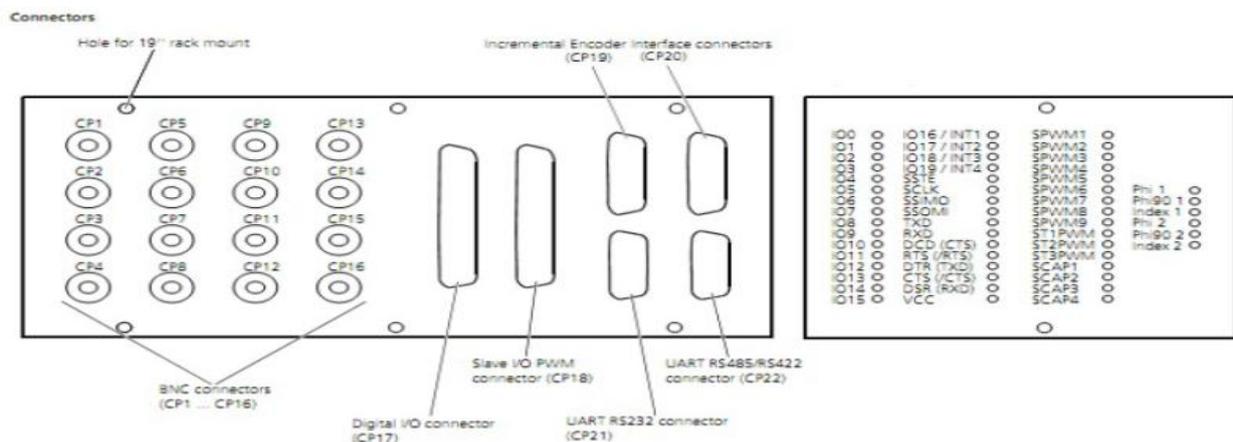
- Channels : 8 channels
- Resolution : 16-bit
- Output range :  $\pm 10$  V
- Settling time: Max. 10  $\mu$ s
- Signal-to-noise ratio :  $> 80$  dB
- $I_{max}$  :  $\pm 5$  mA

###### Digital Incremental Encoder Interface

- Channels : 2 independent channels
- Position counters: 24-bit resolution
- Sensor supply voltage : 5V / 0.5A

###### Slave DSP

- Texas Inst. TMS320F240 DSP, 16-bit procc.
- Clock rate : 20 MHz
- Memory : 32 MB flash memory
- I/O channels : 10 PWM o/p, 4 capture i/p
- A/D converter voltage range : 0 ... 5 V
- Output current: Max.  $\pm 13$  mA



### CLP1104 Connector Panel

Using an adapter cable you can link your external signals from the 100-pin I/O connector on the board to Sub-D connectors. Figure 3 shows CLP1104 Connector Panel. The CPL1104 provides easy to use connections between the DS1104 R&D Controller Board and devices to be connected to it. Devices can be individually connected, disconnected or interchanged without soldering via BNC connectors and Sub D connectors. This simplifies system construction, testing and troubleshooting. For the pin assignment and mapping of I/O signals, please refer the reference [9]

#### How to start the Code Generation?

1. Open the Simulink Model.
2. Set the following configuration parameters.
  - a. Sample time
  - b. Simulation type, can be fixed or continuous
  - c. Select the solver type from listed solvers
  - d. Start and Stop time
3. Set the optimization options.
4. While setting RTW build options you have to mention the board type. After setting all the parameters you have to build the model.

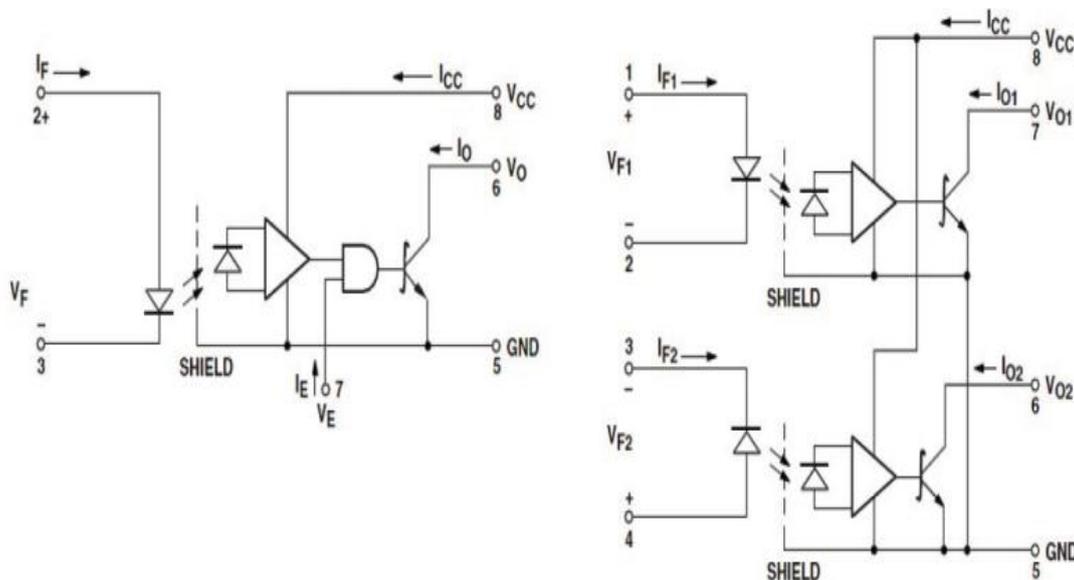
During build process code is generated for Simulink block diagram that include RTI blocks for RCP and HILS. Code generation begins with a two-step process, which is followed by two more steps whenever an executable is being compiled. The four steps (also summarized in the Build Process) are automatically completed when you click the Build button on the Real-Time Workshop dialog (assuming that Real-Time Workshop detects no constraints to generating code for the model; if it does, it will issue warnings).

Real-Time Workshop analyzes the block diagram and compiles it into an intermediate hierarchical representation called “model.rtw”. The Target Language Compiler reads “model.rtw” and translates it to C code, which it places in a build directory in the working directory. The Target Language Compiler constructs a make file from the appropriate target make file template, and places the basic directory.

## V. HARDWARE IMPLEMENTATION

### Gate Driver Circuit

The switches in bridge configurations of inverters need to be provided with isolated gate drive signals. The individual control signal for the switches needs to be provided across the gate and source terminals of the particular switch. The gate control signals are low voltage signals referred to the source terminal of the switch. For MOSFET switches, when gate to source voltage is more than threshold voltage for turn-on, the switch turns on and when it is less than threshold voltage the switch turns off. The threshold voltage is generally of the order of +5 volts but for quicker switching the turn-on gate voltage magnitude is kept around +15 volts whereas turn-off gate voltage is zero or little negative (around -5 volts).[17]-[19]



*Figure 4. Schematic Diagram of Opto-Coupler 6N-137.*

## Opto-coupler

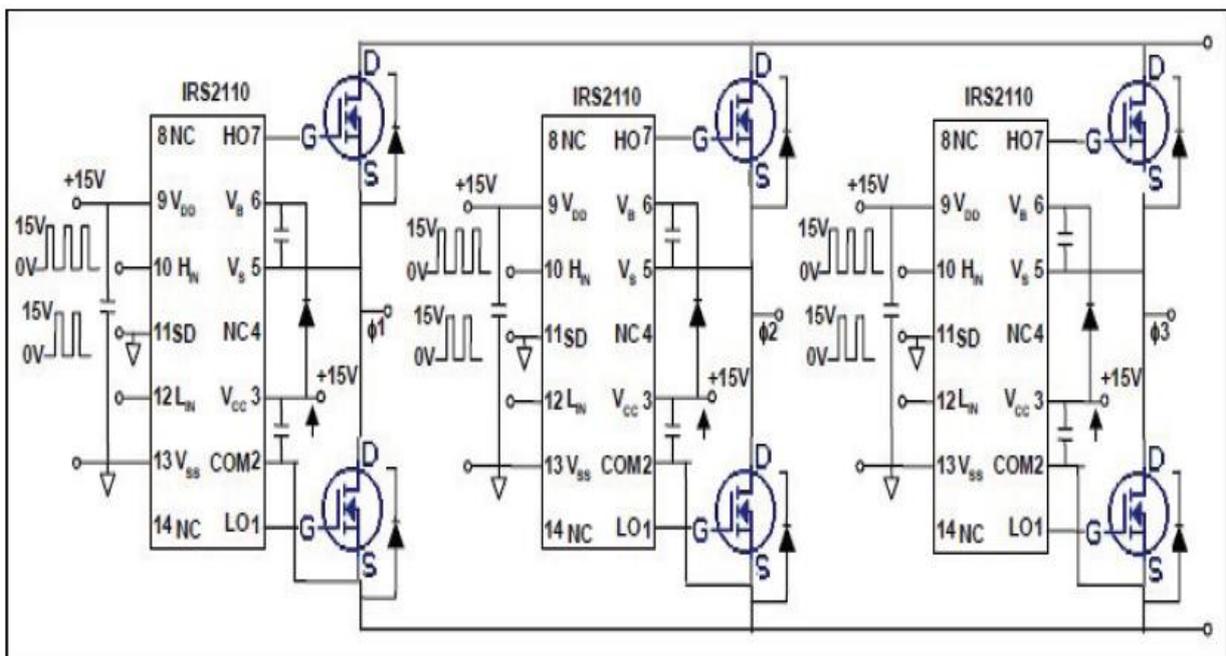
Gate-signal isolation for inverter switches is generally achieved by means of optical-isolator circuit. Figure 5 shows a typical opto-coupler circuit. The circuit makes use of a commercially available opto-coupler IC 6N-137. Input stage of the IC is a light emitting diode (LED) that emits light when forward biased. The light output of the LED falls on reverse biased junction of an optical diode. The LED and the photo-diode are suitably positioned inside the opto-coupler chip to ensure that the light emitted by the LED falls on the photo-diode junction. The gate control pulses for the switch are applied to the input LED. These gate pulses, generated by the gate logic circuit, are essentially in the digital form. A high level of the gate signal may be taken as 'on' command and a low level (at ground level) may be taken as 'off' command. Under this assumption, the cathode of the LED is connected to the ground point of the gate-logic card and anode is fed with the logic card output.

The circuit on the output (photo-diode) side is connected to a floating dc power supply, as shown in Figure 5. When input signal to LED is high, LED conducts and the emitted light falls on the reverse biased p-n junction. Irradiation of light causes generation of significant number of electron-hole pairs in the depletion region of the reverse biased diode. A signal comparator circuit senses this condition and outputs a high level signal, which is amplified before being output. Thus an isolated and amplified gate signal is obtained and may directly be connected to the gate terminal of the switch. For driving high side MOSFET in any topology, opto-couplers can be used with following advantages:

- They can be used to give a very high isolation voltage; 2500 to 5000 Volts of isolation is achievable by use of properly certified opto-couplers.
- Signals from DC to several MHz can be handled by opto-couplers.
- They can be easily interfaced to Microcomputers or other controller ICs or any PWM IC.

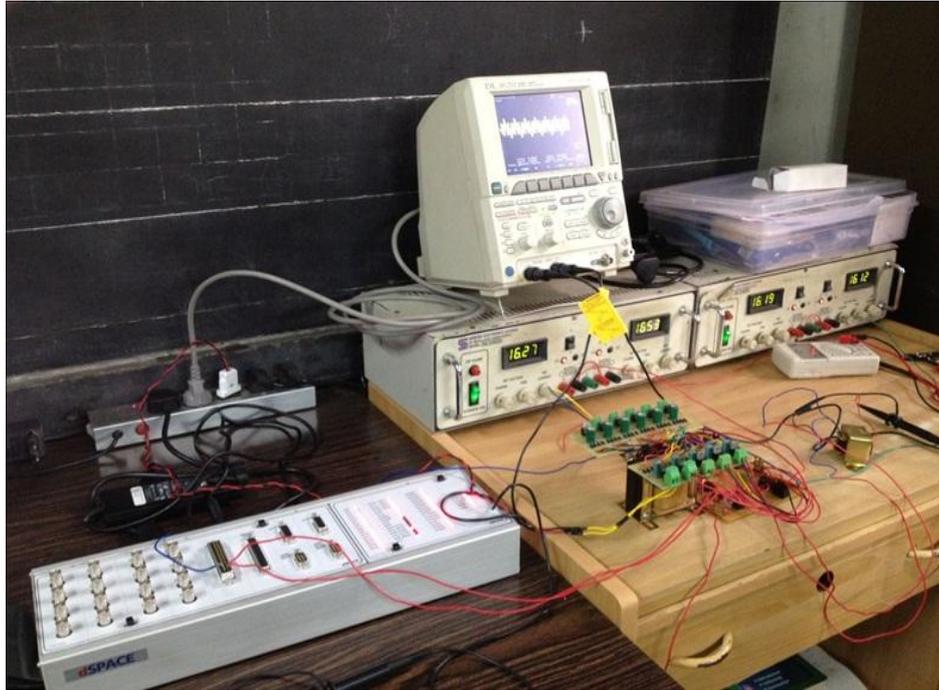
## High Speed MOSFET Gate Drivers

MOSFET can be driven by any circuit capable of providing the right gate voltages & that is fast enough to ensure that the MOSFET spends the absolute minimum amount of time in its linear gate voltage region. This is important, for it's when the MOSFET is in its linear region that it acts like a resistor & produces a lot of heat. Most MOSFET turn on at 10-30 V, and need a high current if you plan to do high speed switching.



**Figure 5. Three-Phase Inverter Using Three IRS2110 Devices to Drive Six MOSFETs**

Therefore you need a MOSFET driver as an interface between your logic system and MOSFET. Therefore you need a MOSFET driver as an interface between your logic system and MOSFET. The IRS2110 are high voltage, high speed power MOSFET drivers with independent high-side and low-side referenced output channels. They provide very fast switching speeds and low power dissipation.



**Figure 6. Actual hardware setup in Laboratory**

The floating channel can be used to drive an N-channel power MOSFET in the high-side configuration which operates up to 500 V or 600 V. Figure 5, shows the Three Phase Inverter using three IRS2110 devices to drive six MOSFETs and Figure 6, shows the actual per phase, gate trigger circuit, implemented and fabricated in research work.

**Inverter**

Inverter or power inverter is a device that converts the DC sources to AC sources. The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Inverters are used in a wide range of applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power.

**VI. SIMULATIONS & RESULTS**

In this paper for case study, 3HP, 220V, 50 Hz, 3-phase induction motor used for simulating vector oriented control drive. Induction motor parameters are given in Table 1.

Sr. No.	Parameters	Values
1	Stator resistance in Ohms	0.435
2	Stator inductance in Henry	2.0e-3
3	Rotor resistance in Ohms	0.816
4	Rotor inductance in Henry	2.0e-3
5	Mutual inductance in Henry	69.31e-3
6	Inertia	0.082
7	Friction Factor	0
8	Pairs of poles	2

**Table 1. Induction motor parameters**

### Simulation Model in MATLAB

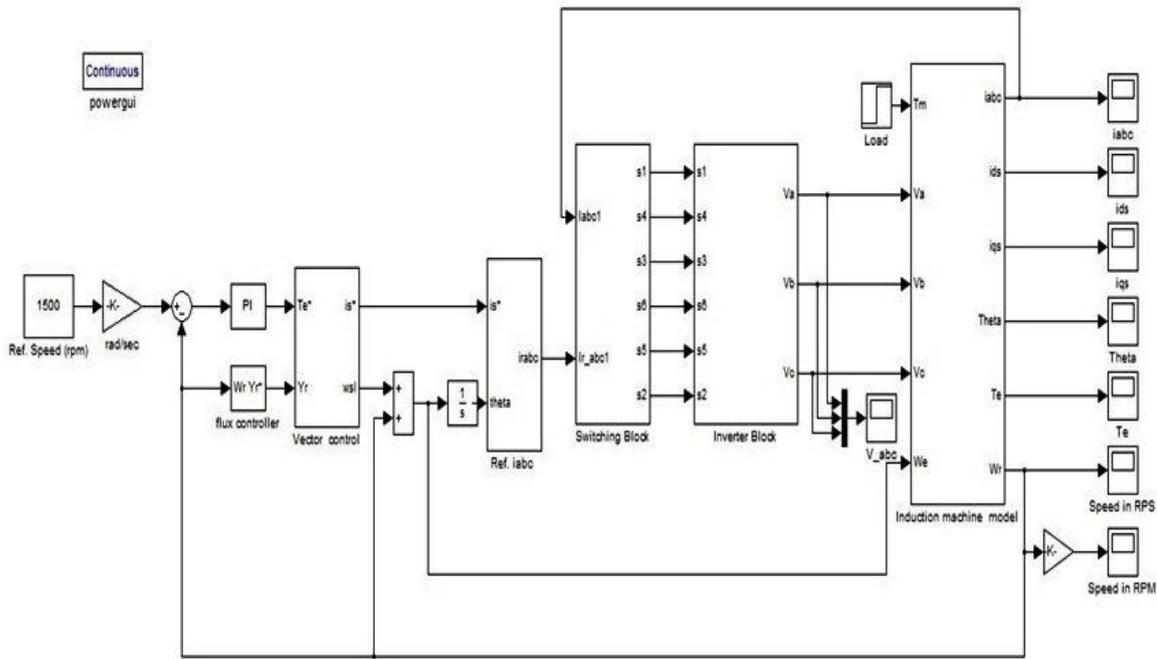


Figure 7. Simulation model in MATLAB with RTI Data

### Simulation Results on dSpace Control Desk

Vector oriented control is simulated in MATLAB which gives the result on dSpace Control Desk as shown in figures below for complete model on rotate on 1500 RPM speed and 250 RPM speed.

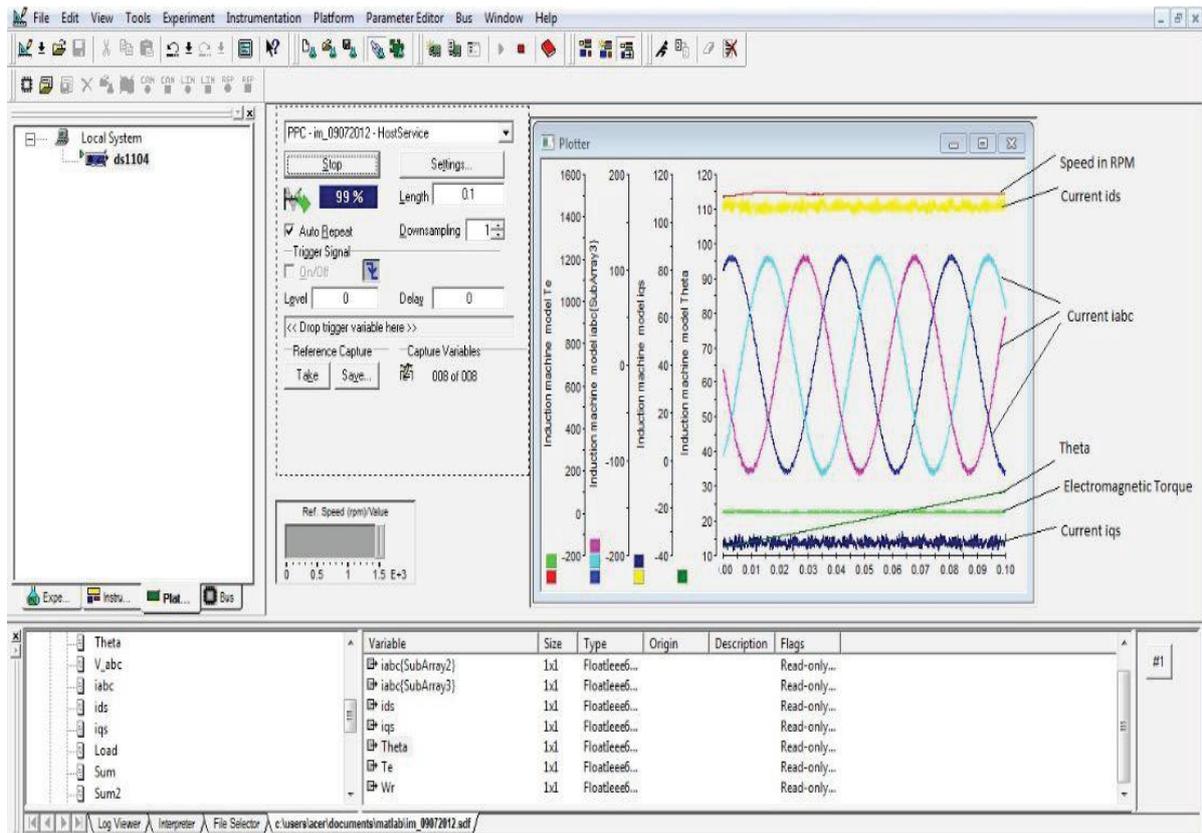


Figure 8. Simulation Results of Complete Model on dSpace Control Desk for 1500 RPM

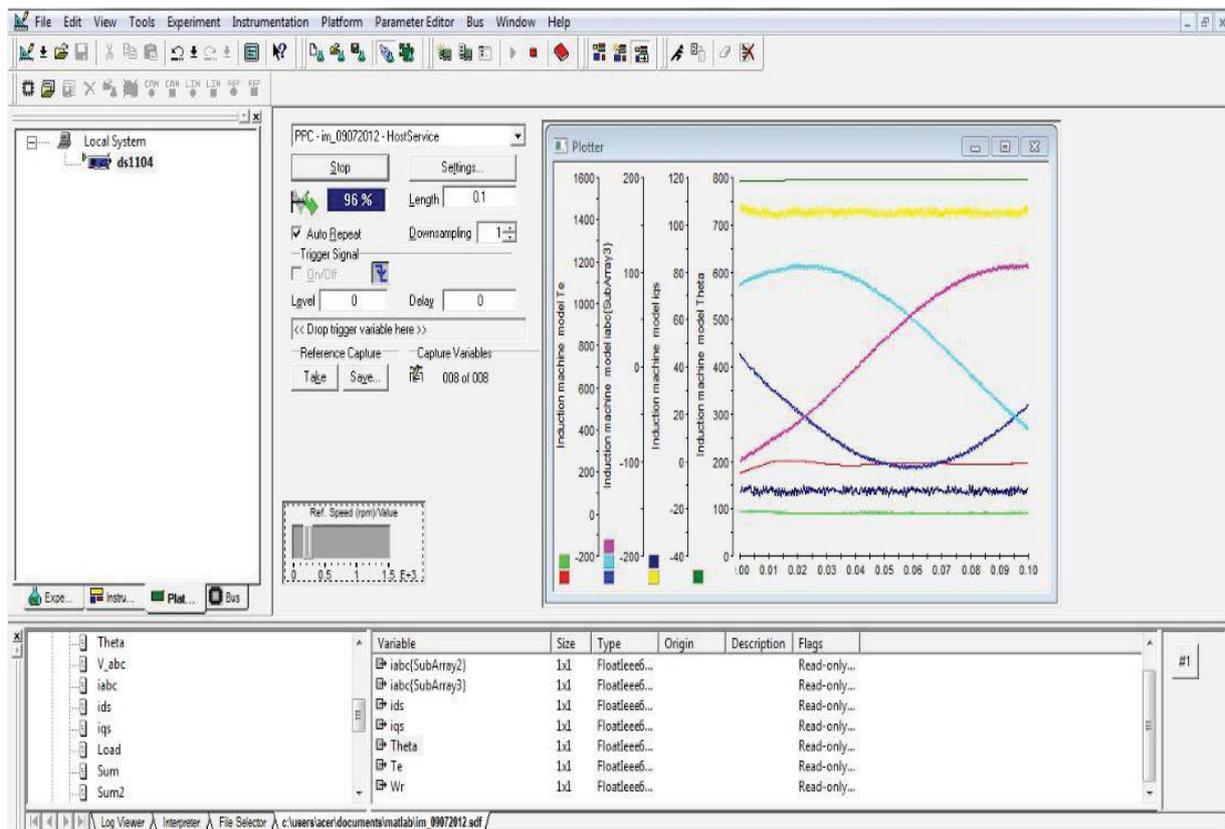


Figure 9. Simulation Results of Complete Model on dSpace Control Desk for 250 RPM

## VII. CONCLUSIONS

The essentials of an induction motor were explored; the construction and working principles of its operation were explained. An implementation and dynamic modeling of a three-phase induction motor using MATLAB/Simulink were presented in a step-by-step manner. This paper presented the concept of Vector Orientated Control (VOC), a vector control method. It was elected to be the motion control technique because it produces controlled results that have a better dynamic response to torque variations in a wider speed range compared to other scalar methods. It was shown, through MATLAB analysis that field oriented control is an effective means of driving an Induction motor. A speed profile with an adequate transient response and steady-state error was generated. Furthermore, the system was stable. The hardware design of Gate Firing and Inverter Circuit which were used to drive an Induction motor was discussed. It illustrates how MATLAB/Simulink and dSPACE are used in the experiment. The use of dSPACE controllers (DS1104), which utilize the Simulink modeling in Programming, is the major advantage over other systems in real-time control. The typical experiment designed to do simulation using MATLAB/Simulink and actual measurement using dSPACE, and to compare simulation with measurement were presented. The use of dSPACE control system is shortened the system design duration and provided to monitor the analog and digital signals, and control variables.

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