



## **Indirect Vector Controlled Induction Motor Propulsion Drive for Marine Applications**

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*Abstract: Marine electric propulsions commonly use variable speed electric propulsion motors connected to propellers in which several types of converter control schemes are applied; mainly scalar control and direct field vector control. This paper considers indirect vector control scheme for induction motor and evaluates its design and operating performance in a marine propulsion drive. This paper also reviews available control schemes of the propulsion drive system and a new model using indirect vector control scheme. An effective solution of speed control using Matlab simulation software is obtained for development of marine propulsion drives.*

*Index Terms: Vector control scheme, indirect vector control scheme, Scalar control, Marine propulsion*

### **I. INTRODUCTION**

The traditional commercial and military ships employed a mechanical propulsion system that uses gas turbines as the prime mover. As they are so large and heavy that ship designers have to design and construct the rest of the ship around it rather than creating a tailored mechanical propulsion system for the ship. [1] This factor limits ship design flexibility. Hence electric propulsion system was thought of. Over the past 30 years, the electric propulsion has been frequently selected as the propulsion system of choice for various types of war ships and auxiliary ships in several nations. Throughout this period, the authors have been involved with navy electric power and propulsion systems as operators, maintainers, trainers, designers, procurers, and testers. The electric propulsion system consists of prime mover, generator, converter, motor, and propeller. In this paper we discuss the schemes for converter typologies. [4]

The most commonly used converters for drives are:

1. DC converters or SCR (Silicon Controlled Rectifier) for DC motors.
2. Cycloconverters (Cyclo) for AC motors, normally for synchronous motors.
3. Current source inverter type (CSI) converters for AC motors (synchronous motors).
4. Voltage source inverter (VSI) type converters for AC motors, i.e. asynchronous, synchronous and permanent magnet synchronous motors.

Variable speed drives have been in industrial use for many years but first AC drive for propulsion was used in later 1980's. Since the AC motor drives emerged commercially competitive, all the new electric propulsion systems are based on one of the AC drive typologies. [8] AC system generates medium voltage (3.3/6.6/11kv) at constant frequency and voltage. These drives mainly use two types of control schemes.

1. Scalar control.
2. Vector control.

This paper presents a detailed explanation of control schemes and also, for marine applications an indirect vector controlled induction motor drive is proposed.

## II. SCALAR CONTROL

Scalar control method contains the simple open loop system using a V/F control. In this control, the applied voltage varies with frequency according to the rule:  $v/f = \text{constant}$ . [3] In this method, the speeds below as well as above the rated values can be achieved by following relations.

$$N_s = \frac{120f}{p} \quad [1]$$

$$N = N_s(1 - s) \quad [2]$$

The drive used for speed control of induction motor to get the speeds below the rated value is called variable voltage variable frequency drive. Scalar control is although easy for implementation, but is not good for high speed applications and also insufficient for the speed control where a wide range of speed control is required. [9] Fig. 1. Shows the block diagram of scalar control scheme. In scalar control the voltage and the frequency are reduced or increased simultaneously in order to make the machine operate in normal operating region, hence to avoid it from entering into the condition of deep saturation.

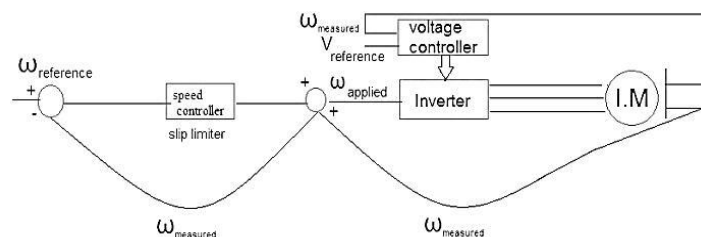


Fig. 1. Scalar Control Scheme

In v/f control scheme, the pure frequency control technique is not employed to get the speed below the rated value due to the following reasons

1. Air gap flux increases due to which the stator and rotor cores enter into deep saturation.
2. The magnetizing component of the current increases.
3. No load and full load power factor of induction motor decrease.

Similarly, if the applied voltage is reduced under the load condition, there is a possibility of stator over-heating due to high currents at low voltages, which in turn may result in the burning of stator windings. Hence the vector control is preferred for high speed applications.

## III. VECTOR CONTROL

The scalar control strategy provides good steady state but poor dynamic response due to the deviation in the air gap flux linkage values. [7] The scalar control uses particular voltage and frequency for the control rather than its phase, hence, the deviation in phase and magnitude values of the air gap flux linkages results. [6]

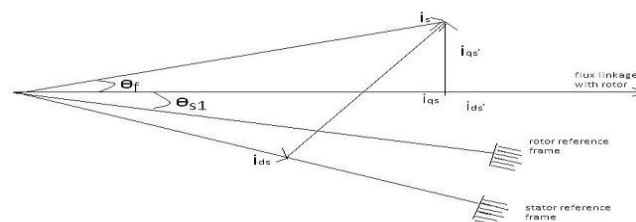


Fig.2. Phasor Diagram of Vector Control

These undesirable deviations may affect high performance of electric propulsion drives. Therefore, a high precision fast positioning speed control is required. A coordinated control of stator current magnitude, frequency and phase, makes AC induction motor drive, a complex control. If the rotor flux linkages are resolved then the control of an AC machine becomes very similar to a separately excited dc machine. This type of control is obtained in the field coordinates, hence the name field oriented vector control scheme. These are classified according to how the field angle is acquired. If the field angle is acquired by voltage and current then it is

known as direct vector control and if it is acquired by the rotor position measurement then it is termed as indirect vector control scheme.

#### IV. DIRECT VECTOR CONTROL TECHNIQUE

The field orientation control of stator current is convenient than controlling stator voltage. We can determine values of the field angle by measuring the magnitude of phase current in motor. [2] Initially, the three phase measured current from the motor is transformed from abc to qdo form by following transformation.

$$\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \quad [3]$$

Hence,  $i_s$  (stator current) and  $\theta_f$  (field angle) are calculated as follows:

$$i_s = \sqrt{(i_{qs})^2 + (i_{ds})^2} \quad [4]$$

$$\theta_s = \tan^{-1} \frac{i_{qs}}{i_{ds}} \quad [5]$$

$$\theta_f = \theta_s \pm \theta_{s1} \quad [6]$$

Where  $\theta_s$  the angle is measured between  $i_{qs}$  and  $i_{ds}$ ,  $\theta_{s1}$  is the desired speed angle, and  $\theta_f$  is the firing angle that is to be applied to inverter circuit or to get pulses. [5] Since current phasor magnitude remains the same regardless of the reference frame, the applied currents of motor is obtained as follows:

$$i_{qs}' = i_{qs} \sin \theta_f \quad [7]$$

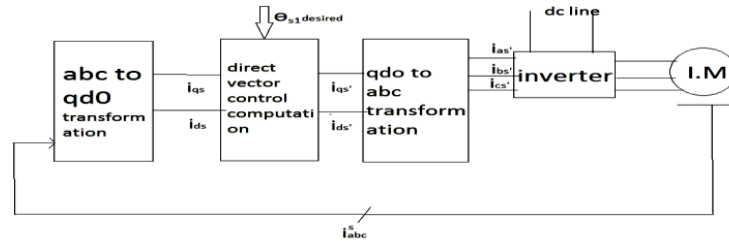


Fig. 3. Direct Vector Control Scheme

$$i_{ds}' = i_{ds} \cos \theta_f \quad [8]$$

Again the calculated currents in qd0 form are transformed in abc form:

$$\begin{bmatrix} i_{as}' \\ i_{bs}' \\ i_{cs}' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} i_{qs}' \\ i_{ds}' \end{bmatrix} \quad [9]$$

$$T_{em} = \frac{3}{2} \frac{p}{2} \frac{L_m}{L_r} \lambda_{dr}' i_{qs}' \quad [10]$$

Direct vector control technique is the most convenient and smooth speed control technique but difficult to implement and many parameters to be sensed from motor. Figure 3 shows a simplified block diagram of the direct vector control technique. All the computations are done in the vector control computation block and induction motor is controlled with inverter switching states.

#### V. INDIRECT VECTOR CONTROL TECHNIQUE

The indirect vector control is implemented for low speed applications and position type control it does not depend upon the measurement of the air gap flux but uses torque and speed equations for speed control. Torque can be controlled by regulating the  $i_{qs}'$ , slip speed  $\omega_e - \omega_r$ . Rotor flux can be controlled by regulating  $i_{ds}'$ . The desired torque of  $T_{em}$  at the given level of rotor flux is given by Eq- [10]. Here rotor position  $\theta_r$  is measured with an encoder/synchronous resolver and converted into necessary digital information for feedback. [10] Some transducers are currently available to convert the rotor position information into velocity; they can be used to eliminate a tachogenerator to obtain the velocity information. The controllers are implemented with microprocessors.

It has been observed when  $i_{ds}'$  is properly oriented to zero then slip speed relation can be written as:

$$w_e - w_r = \frac{r'_r}{L'_r} \frac{i'_{qs}}{i'_{ds}} \quad [11]$$

If above conditions is satisfied then the actual decoupling obtained will depend on the accuracy of motor parameters. Since the values of rotor resistance and magnetizing inductance are known to vary somewhat more than the other parameters. Here the field angle  $\theta_f$  is the sum of the rotor angle  $\theta_r$  and desired angle  $\theta_{s2}$ . These are calculated from integrating the slip speeds. An orthogonal outputs of the form  $\cos \theta_r$  and  $\sin \theta_r$  are available from the shaft encoder. Hence,  $\sin \theta_f$  and  $\cos \theta_f$  are calculated as follows.

$$\sin \theta_f = \cos(\theta_r + \theta_{s2}) \quad [12]$$

$$\cos \theta_f = \sin(\theta_r + \theta_{s2}) \quad [13]$$

The  $\theta_{s2}$  is calculated from the variable frequency oscillator. The remaining process is same as that in direct vector control.

## VI. CIRCUIT DESCRIPTION

In this paper, the current regulated indirect vector controlled induction motor propulsion drive model is simulated using MATLAB/SIMULINK and examined to what extent such control keeps the rotor flux constant during changes in load torque. The improvement in the dynamic response is observed and compared to the scalar control at low speed operations. Here 20 hp 220V four poles induction machine is considered for simulation. The figure shows the complete Matlab simulation diagram of induction motor drive for propulsion with indirect vector control. Here directly the fundamental components of the PWM output voltages are considered. PI torque controller converts the speed error to a reference torque.

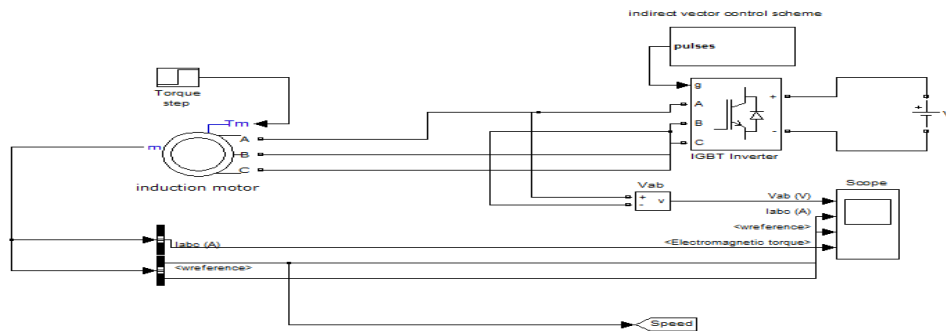


Fig. 4. Indirect Vector Controlled Propulsion Drive

The indirect field control computes the  $i_{qs}$ ,  $i_{ds}$ ,  $w_2$ , and  $\theta_f$  which is the sum of the slip angle  $\theta_{s2}$  and the rotor angle  $\theta_r$ . A qdo to abc transformation is obtained to generate the abc reference current. The motor is simulated in the synchronous reference frame. The look up table for field weakening is same as the mechanical speed of the rotor.

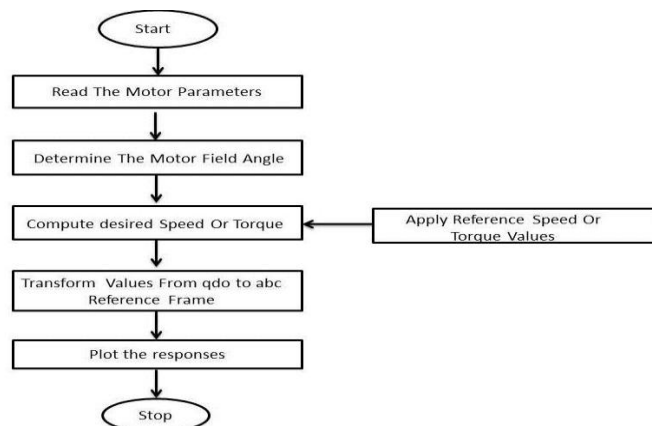


Fig 5. Flow Chart of Indirect Vector Scheme

## VII. RESULTS & ANALYSIS

Using indirect vector control in ship propulsion, we obtain a constant and desirable speed easily. As shown in Fig.9. the voltage and currents in the other phases are similar to that of phase 'a'. As required initial high starting torque is obtained in order to overcome the inertia of rest and thereafter a constant torque perceived hence indirect vector controlled propulsion drive is well suited for the ship propulsion.

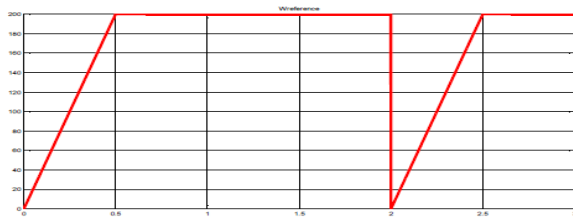


Fig. 6. Reference Speed

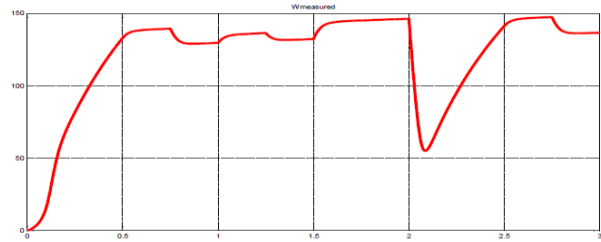


Fig. 7. Measured Speed From Motor

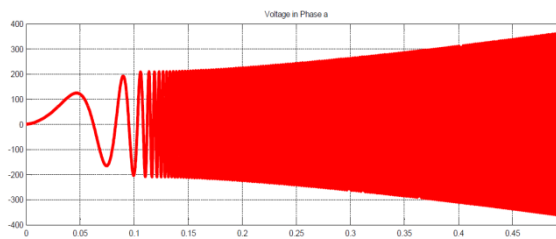


Fig. 8. Voltage in Phase A

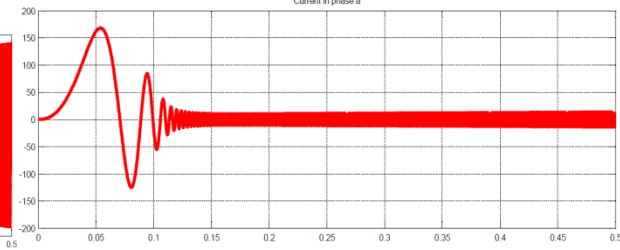


Fig. 9. Current in Phase A

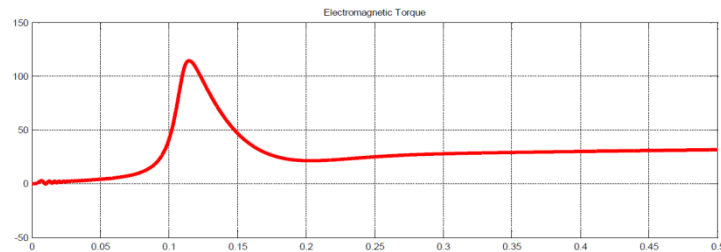


Fig. 10. Electromagnetic Torque

## VIII. Conclusion

This paper presents the formulation and experimental verification of parameter compensation schemes like speed and position sensor less schemes in the indirect vector controlled induction motor propulsion drive. This scheme require a feedback of many machine variables for its computation an inexpensive and effective means of acquiring them is presented and some efforts are being made in the direction of t1he development of the smooth speed control of marine propulsion drives.

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