

# Development of a Load Torque Measurement System for Two Phase Inverter Fed Induction Motor Drive with Vector Control Method

by

Ufot Ufot EKONG<sup>\*1</sup>, Oudam SOK<sup>\*2</sup>, Mamiko INAMORI<sup>\*3</sup> and Masayuki MORIMOTO<sup>\*4</sup>

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## Abstract

An improved method for torque control and measurement of a two-phase inverter fed induction motor drive is proposed. The proposed strategy also enables measurement and evaluation of the motor efficiency in the whole operating region. The proposed strategy was verified by experiment and the results showed that the speed torque characteristics improved in the low-speed region.

**Keywords:** Four-switch three-phase inverter, Emergency drive, Motor efficiency, Fault tolerant control

## 1. Introduction

In the last two decades, due to advances in power electronics, the use of induction motors driven by inverters has significantly increased in various industries. Recently, much research has been conducted on two phase inverter also known as Four Switch Three Phase Inverter (FSTPI)<sup>1)-20)</sup>. Two phase inverter has been proposed as an emergency drive during the breakdown of the conventional three phase inverter<sup>1)2)3)</sup>. Some other researchers have proposed two phase inverter as a means to reduce cost of the conventional three phase inverter drive<sup>4)5)6)</sup>. However, in terms of cost, much progress has not been made because the voltage utilization of a two phase inverter compared to a three phase inverter reduces by approximately 50%<sup>7)</sup>. Hence, two phase inverter is more feasible as an emergency drive.

Earlier results using the conventional VVVF method reported the inadequacy of torque in low speed region and the maximum torque attainable speed reduces by 50%<sup>7)8)</sup>. Some other researches, focused on vector control method because compared to the VVVF control method, torque control is achievable from zero speed. Consequently, the author of this paper reported in (9) that in vector control method compared to VVVF method the maximum attainable torque of two

phase inverter increased but torque is still inadequate in low speed region<sup>9)</sup>.

The motor efficiency of a two phase inverter fed induction motor drive using VVVF control method has been evaluated and reported<sup>8)</sup>. However, the torque and efficiency of the entire operation region could not be measured because of the limitation of the experimental apparatus. Up till date, no research has reported on the motor efficiency of a vector controlled two phase inverter fed induction motor drive.

In this research, the speed torque characteristics in low speed region is improved and the motor efficiency of the whole operating region is measured and evaluated in detail by proposing a new load system.

## 2. Two Phase Inverter

### 2.1 Structure of Two Phase Inverter

The circuit of a two phase inverter is shown in Fig.1. A two phase inverter consists of four switches. In the analysis, the V phase of the inverter is assumed to be damaged and reconnected to the center potential of the battery.

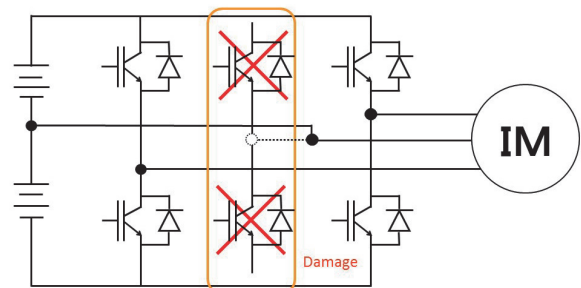


Fig. 1 Inverter failure

\*1 Graduate Student, Course of Science and Technology  
\*2 Graduate Student, Course of Electrical and Electronic System Engineering  
\*3 Junior Associate Professor, Department of Electrical and Electronic Engineering  
\*4 Professor, Department of Electrical and Electronic Engineering

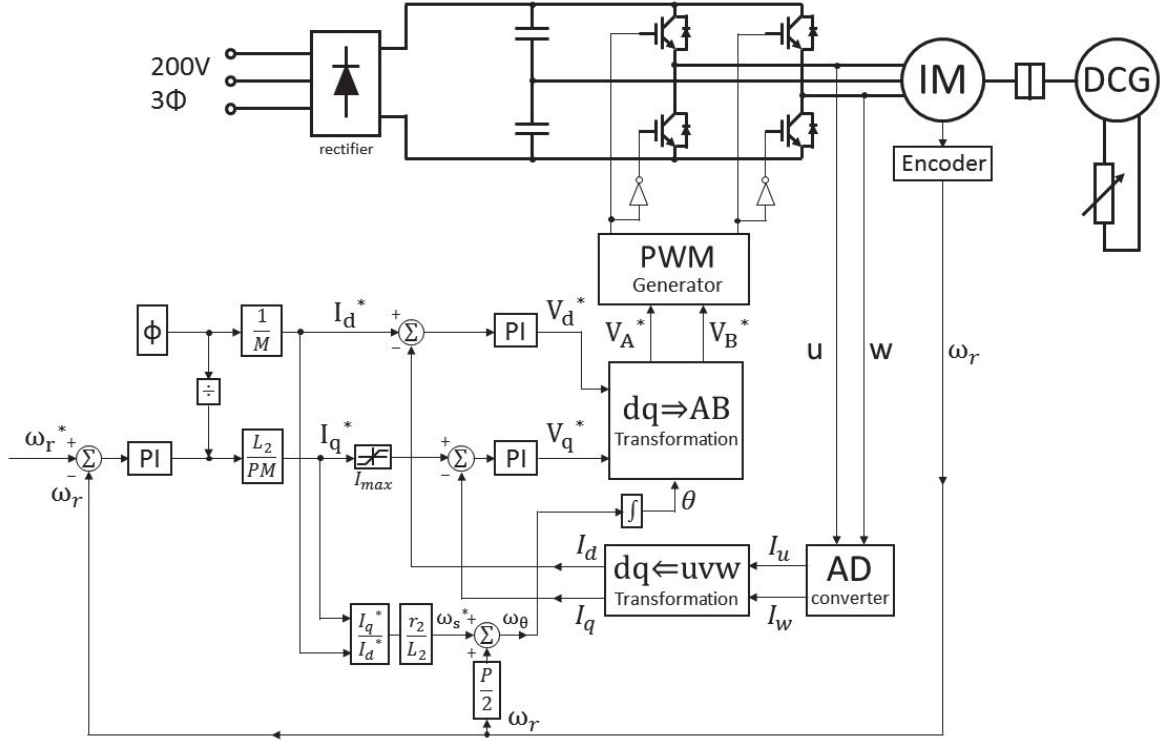


Fig. 2 Vector control block diagram for Two Phase Inverter

**2.2 Vector Control Method**

Vector control is a control procedure for operating an induction motor that results in fast dynamic response and energy efficient operations at all speeds. It maintains high efficiency over a wide range and allows for precise dynamic control of speed and torque.

The block diagram of a vector controlled two phase inverter drive is shown in Fig.2 and its basic equations are given below Eqs (1)-(4). Vector control accomplishes instantaneous commutation with velocity feedback from the motor  $\omega_r$  and a feed forward slip command  $\omega_s$ . The motor current is divided into magnetizing current  $I_d$  and torque component  $I_q$ . As shown in Fig.2, the speed,  $I_d$  and  $I_q$  reference is compared to its feedback value and the error is processed through a PI controller. The output command after vector control  $V_d, V_q$  is transformed to a reference voltage  $V_A, V_B$ . This reference signal is used to generate PWM signals that are transmitted to the inverter and finally to the motor.

$$I_d^* = \frac{\phi_2^*}{M} \tag{1}$$

$$I_q^* = \frac{L_2 T^*}{PM \phi_2^*} \tag{2}$$

$$\omega_s^* = \frac{Mr_2}{L_2 \phi_2^*} I_q^* \tag{3}$$

$$\omega_\theta = \frac{P}{2} \omega_r + \omega_s^* \tag{4}$$

**2.3 Characterisicts of VVVF and Vector Control Method**

The speed torque charactersitics of a VVVF and vector control method fed induction motor drive is shown in Fig 3. Earlier results show that both control techniques have almost the same torque characteristics from 0[rpm] to 300 [rpm] and vector control method can produce more torque above 300[rpm] compared to the VVVF method.

However, the maximum attainable torque in low speed region is inadequate for traction motion used in electric vehicles and high performance drives. In order to apply two phase inverter as an emergency drive, a control strategy that can improve the torque characteristics in low speed region is required.

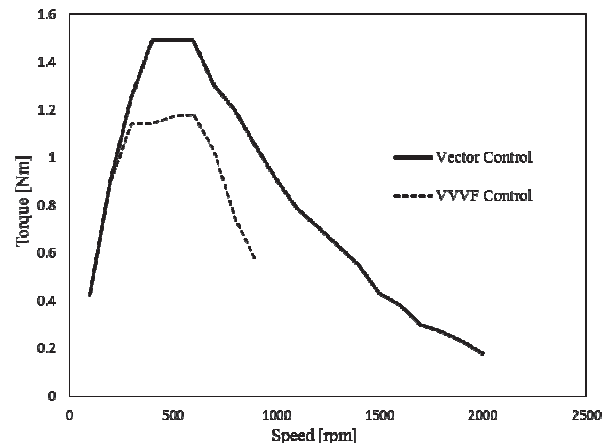


Fig. 3 Speed Torque Characteristics

### 3. Experiment

#### 3.1. Conventional Load System

One of the advantages of vector control is that torque control is achievable from zero speed. However, the load machine must be picked accurately considering its application. Undersizing and oversizing can have a big impact on the torque characteristics and efficiency of the driving motor.

In indirect vector control as earlier explained in subsection 2.2, an encoder is used to measure the speed at which the motor is running and its feed back to the control circuit. Fig. 4 shows an induction motor with a DC generator as a load. Here, the encoder can be attached to either the back of the induction motor or the DC generator because the shaft is moving at the same angle and velocity.

In a two phase inverter drive this load system cannot provide adequate torque and efficiency measurement in low speed region.

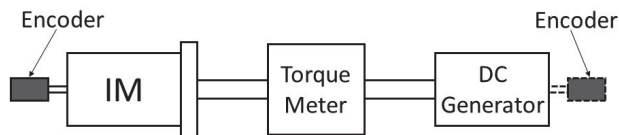


Fig. 4 Induction motor with a DC Generator load

#### 3.2 New Load System

A geared DC generator connected as a load to an induction motor is shown in Fig.5. Typically, gearbox serves to take motor power, reduce its speed, and magnify its torque. Thus, in this application, the encoder must be connected to the induction motor (driving motor) because the speed at the shaft of the induction motor and the load machine will vary.

In this research, attaching a gear to the load machine is proposed. In the control strategy, the maximum current ( $I_{max}$ ) is calculated considering the gear ratio and the torque control axis  $I_q$  is modified by limiting the maximum output current.

A DC geared generator that is applicable to the drive is chosen and its specification is shown in TABLE.1. From calculations, a gear ratio of 1:5 is appropriate. A gear is connected to a DC Motor as shown in Fig.6. A Torque Sensor (TS) is connected in between the Induction Motor (IM) and the load.

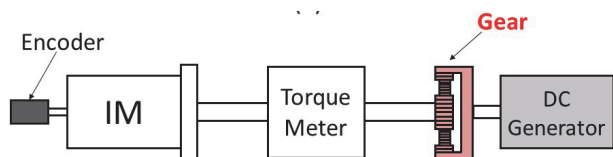


Fig. 5 Geared DC Generator

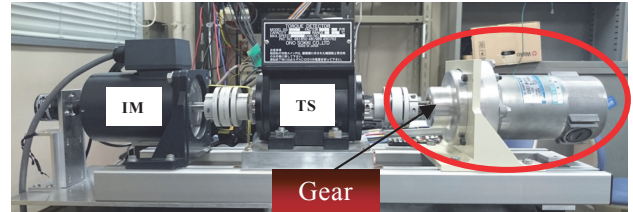


Fig. 6 IM connected with New Geared DCgenerator load

#### 3.3 Control System Configuration

An experiment is carried out to verify the feasibility of the proposed control and measurement method. In this experiment, the V phase of the inverter is assumed to be broken down and its reconnected to the center potential of the DC source. The specification of the induction motor, load machines, and the inverter parameters for both experiments are shown in TABLE.1.

The experimental system configuration is shown in Fig.7. PE-Expert 3 is the digital system which is equipped with a Digital Signal Processor (DSP), Analog Digital (AD) converter and PWM functions. As shown in Fig.7, the program signals are transmitted from the host computer to the DSP of the PE-Expert3.

Table I

Motor and Inverter Parameters

Induction Motor	Rated Power	$p$	200	[W]
	Rated Frequency	$f$	50	[Hz]
	Rated Speed	$n$	1250	[rpm]
	Rated Torque	$T$	1.49	[Nm]
	Rated Voltage	$V_{line-line}$	200	[V]
	Rated Current	$I$	1.1	[A]
	Number of poles	$P$	4	[poles]
Inverter	DC link voltage	$E_{dc}$	283	[V]
	Filter Capacitor	$C$	8200	[ $\mu$ F]
	Carrier Frequency	$f_c$	5	[kHz]
	Dead Time	$DT$	3.5	[ $\mu$ s]
DC Geared Generator	Rated Speed	$n$	500	[rpm]
	Rated Voltage	$V$	100	[V]
	Armature Current	$I$	1.7	[A]
	Armature Resistance	$R$	8.7	[ $\Omega$ ]
	Gear ratio	$GR$	1:5	[mG]
DC Motor	Rated Speed	$n$	2500	[rpm]
	Rated Voltage	$V$	100	[V]
	Armature Current	$I$	4.8	[A]
	Armature Resistance	$R$	2.4	[ $\Omega$ ]

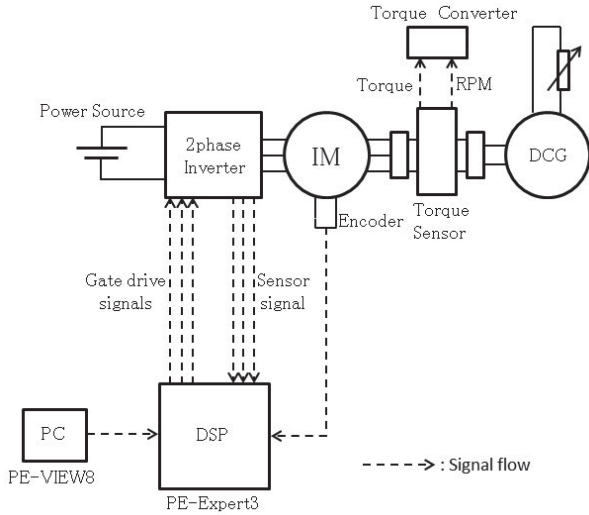


Fig. 7 Experiment System configuration

#### 4. Experimental Results

In this experiment, the speed-torque characteristics of the drive are measured and the motor efficiency in the whole speed operating region is evaluated and examined.

##### 4.1 Speed-Torque Characteristics

###### 4.1.1 Integrated Torque Characteristics

The speed torque characteristics are examined from the experiment results. Two experiments are carried out. A geared DC generator is used as the load from 0rpm to 600 rpm. A DC generator is used from 500rpm to 2000rpm. In this two experiments the maximum torque is set to 1.49Nm (rated torque). The two results are integrated and shown in Fig.8. From the results;

1. The maximum torque 1.49Nm is achievable in low speed region, from 0rpm to 600rpm.
2. In the high speed region from 500 rpm to 2000 rpm, the maximum attainable torque reduces as the speed increases.

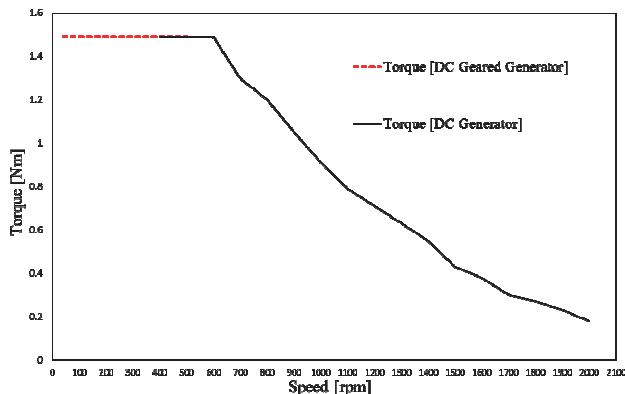


Fig. 8 Speed -Torque Characteristics

###### 4.1.2 Comparison of VVVF and Vector Control

The results of both experiments using vector control and VVVF control method are shown in Fig.9. A comparison of the results show that vector control can produce full torque from zero speed to middle speed region. In general, the torque characteristics of vector control are better than that of the VVVF control method.

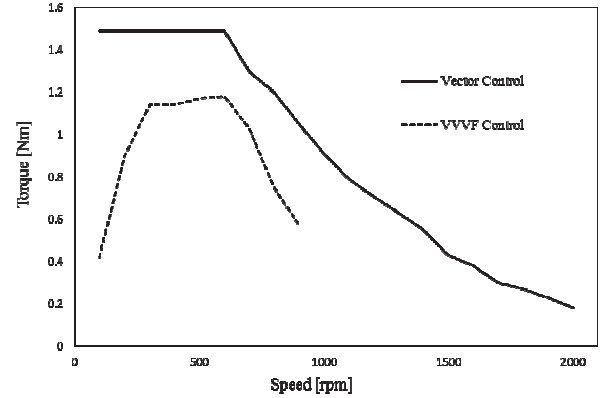


Fig. 9 Torque Characteristics of VVVF and Vector Control

##### 4.2 Motor Efficiency

The motor efficiency when driven by a two phase inverter is examined by using the torque characteristics to determine the maximum output power produced by the drive. The input power is read from a power meter used in the experiment. The motor efficiency formula is shown below in Eqs. (5) and (6). The maximum torque is set to 1.49[Nm], the rated torque of the induction motor. During the experiment, the torque is increased by 0.1[Nm] from 0[Nm] to 1.49 [Nm] at every speed and all data points are recorded.

$$MotorEfficiency = \frac{PowerOut}{PowerIn} \times 100 \quad (5)$$

$$PowerOut = Speed[rad/s] \times Torque[Nm] \quad (6)$$

###### 4.2.1 Maximum Motor Efficiency Per Speed

The maximum efficiency at each speed from 100rpm to 2000rpm is calculated and shown in Fig.10. From Fig.10, it is visible that as the speed increases the maximum efficiency also increases up till 700 rpm.

The maximum efficiency at each speed is replotted in a 3D format to examine the relationship between the speed, torque and motor efficiency as shown in Fig.11. Results show that at every speed, the torque at which the maximum efficiency is achieved is between 0.5[Nm] and 0.8[Nm], which is half of the rated torque (1.49[Nm]) of the motor.

From the results, the maximum attainable torque at every speed has an effect on the efficiency of the motor. Therefore, it can be said that as the maximum attainable torque increases

the maximum efficiency at every speed also increases.

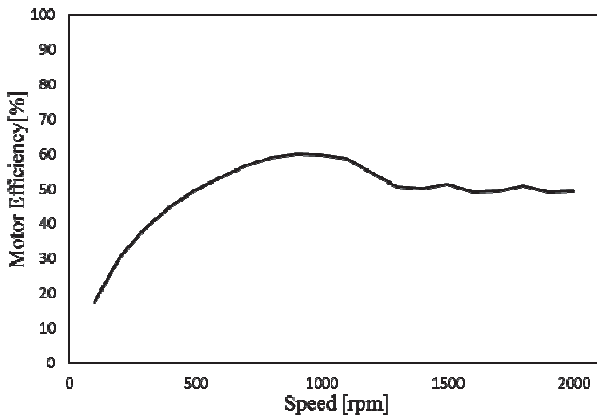


Fig. 10 Maximum Motor Efficiency Per Speed

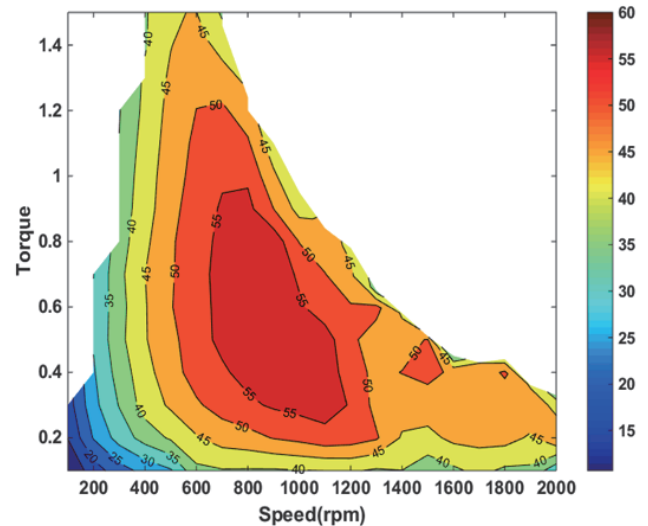


Fig. 12 Motor Efficiency Map (Conventional Load System)

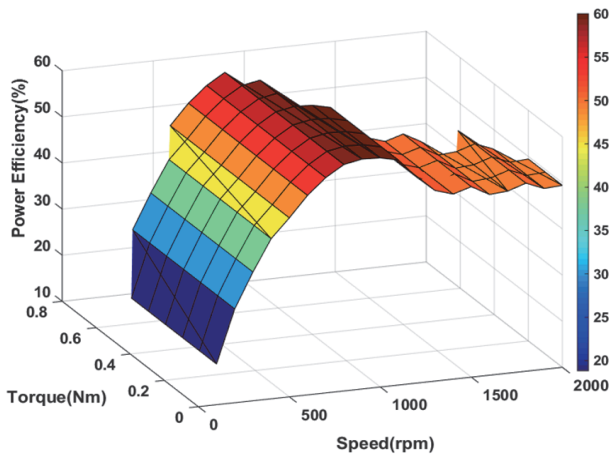


Fig. 11 3D Maximum Motor Efficiency per Speed (Integrated)

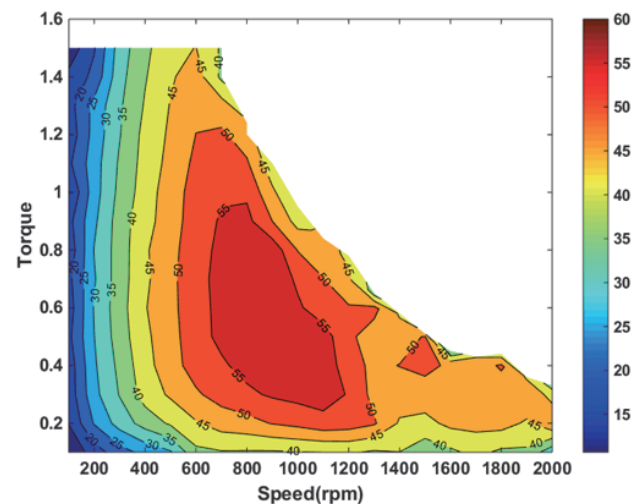


Fig. 13 Motor Efficiency Map (New Load System)

#### 4.2.1 Motor Efficiency Map

A motor efficiency map of a two phase inverter fed drive connected to a DC generator as a load is shown in Fig.12 and integrated results using a geared DC generator in low speed region and DC generator in high speed region as a load is shown in Fig.13.

An efficiency map is a 2-D plot of the efficiency and torque of the motor versus its rotation speed. An efficiency map facilitates easier evaluation of low and high efficiency speed range of a motor. The results in Fig.12 shows the speed range where the maximum efficiency is achievable is between 800rpm and 1200rpm. However, the motor efficiency in the low speed region is not measurable because of the inadequacy of torque and limitation of the load machine.

Fig.13 shows by using the proposed control strategy and a geared DC generator as a load, the motor efficiency in low speed region is measurable.

## 5. Conclusion

In this paper, a new torque measurement system is proposed for a two phase inverter fed induction motor drive. Furthermore, by applying the proposed strategy, the efficiency of the motor in the whole operating region is measurable and a detailed evaluation can be carried out.

Experimental results show;

- 1) The maximum torque is achievable in the low speed region.
- 2) Compared to the VVVF control, vector control method can provide a higher motor efficiency over a wider speed range

Further work will be done to improve speed-torque characteristics and motor efficiency in high speed region by proposing a flux weakening control method for two phase inverter.

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