PERFORMANCE CHARACTERISTICS OF INVERTER DRIVEN SYNCHRONOUS MOTOR

MAHYUZIE BIN JENAL

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For my dearest wife Nazalina,

My beloved sons M.Luqman Al-Hakim and M.Uwais Afiq,

My beloved daughters Nuraniqah Humaira and Nurqamarina Husna.

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ABSTRACT

Three phase synchronous motor has a wide range of applications. Its constant-speed operation (even under load variation and voltage fluctuation) and high efficiency make it most suitable for constant-speed, continuous-running drives such as motor-generator sets, air compressors, centrifugal pumps, blowers, crushers and many types of continuous-processing mills. However, this motor is not a self-started type. There are many methods implemented in order to bring up the motor's speed to the required limit. One of the approaches is by using variable-frequency supply starter that is used in this project work. Realizing the importance of motor performance information in practice, this project aimed to carry out the standard motor tests and observe the characteristics. Two main methods are applied in this particular system where one of them is by running up the synchronous motor conventionally. "Prime mover" is coupled to the motor and drives it to the desired speed before supplying electrical sources. The other method is by using variable-frequency (inverter) supply connected to the synchronous motor and run the motor accordingly. A number of experiments are set up either with and without the inverter to analyze and compare their performance characteristics. The results are reported and discussed in this work.

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ABSTRAK

Motor segerak tiga fasa memiliki aplikasi penggunaan yang sangat meluas. Operasi kelajuan yang tetapnya (walau pun beroperasi dibawah nilai beban yang pelbagai dan ketidakstbilan voltan) dan kecekapan yang tinggi membuatkannya adalah yang paling sesuai bagi pemacu dari jenis kelajuan-tetap dan memerlukan operasi yang berterusan seperti set motor-penjana, pam empar, peniup , mesin penghancur dan lain-lain kategori industri yang berkaitan. Walaubagaimanapun, motor ini bukanlah dari jenis yang boleh digerakkan dengan hanya memberikan bekalan elektrik. Terdapat banyak kaedah yang digunakan untuk menggerak motor daripada keadaan rehat kepada tahap kelajuan yang dikehendaki. Salah satu daripadanya adalah dengan menggunakan bekalan pemula pembolehubah frekuensi yang juga telah digunakan didalam kerja ini. Atas kesedaran akan kepentingan motor segerak, tesis ini bermatlamat untuk melaksanakan beberapa ujikaji dan pemerhatian keatas karektor prestasinya. Dua kaedah telah digunapakai didalam sistem ini diman salah satu daripadanya adalah memacu motor secara konvensional. "Penggerak utama' disambung kepada motor dan memacunya kepada kelajuan yang dikehendaki sebelum sumber elektrik dibekalkan. Satu lagi kaedah adalah dengan menyambungkan bekalan pembolehubah frekuensi (penyongsang) kepada motor segerak dan memacunya. Beberapa set ujikaji dijalankan sama ada menggunakan penyongsang atau tidak telah dijalankan untuk menganalisis dan membandingkan karektor prestasi motor tersebut. Hasilnya telah diapor dan dibincangkan didalam kerja ini.

TABLE OF CONTENTS

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF SYMBOLS/ ABBREVIATIONS

Symbols:

μ	-	Micro (10^6)
Ω	-	Ohm
f	-	Frequency (*Hz*)
π	-	Pi (180)
ϕ	-	Flux
ω	-	Omega
φ	-	Phase displacement
δ	-	Torque angle
η	-	Efficiency
s	-	Slip
S	-	Apparent Power
Ra	-	Armature Resistor
T	-	Torque
n	-	Speed
m	-	mili (10^{-3})
M	-	Mega (10^6)
I	-	Current
Xs	-	Synchronous Reactance
p	-	Pole
P	-	Power
A	-	Ampere
E	-	Generated Voltage
V	-	Voltage
t	-	Time
Z	-	Impedance

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Abbreviations:

AC (a.c)	-	Alternating Current
DC (d.c)	-	Direct Current
e.m.f	-	Electric Magnetic Force
m.m.f	-	Magnetomotive force
LN	-	Lucas Nulle
KV	-	Kilo-Volt
IEEE	-	Electrical and Electronic Engineer
FKEE	-	Fakulti Kejuruteraan Elektrik & Elektronik
UTHM	-	Universiti Tun Hussein Onn Malaysia
VSI	-	Voltage Source Inverter
CSI	-	Current Source Inverter
VVVVF	-	Variable Voltage Variable Frequency
BJT	-	Bipolar Junction Transistor
TTL	-	Transistor-transistor Logic
MOS	-	Metal Oxide Semiconductor
CMOS	-	Complementary Metal Oxide Semiconductor
SCR	-	Silicon Controlled Rectifier
IGBT	-	Insulated Gate Bipolar Transistor
PWM	-	Pulse Width Modulation
THD	-	Total Harmonic Distortion
sync	-	Synchronous
ACC	-	Acceleration
DEC	-	Deceleration

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF APPENDIXES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER II

LITERATURE REVIEW

This chapter will review past literature and discuss about operating characteristics of synchronous motor. The elements of speed control will be briefly discussed as well as the application for three phase synchronous motor. Finally, all the reviewed literature will be summarized.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

2.1 Synchronous Motor

Synchronous means *to occur at regular or fixed intervals*. An AC Synchronous Motor is an electrical motor that rotates at a fixed speed, regardless of any increase or decrease in load. The motor will keep its fixes speed regardless of the torque required up until it reaches its stall torque rating. If the load becomes greater than the motor's stall torque, the AC Synchronous Motor will not slow down until it reaches a point at which it will stall and stop turning. The AC Synchronous motor is an effective way to obtain a fixed speed at a very low motor system cost [10]. No expensive driver or amplifier is necessary. Most synchronous motors are used where precise timing and constant speed are required.

AC Synchronous Motors range in size from sub-fractional horsepower to over 10,000 horsepower. Smaller synchronous motors can be found in household devices such as clocks, timers, fans and cassette players, and as stepper motors in computer disk drives and printers. Larger synchronous motors are used in process industries and drive equipment such as compressors. Large synchronous motors most commonly employ a three-phase system. The smaller AC Synchronous Motors commonly use a single-phase system. The three-phase AC Synchronous Motor is the focus of this study.

Basically, according to the shape of the field, synchronous motor may be classified as cylindrical-rotor (non-salient pole) motor (Figure 2.1) and salient-pole machines (Figure 2.2).

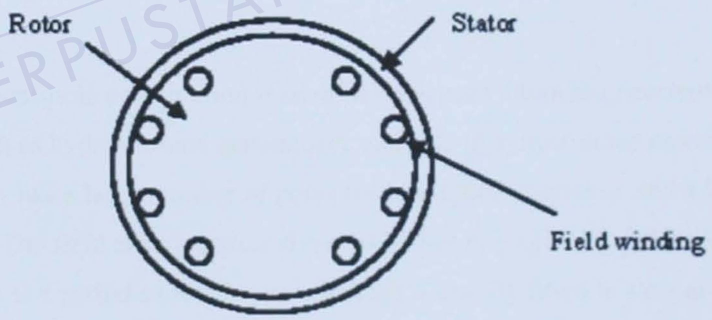

Figure 2.1: Basic construction of cylindrical-rotor synchronous motor type

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

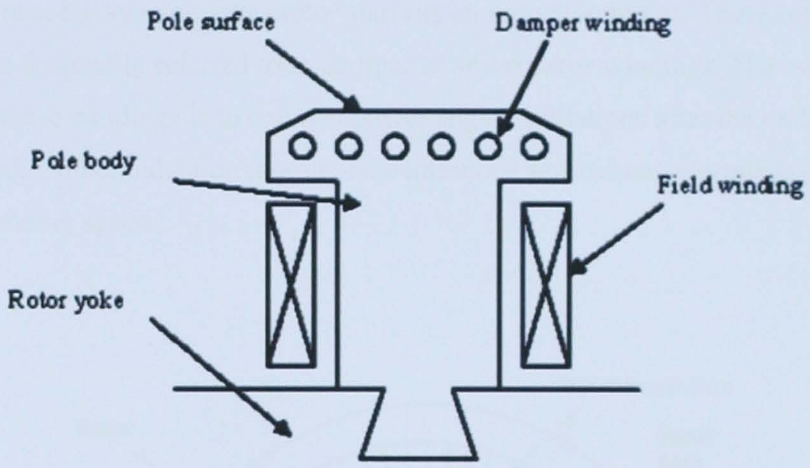

Figure 2.2: Basic construction of salient-pole synchronous motor type

The cylindrical-rotor construction is used in generators that operate at high speeds, such as steam-turbine generators (usually two-pole machines). This type of machine usually has a small diameter-to-length ratio, in order to avoid excessive mechanical stress on the rotor due to the large centrifugal forces.

The salient-pole construction is used in low-speed alternating current (AC) generators (such as hydro-turbine generators), and also in synchronous motors. This type of machine usually has a large number of poles for low-speed operation, and a large diameter-to-length ratio. The field coils are wound on the bodies of projecting poles. A damper winding (which is a partial squirrel-cage winding) is usually fitted in slots at the pole surface for synchronous motor starting and for improving the stability of the machine.

The most attractive and widely applied method of starting a synchronous motor is to utilize squirrel cage windings in the pole faces of the synchronous motor rotor. The presence of these windings allows for a reaction (or acceleration) torque to be developed in the rotor as the AC excited stator windings induce current into the squirrel cage windings. Thus, the synchronous motor starts as an induction motor. These rotor windings are frequently referred to as damper or amortisseur windings. The other major function of these windings is to dampen power angle oscillations after the motor has synchronized. Unlike induction motors, no continuous squirrel cage torque is developed at normal running speeds.

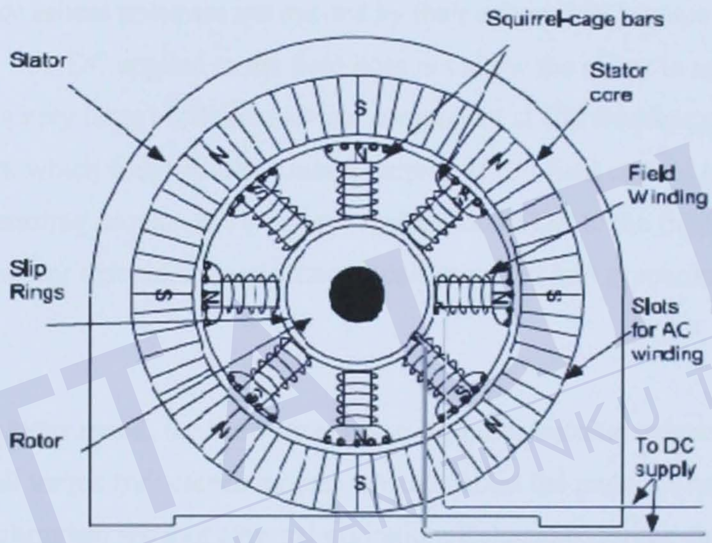

Figure 2.3: Cross section of salient pole synchronous motor

When the motor accelerates to near synchronizing speed (about 95% synchronous speed), DC current is introduced into the rotor field windings. This current creates constant polarity poles in the rotor, causing the motor to operate at synchronous speed as the rotor poles "lock" onto the rotating AC stator poles. Torque at synchronous speed is derived from the magnetic field produced by the DC field coils on the rotor linking the rotating field produced by the AC currents in the armature windings on the stator. Magnetic polarization of the rotor iron is due to the rotor's physical shape and arrangement and the constant potential DC in coils looped around the circumference of the rotor.

Synchronous motors possess two general categories of torque characteristics. One characteristic is determined by the squirrel-cage design, which produces a torque in relation to "slip" (some speed other than synchronous speed). The other characteristic is determined by the flux in the salient field poles on the rotor as it runs at synchronous speed. The first characteristic is referred to as *starting torque*, while the second characteristic is usually referred to as *synchronous torque*. In starting mode, the synchronous motor salient poles are not excited by their external DC source. Attempting to start the motor with DC applied to the field does not allow the motor to accelerate. In addition, there is a very large oscillating torque component at slip frequency, produced by field excitation, which could result in motor damage if full field current is applied during the entire starting sequence. Therefore, application of DC to the field is usually delayed until the motor reaches a speed where it can be pulled into synchronism without slip.

At synchronous speed, the ferro-magnetic rotor poles become magnetized, resulting in a small torque (reluctance torque) which enables the motor to run at very light loads in synchronism without external excitation. Reluctance torque can also pull the motor into step if it is lightly loaded and coupled to low inertia. It is convenient to make an analogy of a synchronous motor to a current transformer for the purpose of demonstrating angular relationship of field current and flux with rotor position.

2.2 Electromagnetic Power and Torque

Let us presume that a synchronous motor is to drive a mechanical load, in steady state, the mechanical torque of the motor should balance the load torque and the mechanical loss torque due to friction and windage, that is

$$T = T_{load} + T_{loss} \tag{2.1}$$

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Multiplying the synchronous speed to both sides of the torque equation, we have the power balance equation as

$$P_{em} = P_{load} + P_{loss} \tag{2.2}$$

where $Pem = \tau\omega_{syn}$ the electromagnetic power of the motor, $P_{load} = \tau_{load}\omega_{syn}$ is the mechanical power delivered to the mechanical load, and $Ploss = \tau_{loss}\omega_{syn}$ the mechanical power loss of the system. The electromagnetic power is the amount of power being converted from the electrical into the mechanical power. That is

$$Pe_m = 3E_aI_a \cos\varphi_{E_aI_a} = \tau\omega_{syn} \tag{2.3}$$

where $\varphi_{E_aI_a}$ is the angle between phasors E_a and I_a.

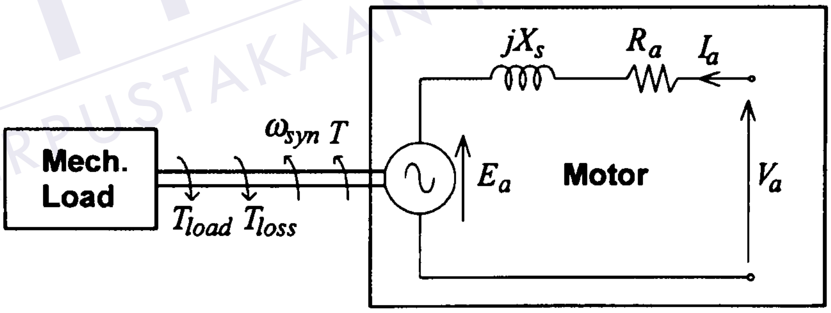

Figure 2.4: Power distribution in synchronous motor

When the stator winding resistance is ignored, the per phase circuit equation can be approximately written as

$$V_a = E_a + jX_s I_a \tag{2.4}$$

The corresponding phasor diagram is shown Figure 2.5. From the phasor diagram, we can readily obtain

$$V_a \sin\delta = X_s I_a \cos\varphi_{E_a I_a} \tag{2.5}$$

Where $\varphi_{E_a I_a} = \varphi - \delta$

Therefore,

$$P_{em} = \frac{3E_a V_a}{X_s}\sin\delta \tag{2.6}$$

and

$$T = \frac{P_{em}}{\omega_{syn}} = \frac{3E_a V_a}{\omega_{syn} X_s}\sin\delta \tag{2.7}$$

where δ is the load angle. When the stator winding resistance is ignored, δ can also be regarded as the angle between the rotor and stator rotating magnetic fields.

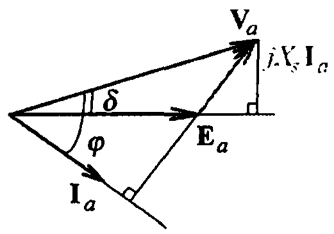

Figure 2.5: Motor phasor diagram

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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PTTA UTHM
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