CONSTANT STARTING TORQUE CONTROL OF WOUND ROTOR INDUCTION MOTORS

A Thesis

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ABSTRACT

The three phase induction motor is the most popular one used in industry. Both the speed control and starting of polyphase induction motors are still among the perennial research topics in electrical engineering.

In this paper the author proposes a new starting method for the wound rotor induction motor. The relevant empirical equations are developed. The equations are good for any wound rotor motor operated at any desired starting torque under any applied voltage.

Recommended control circuits in connection with this new starting method have been designed, and the author does anticipate the proposed starting method could be used.

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LIST OF PRINCIPAL SYMBOLS

V Phase applied voltage, p.u.value/phase.

I Phase rotor current, p.u.value/phase.

r_1 Stator resistance per phase, p.u.value/phase.

x_1 Stator reactance per phase, p.u.value/phase.

r_2 Rotor resistance per phase, p.u.value/phase.

x_2 Rotor reactance per phase, p.u.value/phase.

g_c Shunt conductance per phase, p.u.value/phase.

b_m Shunt susceptance per phase, p.u.value/phase.

r External series resistance per phase, p.u.value/phase.

x External series reactance per phase, p.u.value/phase.

Re External parallel resistance per phase, p.u.value/phase.

Xe External parallel reactance per phase, p.u.value/phase.

r' Resistance component in Xe, p.u.value/phase.

R' Equivalent resistance of parallel combination, p.u.value/phase.

X' Equivalent reactance of parallel combination, p.u.value/phase.

R Total equivalent resistance per phase, p.u.value/phase.

X Total equivalent reactance per phase, p.u.value/phase.

Z Circuit impedance per phase, p.u.value/phase.

Y Circuit admittance per phase, p.u.value/phase.

T Internal electromagnetic torque per phase, p.u.value/phase.

T_{max} Maximum internal electromagnetic torque per phase, p.u.value/phase.

$\cos\theta$ Power factor.

P_{g1} Power delivered to the air gap per phase, watts/phase.

P Internal mechanical power per phase, watts/phase.

P_{12} Copper loss of rotor per phase, watts/phase.

f Frequency, Hz.

S Slip.

S_r Rated slip.

S_m Slip at T_{max}.

ω_s Synchronous angular speed, radians/second.

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CHAPTER I

THE STUDY OF WOUND ROTOR INDUCTION MOTOR STARTING

I. INTRODUCTION

The three phase induction motor is the most popular one among electrical motors. It is widely used in industry.

Its advantages, over other motors, are as follows:

(1) Its convenience in utilization of electrical supply,

(2) Its low initial cost,

(3) Its ease of control and maintenance,

(4) Its rigidity and ability to stand abuse.

There are two types of induction motor:

(1) Cage rotor,

(2) Wound rotor.

From the operation point of view, the main difference between the wound rotor and the cage rotor is that the former can be regulated in torque but the latter cannot.

The deep bar and double squirrel cage rotor can offer a good starting characteristic as shown in Fig. 1. However, the wound rotor has an advantage as stated by G.W.Heumann[10], "Wound-rotor motors are also applied to large drives, sometimes because it is desirable to control the starting torque, sometimes to reduce starting current peaks to a value which can be tolerated by the power system."

Since the torque of the wound rotor can be regulated, it is possible to operate it as a variable speed motor.

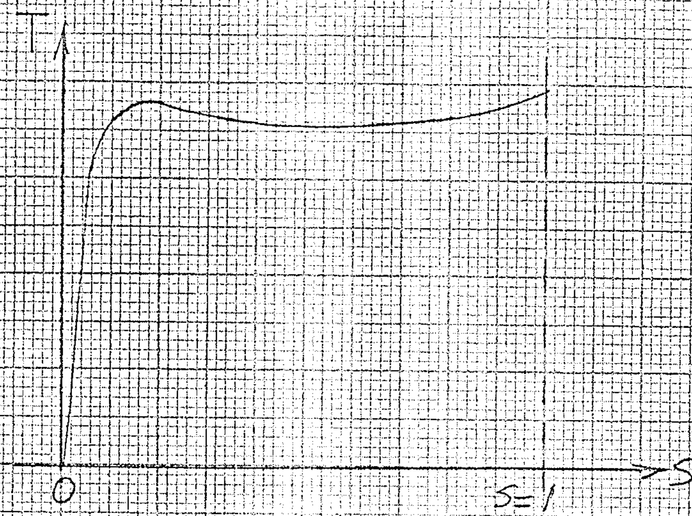
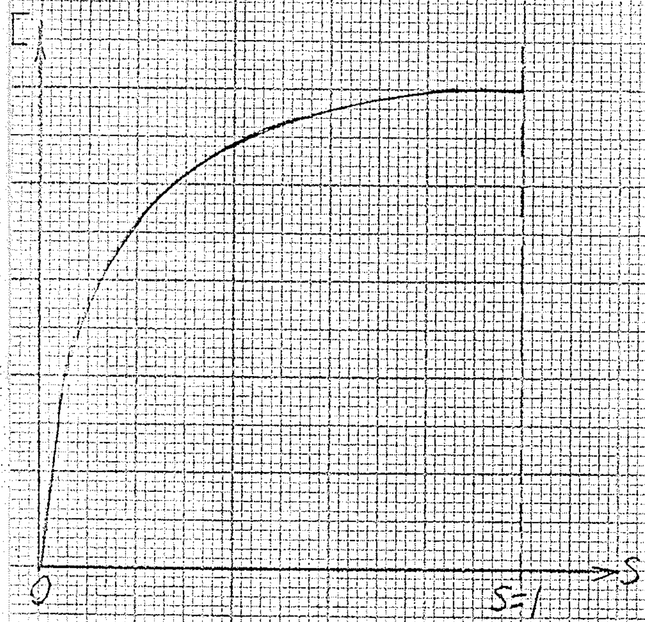
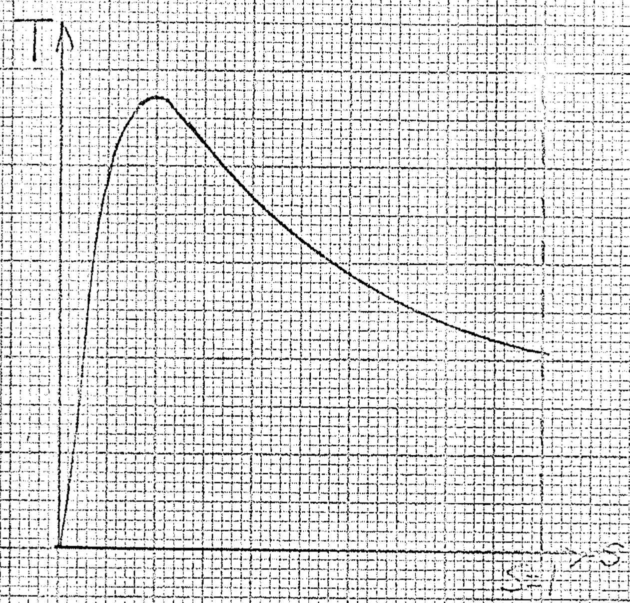


Fig. 1. Starting torque characteristic of Double Cage Rotor Motor



a. Starting current characteristic



b. Starting torque characteristic

Fig. 2. Cage Rotor Motor

The characteristic curves of current and torque versus slip for squirrel cage machines are shown in Fig. 2.

We assume in this thesis that it is desirable to control the starting torque-speed characteristic of a given wound rotor machine in a particular way, namely, that the torque be essentially constant throughout the starting period. In this paper, a new starting method is developed which attains this end.

The results, based on reasonable assumptions and simplifications, indicate that the proposed method can be used to arrive at a solution well within practical engineering tolerances.

II. PER UNIT VALUE

In the following calculations and analysis, the bases of per unit value are as follows:

Voltage: $V_{base} = V$ = rated phase voltage, volts

Current: $I_{base} = I$ = rated phase current, amperes

Speed: $\omega_{base} = \omega_s$ = synchronous angular speed, radians/second

Torque: $T_{base} = \dfrac{I_{base}^2}{\omega_{base}} \left(\dfrac{r_2}{S_r} \right)$, newton-meters/phase

Impedance: $Z_{base} = \dfrac{V_{base}}{I_{base}}$, ohms

III. EQUIVALENT CIRCUIT AND MOTOR PERFORMANCE

The equivalent circuit of an induction motor is shown in Fig. 3 in which the current and impedance of the rotor are defined as their values referred to stator. The exciting branch can be neglected and the results are still within the engineering tolerances.[1] The simplified equivalent circuit, which will be used in the following development, is shown in Fig. 4.

For the three phase induction motor, the per unit phase internal electromagnetic torque T in newton-meters is

$$T = \frac{1}{\omega_s} V\, I \cos\theta$$

and the power P delivered to the air gap by the stator is

$$P = (1 - S)\omega_s T = (1 - S)P_{g1} = I^2 r_2 \frac{1-S}{S}$$

$$\text{Therefore, } T = \frac{1}{\omega_s} I^2 (r_2/S)$$

The torque T and power P are not the output values avaliabl at the shaft, because friction, windage and stray losses have to be accounted for.

Mechanical Output = Internal mechanical power - (Friction and windage losses + Stray load loss)

From the simplified equivalent circuit of Fig. 4,

$$I = \frac{V}{r_1 + r_2/S + j(x_1 + x_2)} = \frac{V}{\sqrt{(r_1 + r_2/S)^2 + (x_1 + x_2)^2}}$$

$$T = \frac{V^2}{\omega_s \left[(r_1 + r_2/S)^2 + (x_1 + x_2)^2\right]} r_2/S$$