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Research Article

DELTA CONFIGURATION OF SILICON CONTROLLED RECTIFIER FOR MORE ECONOMICAL AND EFFICIENT SPEED CONTROL OF INDUCTION MOTORS.

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***ABSTRACT*:** *Delta connection of three phase thyristor placed at the open star point of the rotor circuit was investigated. The various functional blocks of the system which govern the behaviour for a variation in operating point were derived. The responses for load and reference speed perturbations were obtained practically and analytically. The result is 20% improvement over the conventional speed control.*

Keywords: *Load, Rotor circuit, speed perturbations, thyristors, variation.*

I. INTRODUCTION

Among many types of electric motors, induction motor is the one most chosen for industrial devices and they still enjoy the same popularity as they did a century ago. [1] Even though it is basically a constant speed motor [2]. Induction motors are always a better choice for variable industrial derives because of its simplicity, robustness in construction and most suitable for hostile environment. They require minimum maintenance and have good starting torque which enables the motor to start against load without an unreasonable heavy starting current. Most importantly, its cost per kilovolt/Amp (KVA) is one fifth of its immediate competitor – direct current (DC) machine. Induction motor drives with speed control have huge applications in the modern industrial set up. More than 75% of the load today in the industry of any country consists of induction motor drives. [3]

Unfortunately, controlling their speed economically and efficiently remains a challenge to engineers, hence, so many methods which were dependent on the knowledge of the basic formulae for the speed and torque, have been adopted to overcome this impediment.

The basic well known techniques through which efforts have been made to obtain a suitable variable speed drive system include;

Stator Voltage Control Technique

The torque produced by running three phase induction motor is given by;

$$T \propto SE_2^2R_2 \qquad \text{Equation (1.1)}$$

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$R_2^2 + (SX_2)^2$

In low slip region, (SX_2) is very small when compared to R_2, so it can be neglected. The torque becomes;

$$T \propto \frac{SE_2^2}{R_2^2} \qquad \text{Equation (1.2)}$$

Since rotor resistance R_2 is constant, the equation of torque further reduces to;

$$T \propto SE_2^2 \qquad \text{Equation (1.3)}$$

Rotor induced electromotive force (EMF) E_2 varies directly as supply/stator voltage $E_2 \propto V_S$, So torque varies as the product of slip and stator voltage;

$$T \propto SV_S \qquad \text{Equation. (1.4)}$$

From the equations above, decrease of the stator voltage leads to decrease of torque, but to supply the same load, the torque must remain constant and is only possible if the slip is increased, and increasing the slip will make the motor to run at reduced speed [4]. This method shows that a small change in speed requires large reduction in stator voltage and the current drawn by the motor increases, which causes over heating of the motor.

In this technique, soft starter which generally consists of solid state devices like thyristors to control the applied supply voltage to the motor can be used.

II. STATOR VOLTAGE AND FREQUENCY CONTROL

Three phase supply to the stator produces rotating magnetic field and the synchronous speed is gives as;

$$N_S = \frac{120f}{P} \qquad \text{Equation (2.1)}$$

Similar to transformer action, EMF of is induced in the rotor. From equation (2.1), a change in frequency leads to a change in synchronous speed, but with decrease in frequency, flux will increase causing saturation of rotor and stator cores which will further cause an increase in no – load current of the motor; so it is important to maintain flux, Φ constant. This method demands that only voltage should be altered which leads to a corresponding change in flux and it remains constant. Therefore the ratio of voltage to frequency, simply called V/F ratio should remain constant and the motor speed could only be controlled when supplied with the variable ratio which is easily obtain by using converter and inverter set [5].

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III. ROTOR POWER CONTROL TECHNIQUE

In this technique, external resistances are added on the rotor side. This has been the traditional speed control of induction motor. [2]

As earlier stated,

The equation of torque for three phase induction motor is

$$T \propto \frac{SE_2^2R_2}{R_2^2 + (SX_2)^2} \quad \text{and from equation (1.1)}$$

The three phase induction motor operates in low slip region and the term $(SX_2)^2$ becomes very small when compared to R_2, So, it can be neglected. Also E_2 is constant, so the equation of torque after simplification becomes:

$$T \propto \frac{S}{R_2} \quad \text{Equation (2.2)}$$

If rotor resistance R_2 is increased, torque decreases, but to supply the same load, torque must remain constant. So we increase slip which will further result in decrease of rotor speed. Hence addition of resistances in rotor circuit will reduce the speed of three phase induction motor.

In this system, starting torque is increased but speed above normal is impossible and large speed change leads to increased losses and reduction in efficiency.

IV. ROTOR IMPEDANCE CONTROL TECHNIQUE

In this, external resistance is added on the rotor side. From the torque equation (1.1) of the motor, [6] considering that it operates in low slip region and the induced EMF E_2 is constant, the torque equation after simplification becomes;

$$T \propto \frac{S}{R_2} \quad \text{from eq. 1.6}$$

Increasing rotor resistance R_2 decreases torque, but to supply the same load, torque must remain constant, so slip should be increased which will further result in decrease of rotor speed. Its main advantage is increased starting torque [7].

V. SCALAR CONTROL TECHNIQUE

This is aimed at controlling the induction machine to operate at the steady state by varying the amplitude and frequency of the fundamental supply voltage [8]

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With the recent advancement in semiconductor power electronic, the control methods can be achieved electronically. The easiest of the control system is rotor impedance because it is the simplest and relatively more economical for low and medium power applications. In this control system, different schemes of electronic devices can be adopted, like back to back connection of silicon controlled rectifiers (SCR_S) in series with the rotor phase [9], chopper controlled external resistance [10], [8], controlled rectifier in rotor circuit to feed the external resistance [9].

Delta configuration of silicon controlled rectifiers in rotor circuit to feed the external resistance is adopted in this approach. It is more economical and efficient than other speed control methods used. Silicon controlled rectifier is a four layer solid state current controlling device which is synonymous with thyristor and is used generally in switching applications. They are used in devices where the control of high power is needed, like rectification of high power alternating current (AC). and high voltage A.C. power transmission.

The suggested method overcomes the draw backs of traditional three phase induction motor speed control system which are only effective under certain narrow state, insensitive in performance to system parameter variation and inadequate rejection of external perturbations and load changes [1].

In this paper, delta configuration of larger silicon controlled rectifiers which require substantial triggering current than sensitive gate silicon controlled rectifiers which can be triggered by slightest positive gate signal was used.

VI. PRACTICAL EXPERIMENT

Practically a three phase wound rotor slip ring induction motor whose rotor circuit was delta configured with three pairs of large silicon controlled rectifiers was powered with 415v, $50H_z$ supplies and the reference/variable DC supply representing the set speed adjusted manually. Designated SCR_S of TA and TB which are assumed to be turned on in the first cycle of output voltage when $0 \leq \omega t < \pi/_3$ and their pairs with TC which are fired with appropriate delay that are multiples of $\pi/_3$ radian were used in the practical experiment. To achieve full wave conduction, two SCR_S were connected in parallel per phase but in opposite direction to each other.

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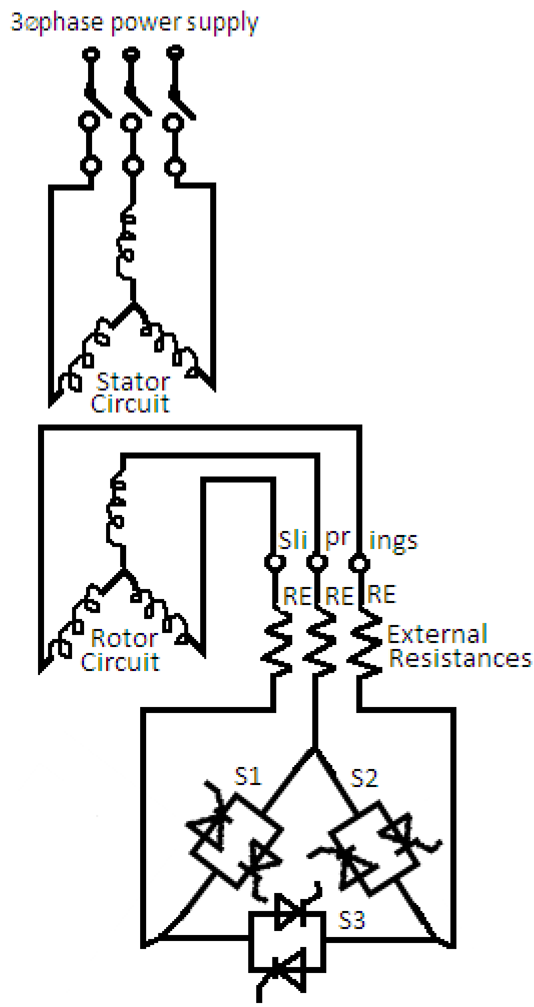

Figure 1: Schematic diagram of SCR_S in delta configuration.

6.1 System Performance

The torque developed by the machine at a given operating time is a function of the speed and the firing angle αf of the thyristor. The difference between the developed torque and the load torque is applied to the rotating system. The torque developed by the machine can be represented as:

$Td = F(\omega, \alpha_f)$ Equation (6.1)

Where Td is developed torque, ω is the rotor speed in radian per second and α_f is the firing angle in degree.

The behaviour for a given change in the system parameter can then be represented as:

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$$\Delta Td = \frac{\Delta Td}{\Delta \alpha_f} \Big/ \Delta\alpha_f \;\; \omega = \text{constant} \;+\; \frac{\Delta Td}{\Delta \omega} \Big/ \Delta\omega \;\; \alpha_f = \text{constant} \qquad \text{Equation (6.2)}$$

$$\Delta Td = K_1 \Delta\alpha_f + K_2 \Delta\omega \qquad \text{Equation (6.3)}$$

The constants K_1 and K_2 depend upon the operating point and they are to be obtained from the steady state characteristics of the system. The study was carried out at two operating points, one at N = 1050 rpm, $\alpha_f = 25^0$ and the other at N= 750 rpm, $\alpha_f = 70^0$. The various system parameters (gain and time constants) used for the study are given in table 1.

Table 1: The Various Gains and Time Constants Used For the Perturbation Study.

Speed	1000 rpm	800 rpm	600 rpm
K1	0.033	0.033	0.033
T1	0.008	0.008	0.008
K2	0.23	1.75	1.95
T2	0.20	0.20	0.20
K3	-50	-50	-50
T3	0.132	0.0088	0.0044
K4	-0.025	-0.0826	-0.0888
T4	-0.085	-0.65	-0.045
KG	35	29.5	24
TG	14.5	12.4	10.3

VII. CONCLUSION

The configuration of silicon controlled rectifier (SCR) in delta form in the rotor circuit has provided an increased efficiency in three phase induction motor as opposed to the conventional methods which had so many draw backs. The increased efficiency is estimated to be above 20%.

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