

PERFORMANCE EVALUATION OF SLIP-RING INDUCTION MOTOR SPEED CONTROL SYSTEM WITH VARIABLE ROTOR VOLTAGE

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Abstract

Dynamic behaviour of a closed loop variable speed three phase slip ring induction motor drive which uses delta connected Silicon Controlled Rectifiers (SCRs) placed at rotor circuit is studied. The functional blocks of the feedback responsible for its behaviour for a small variation of the dc level representing the set speed about the operating point are derived. The performance characteristics are analysed and the data for the perturbation study are simulated using matlab. The responses for load and speed are obtained and the two results are found to be in close agreement.

Key words: Rotor circuit, silicon controlled rectifier, small variation, load and speed.

1.0 Introduction

Among the numerous existing a.c. motors, induction motor has always been preferred to other a.c. motors for industrial drives like motor – generator sets, large pumps, elevators in building and fan compressors, due to their merits. They are very simple and extremely rugged almost unbreakable construction, their cost is very low and reliable. They require minimum maintenance and have good starting torque which enables the motor to start against load without an unreasonably heavy starting current. The machine is mainly limited by the difficulties of controlling its speed, hence the attention of scientists and engineers is diverted towards the speed control which is its major problem. So many methods have been adopted to overcome this impediment like stator voltage control, rotor power control, operating two motors in cascade, rotor impedance control, and scalar control which is aimed at controlling the induction machine to operate at the steady state by varying the amplitude and frequency of the fundamental supply voltage [1].

With the advancement in power electronics, the control methods can be achieved electronically and

economically too. The simplest of the control system is rotor impedance, in which different schemes of electronic devices can be adopted, like back to back connected SCRs in series with the rotor phase [2], chopper controlled external resistance [3] [4], controlled rectifier in rotor circuit to feed the external resistance [5] and delta connected SCRs in rotor circuit to feed the external resistance [6]. The delta configuration of SCRs is more economical as it uses only three phase control. 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 mainly used in devices where the control of high power is needed, like rectification of high power a.c. and high voltage a.c. power transmission, control of welding machine and motors. The suggested method could overcome the drawbacks of traditional speed control system which are only effective under certain narrow state, insensitivity in performance to system parameter variations and inadequate rejection of external perturbations and load changes [7]. In this paper, the dynamic behaviour of closed loop speed control system with delta connected SCRs in the rotor circuit is discussed.

The various functional blocks of the feedback system are derived and the responses for load and reference speed are obtained analytically, then compared with the simulation result.

1.1 Motor under Study

The system used in this study is a three phase slip-ring induction motor with three phase rotor winding connected in delta and terminated in slip-rings to which equal external resistances and SCRs in delta configuration are connected. See fig. 1.

A d.c. tachogenerator was mounted on the rotor shaft to provide a d.c. signal proportional to the rotor speed, to serve as a feedback to the control circuit, as shown in fig. 2.

In fig.1, the motor under study is supplied with constant voltage and frequency, the rotor speed gets adjusted with the variation of the firing angle, α which is the time during which SCR is 'ON'. The output voltage of the tachogenerator is proportional to rotor speed and is compared to the fixed d.c. level (VR) representing the set speed. The error voltage was then fed to the controller. The set speed could be changed manually by varying the VR.

The controller can be of the type proportional (P) or proportional plus integral (PI) or proportional plus integral plus derivative (PID). In this study, only (PI) controller was considered as shown in the circuit configuration of fig. 3.

When the three phase a.c. power is supplied to the stator, it creates a rotating magnetic field that induces current in the rotor which also creates its own magnetic field that reacts against the stator field. To ensure current flow in rotor, the synchronous speed should be greater than the actual speed by 0.5 to 5%. The rotor impedance is inversely proportional to the speed and the value depends on the conducting / firing angle α of the thyristor. The more the conducting angle α , the more the voltage, current and torque but the lesser the speed.

The speed controller houses the thyristors and determines their firing angles which have direct influence on the rotor voltage. So variable rotor voltage is developed as the controller alters the firing angles of the thyristors and the voltage is directly proportional to the motor / rotor speed.

This strategy is employed in the speed control of induction motor to achieve increased efficiency.

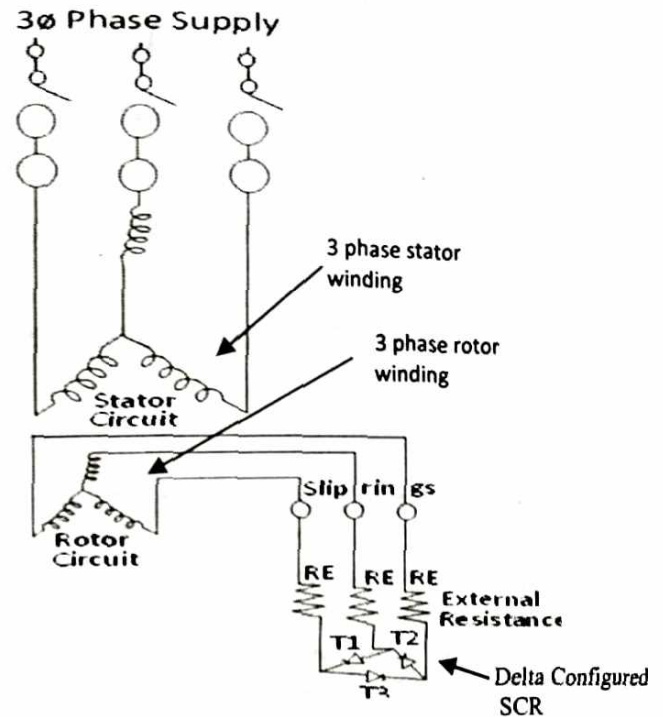


Fig. 1 slip-ring induction motor with delta configuration in rotor of motor under study

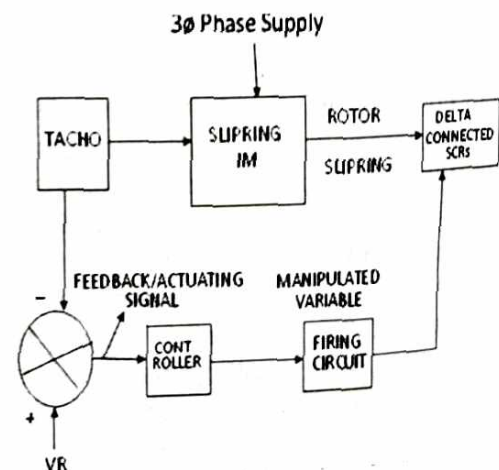


Fig. 2 Block diag. of the feedback of delta configured SCR

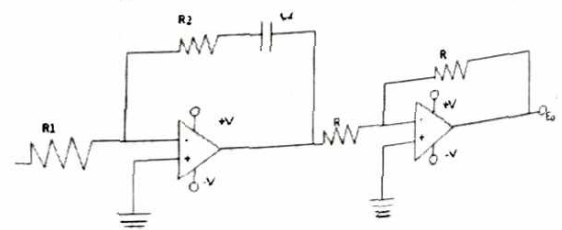


Fig. 3. Circuit configuration of the PI Speed controllers

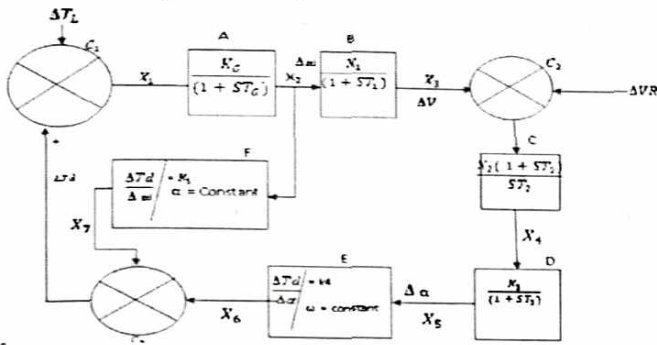


Fig. 4 Functional blocks of the closed loop of delta configured SCR

1.2 Theoretical analysis of the functional blocks:

Mechanical System

From block A of fig. 4, the transfer functions of the mechanical system is

$$G_m(S) = \frac{KG}{1+ST_g} \quad (1)$$

Tachogenerator:

From block B of fig. 4, its transfer function of tachogenerator with the filter is

$$G_g(S) = \frac{KG}{1+ST_1} \quad (2)$$

Where K_1 is the gain of the tachogenerator and T_1 is the time constant of the filter

Controller:

From block C of fig 4 the transfer function of firing circuit is

$$G_c(S) = \frac{K_2(1+ST_2)}{1+ST_2} \quad (3)$$

Firing Circuit:

From Block D of fig.4, the transfer function of firing circuit is

$$G_f(s) = \frac{K_3}{1+ST_3} \quad (4)$$

2.0 System Performance

The study investigates the change in rotor speed due to change in reference voltage and load torque. Considering the various functional

blocks in fig. 4., the analytical results are obtained with reference to input and output variables which are denoted by X_1 to X_7 and defined as follows.

$$X_1 = \Delta T_d - \Delta T_L \quad (5)$$

where Δ denotes change in variables, T_d is the developed torque, T_L is the load torque with reference to the comparator and $X_1 - X_7$ are assigned input and output variables.

$$X_2 = \Delta w \quad (6)$$

where w is the rotor speed in radians per second.

$$X_3 = \Delta V \quad (7)$$

where V is the voltage from tachogenerator.

$$X_4 = \Delta V_c \quad (8)$$

where V_c is control voltage to the firing circuit.

$$X_5 = \Delta \alpha \quad (9)$$

where α is the firing angle.

$$X_6 = K_4 \Delta \alpha \quad (10)$$

where $K_G, K_1 - K_7$ are constants obtained from the steady state characteristics of the system.

$$X_7 = K_5 \Delta w \quad (11)$$

$$\Delta T_d = X_6 + X_7 \quad (12)$$

These variables named are also marked in fig. 4.

The differential and algebraic equations which govern the variation are written down in terms of the variables.

$$X_1 = \Delta T_d - \Delta T_L \text{ as in (5)}$$

$$\text{But } \Delta T_d = X_6 + X_7 \text{ from (12)}$$

$$X_1 = T_d + X_7 - \Delta T_L \quad [13]$$

$$X_2 = \Delta w = \frac{K_G X_1}{1+ST_G} \text{ as in (2) with reference to mechanical system (block A)}$$

$$X_2 + ST_G X_2 = K_G X_1$$

$$ST_G X_2 = K_G X_1 - X_2$$

$$SX_2 = \frac{K_G X_1 - X_2}{T_G}$$

$$\text{But } S = \frac{d}{dt}$$

$$\frac{dX_2}{dt} = \frac{K_G X_1 - X_2}{T_G} \quad (14)$$

$$X_3 = \frac{K_1 X_2}{1 + ST_1} \quad (15)$$

as shown in block B of fig. 4.

$$X_3 (1 + ST_1) = K_1 X_2$$

$$X_3 + ST_1 X_3 = K_1 X_2$$

$$ST_1 X_3 = K_1 X_2 - X_3$$

$$SX_3 = \frac{K_1 X_2 - X_3}{T_1}$$

$$\frac{dx_3}{dt} = \frac{K_1 X_2 - X_3}{T_1} \quad (16)$$

$$X_4 = (\Delta VR - X_3) \frac{(K_2)(1 + ST_2)}{ST_2} \quad (17)$$

reference to comparator and controller block C

$$ST_2 X_4 = X_2 (\Delta VR - X_3)(1 + ST_2)$$

$$= K_2 (\Delta VR + S\Delta VRT_2 - X_3 - SX_3 T_2)$$

$$= K_2 \Delta VR + K_2 S\Delta VRT_2 - K_2 X_3 - K_2 SX_3 T_2$$

$$SX_4 = K_2 \Delta VR + \frac{K_2 S\Delta VRT_2 - K_2 X_3 - K_2 SX_3 T_2}{T_2}$$

$$\frac{dx_4}{dt} = \frac{K_2}{T_2} (\Delta VR + S\Delta VR - X_3 - SX_3) \quad (18)$$

Since $\Delta VR = \text{constant}$ at an instance

$$\text{Hence, } K_2 \frac{\Delta VR}{dt} = 0$$

$$X_5 = \Delta \alpha = \frac{X_4 K_3}{1 + ST_3} \quad (19)$$

as shown in block D of the system

$$X_5 (1 + ST_3) = X_4 K_3$$

$$X_5 + X_5 ST_3 = X_4 K_3$$

$$SX_5 T_3 = X_4 K_3 - X_5$$

$$SX_5 = \frac{X_4 K_3 - X_5}{T_3}$$

$$\therefore \frac{dX_5}{dt} = \frac{X_4 K_3 - X_5}{T_3} \quad (20)$$

$$X_6 = K_4 \Delta \alpha = K_4 X_5 \quad (21)$$

From block E and equation (10) and (19)

$$\text{But } X_5 = \frac{X_4 K_3}{1 + ST_3}$$

$$\therefore X_6 = K_4 \left(\frac{X_4 K_3}{1 + ST_3} \right)$$

$$= \frac{K_4 X_4 K_3}{1 + ST_3}$$

$$X_6 (1 + ST_3) = K_4 X_4 K_3$$

$$X_6 + SX_6 T_3 = K_4 X_4 K_3$$

$$X_6 + SX_6 T_3 = K_4 X_4 K_3$$

$$SX_6 T_3 = K_4 X_4 K_3 - X_6$$

$$SX_6 = \frac{K_4 X_4 K_3 - X_6}{T_3}$$

$$\frac{dX_6}{dt} = \frac{K_4 X_4 K_3 - X_6}{T_3} \quad (22)$$

$$X_7 = K_5 X_2 \quad (23)$$

$$\text{But } x_2 = \Delta w = \frac{K_G X_1}{1 + ST_G}$$

$$\therefore X_7 = K_5 \left(\frac{K_G X_1}{1 + ST_G} \right) = \frac{K_5 K_G X_1}{1 + ST_G}$$

$$X_7 (1 + ST_G) = K_5 K_G X_1$$

$$X_7 + SX_7 T_G = K_5 K_G X_1$$

$$SX_7 T_G = K_5 K_G X_1 - X_7$$

$$\frac{dX_7}{dt} = \frac{K_5 K_G X_1 - X_7}{T_G} \quad (24)$$

3.0 System Simulation and Data Analysis

The various data for the gain and time constants used for the perturbation study were chosen as seen in table 1, and simulated on a matlab functional block of the closed loop system. The parameters for the simulation fig. 5 were chosen at random.

The result was the change in motor speed due to the change in firing angle of the thyristors. This was due to the fact that change in output voltage of the tachogenerator was compared with the change in the reference voltage and the resultant change in voltage was fed to the controller. The controller output voltage was corrected in accordance with the input change in voltage.

The firing pulses were given to the thyristors and when the ramp crossed the control voltage, the comparator adjusted the firing angle to the new value as soon as there was a change in the control voltage, V_c .

Table 1. The various gains and time constants used for the perturbation study.

Speed	K_1	T_1	K_2	T_2	K_3	T_3	K_4	K_5	K_G	T_G
1000	0.033	0.008	0.23	0.20	-50	0.132	-0.0252	-0.085	35.0	14.4
800	0.033	0.008	1.75	0.20	-50	0.0088	-0.0826	-0.065	29.5	12.4
600	0.033	0.008	1.95	0.20	-50	0.004	-0.08839	-0.045	24.0	10.3

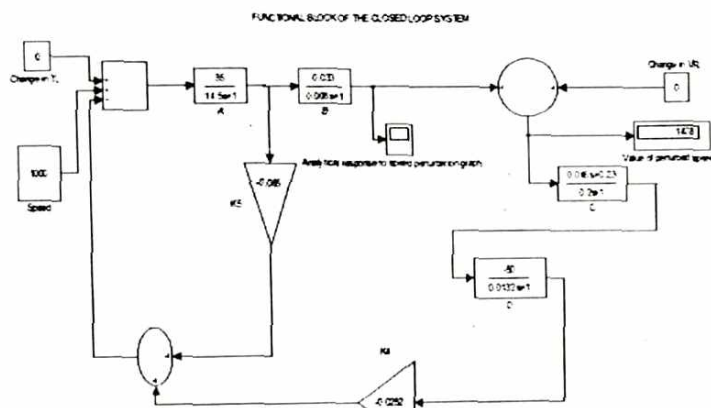


Fig. 5. Matlab simulation block of the closed loop test system

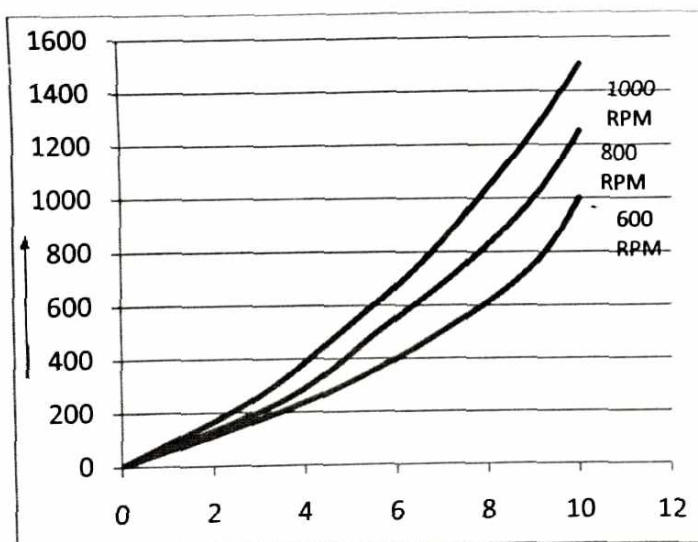


Fig. 5. Simulation graph Result

4.0 Result Analysis

A change in input variable which can be load torque (T_L) or reference voltage (V_R), brings about perturbation in the system and results in the speed change which can be observed in simulation perturbation speed.

The motor speed response is proportional to load changes. Hence the simulation result shows that at a rotating speed of 800rpm and at a time of 4 seconds, speed is 250rpm. This is in agreement with the analytical result.

5.0 Conclusion

The various gains and time constants used for the perturbation study were simulated in the functional block of the closed loop system. The response curve showing the variation of speed with time for the given load torque and reference speed perturbations was plotted.

The resulting simulation curves agreed with the analytical one. The overall performance of the speed control system is far better than the conventional and other methods adopted to overcome the speed control impediment inherent in the use of induction motors.

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