SOLAR TRACKING SYSTEM

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GRADUATION PROJECT

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ABSTRACT

The amount of solar energy reaching the earth's atmosphere is enormous. In fact the amount of energy depends on the position of the sun. The sun position is not fixed and vary from time to time. So the collection of solar energy depends on the position of collector with respect to the position of the sun.

In this project solar tracking system is studied using two photo cells to determine the relative position of the collectors with respect to the sun position. The error detector "two photo-cells" detects any deviation between the position of the sun and the position of the collectors. It provides the induction motor firing circuit with an electrical signal which activates this controlling circuit. So, a set of thyristors will be triggered and flow of electrical energy force the 3-Q induction motor to rotate in a direction to minimize the position's deviation.

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INTRODUCTION

1. POSITION CONTROL SYSTEM

2. SERVO AMPLIFIER

3. Electrical Drivers

INTRODUCTION(1)

If all the world reserves of coal, oil, and gas were burned at a rate fast enough, to give us the same amount of heat we are accustomed to receive from the sun, the supply would be entirely gone less than three days. The sun is a vast, almost ever lasting source of energy that has never been effectively utilized. Growing industrial activity and rising standard of living throughout the world make the amount of an increased supply of energy to be essential up to now the sun holds more promise of filling this need than any other source.

The solar energy can be converted from being just light into heat energy in terms of hot water, space heating and cooling. It can also be directly converted to electrical energy using photo voltiac system, or the light energy is converted into heat energy through mirrors called heliostats that reflect the sun rays into a central receiver mounted on tower, at which the concentrated solar energy is absorbed by a circulating fluid, which vaporises into steam used to drive a turbo-generator to produce great electrical energy "heat energy into electrical energy".

In order to increase the amount of used solar energy by the collectors, the collectors should track the sun, so that the incident angle of sun rays make an angle of 90° with the collectors. So tracking mechanism to follow the sun is required. This requires to control the angular position of the driven shaft where the collectors are mounted.

Chapter one handles the definition of position control, control system,open-loop system, closed-loop system.

Chapter two handles different types of servo amplifiers to control the power flow to a servo system.

Chapter three handles different types of electrical drivers. Induction motor and a circuit for phase control of three phase induction motor is designed.

CHAPTER 1

POSITION CONTROL SYSTEM

The main function of using the position control system is just to control the angular position of an output shaft or drivers shaft such as controlling the angular position of a tracking antenna to follow a moving object, or controlling the angular position of a collector so that the solar energy which is collected is maximum.

In general, there are two types of control systems. 1) Open –Loop Systems. 2) Closed-Loop Systems.

1.1 Open-Loop System (2)

In an open-loop system an input signal or command is applied, amplified in a "controller" and a power output is obtained from an output "element". The location of the output element, is often remote from input station. The input maybe applied manually. The expected output is normally predetermined by calibration, and the input signal may be accompanied by some sort of calibration chart. The actual output obtained depends on the validity of the calibration chart. If at least one component of the system were affected by time, temperature, humidity and lubrication, the actual output may vary from the desired output. Such systems are also affected by load variation. Figure 1.1 shows an example of open-loop system.

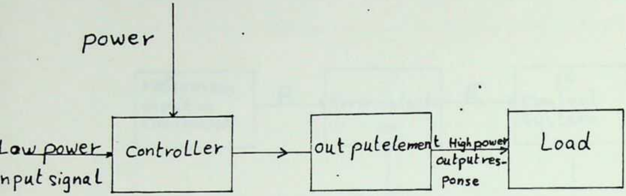


Figure 1.1 Open Loop-System

Closed-Loop System

As shown in the block diagram of Figure 1.2.a, closed-loop system contains the following devices features: 1) a steady device giving an input signal R, often called the command or reference input, that sets the desired level or position which asked to hold; 2) the controlled quantity C, which is the resulting level or position, that is controlled by this system; 3) feedback path or element H, to supply a feedback signal B that truly indicates the size or position; 4) an error detecting device that receives the feedback signal B and compare it with the reference input signal R; any error or difference between B and R produces an output or actuating signal E, so the large external power is applied in order to restore C to the desired size or position.

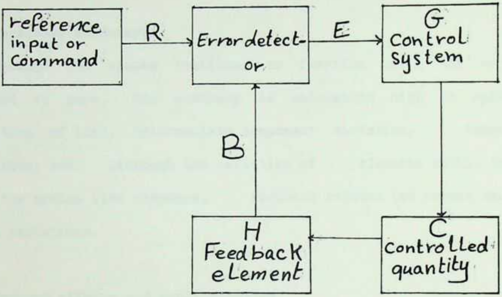


Figure 1.2.a

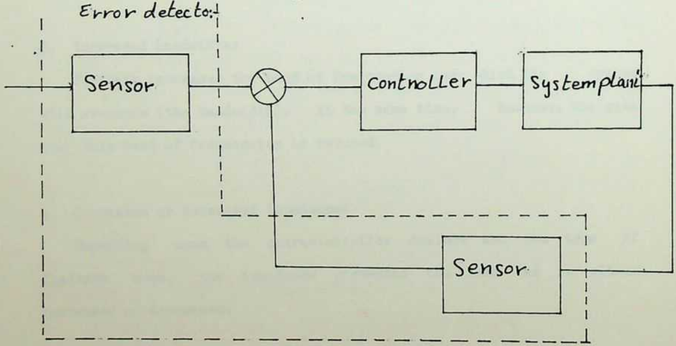


Figure 1.2.b

(3) The effects of feedback, which can also be classified as the advantages of closed loop systems, can be summarized as follows.

1. Increased accuracy:

Because the system continues to function until the error is reduced to zero, the accuracy is maintained high in spite of variation of load, intermediate component variation, temperature variation, etc. Although the variation of elements within the loop vary the system time response, feedback reduces the errors caused by these variations.

2. Reduced effects and nonlinearities:

Feedback reduces the effects of distortion and nonlinearities which occure within the loop. The dynamic performance is affected by the nonlinearities; however, the effects of some nonlinearities, such as amplifier saturation, are greatly reduced by feedback.

3. Increased bandwidth:

Feedback increases the band of frequencies over which the system will responde (the bandwidth). At the same time, however, the gain over this band of frequencies is reduced.

4. Increased or decreased impedance:

Depending upon the characteristics desired and the type of feedback used, the impedance presented the load can be either increased or decreased.

1.2 Servomechanisms (4)

A servo mechanism is a closed loop-system that moves or changes the position of the controlled object so that it "follows up" the position of a control device. It includes a motor which causes, such mechanical movement. The shorter term servo is commonly used to apply to any type of closed loop systems.

In response to an input signal of low power level, servo controls much greater amount of power. A good servo gives close "line up" or high accuracy at stand still. It provides fast response when moving to a new required position. It permits control of equipment from a remote position. By the nature of its self-checking action, it decreases the errors expected from any variation in the components of which is made. It is smooth in its action. It reduces the effects of any disturbances so it obtains high accuracy and fast response, servo requires careful and precise design so as to prevent unstable operation, violent oscillation and undesirable movement of the heavy controlled unit. Since any servo continually is exposed to outside disturbance, it is considered to be stable only if it is designed so that the effects of such disturbance quickly disappear. Stability is the greatest problem in the design of a modern closed-loop system.

As an example, Figure 1.3 shows a servomechanism system which is used to direct a gun position. The gun director is pointed easily at the desired target by the gunner, who may be at some distance from the gun. The pointing of this director delivers a command signal R. The actual gun position feeds back a signal B, which is proportional to the actual gun position, an error or actuating signal E (when /R-B/ ≠ 0) is amplified so as to make a motor turn in a direction such that /R-B/ = 0. Of course the steady state accuracy must be high, the servo must point the gun in exactly the required direction.

To obtain fast response, so much power must be applied through the motor that it may turn the heavy gun beyond the required direction.

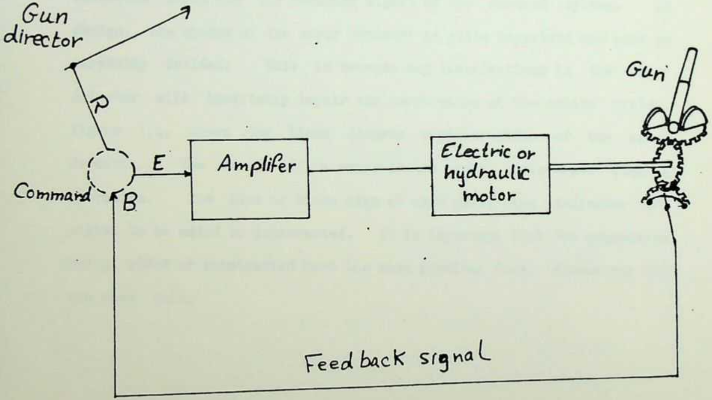


Figure 1.3 Servomechanism for control of gun position

Basic components of a servo are shown in Figure 1.2.a. In a good servo, the control system G must include amplifiers, part of which usually is electronic. Any device that controls large amount of power in response to a small amount of power, is called a power amplifier. This large amount of power, controlled by the amplifier, is applied to an actuator device that corrects the system error by causing the right change in the controlled quantity C. In a servomechanism the error corrector must produce motion so as to change the position C; therefore, some form of motor device is indicated.

1.2.2 Error Detectors (5)

The error detector produces a signal which is the difference between the reference input and the feedback signal of the control system. In design, the choice of the error detector is quite important and must be carefully decided. This is because any imperfections in the error detector will inevitably impair the performance of the entire system. Figure 1.4, shows the block diagram representation of the error detector. The circle with a cross is the symbol indicates a summing operation. The plus or minus sign at each arrow head indicates the signal to be added or substracted. It is important that the quantities being added or substracted have the same physical form, dimensions and the same unit.

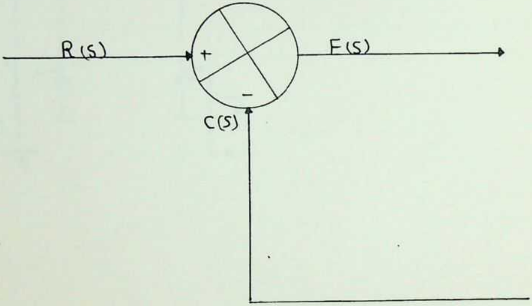


Figure 1.4 Block diagram of an error detector

There are many examples of error detectors, such as, potentiometer detectors. Figure 1.5, shows the d.c form of potentiometer detector. A summing amplifier is used to add the voltage proportional to the input shaft position to the voltage proportional to the output shaft position.(6)

Synchro error detector which is another example of error detectors, is an a.c position detector and utilizes two components, a control transmitter (x) and a control transformer (t). Figure 1.6.a, shows ac error detector.

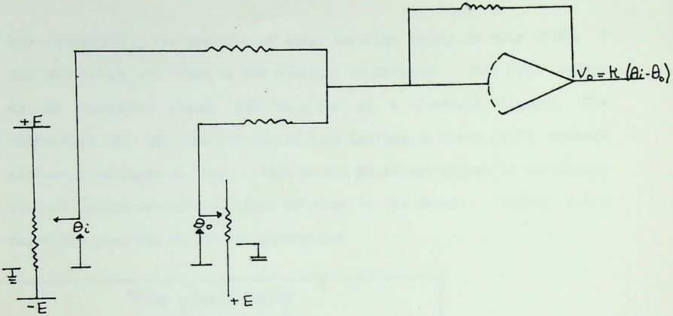


Figure 1.5   dc Error Detector

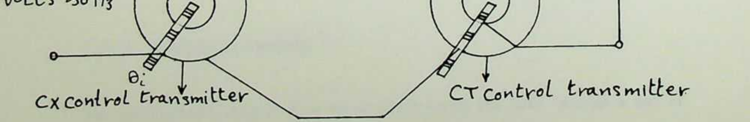


Figure 1.6.a   ac Synchro Error Detector

For controlling the position of solar tracking energy in this study, a two photocells are fixed on the tracking collectors. One cell serves as an inference signal and the other as a feedback signal. The difference of the quantity of sun rays falling on these cells creates different voltages on them. This causes an actuat signal to the firing circuit which controls the flow of power to the motor. Figure 1.6.b shows the position of the two photocells.

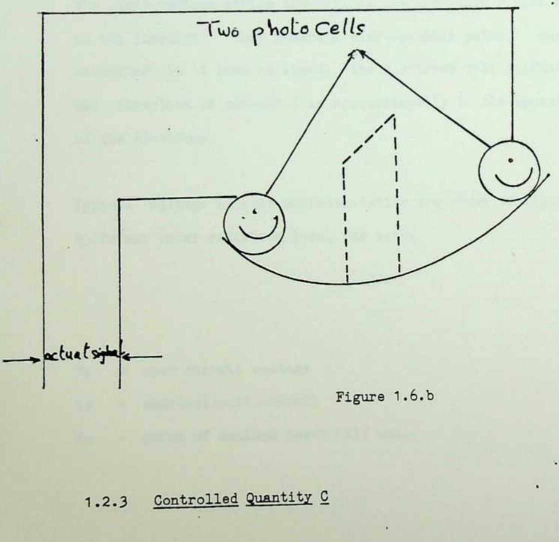


Figure 1.6.b

1.2.3 Controlled Quantity C

The controlled quantity is a motor which turns the load through a set of gears, chapter 3 deals primarily with the servo motors.

1.3 Solar Cell (7)

Figure 1.7 shows a schematic representation of a solar cell composed by pn semiconductor junctions. For single crystal P is obtained by doping silicon with boRon and is typically 1u m thick, n is obtained obtained by doping silicon with arsenic and is typically 800 mm thick. This film cells are composed of copper sulfide P, and cadmium sulfide forn, the sun's photons strike the cell on the microthin P side and penetrate to the junction. They generate electron-hole pairs. When the cell is connected to a load as shown, the electrons will diffuse from n top. The direction of current I is conventionally in the opposite direction of the electrons.

Typical voltage current characteristics are shown in Figure 1.8 at two different solar radiation level for each.

Vo = open circuit voltage
Io = short-circuit current
Pm = point of maximum power (VI) max.

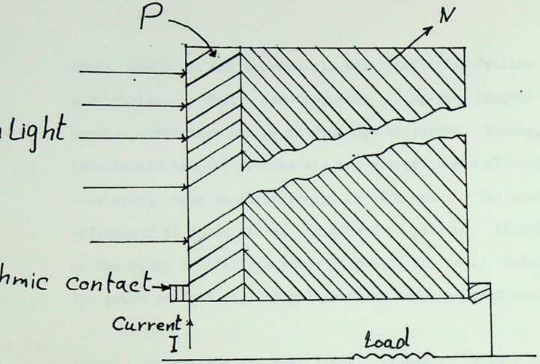


Figure 1.7 A Schematic Cross Section of a Solar Cell

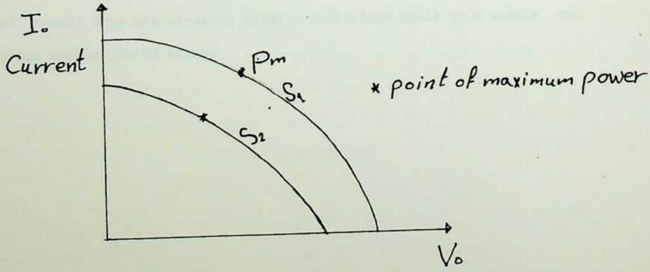


Figure 1.8 Typical Performance Characteristics of a Silicon solar cell at two solar radiations

Solar cells do not convert all solar radiation falling upon them to electricity. Weak, low-frequency (long-wave length) photons do not possess sufficient energy to dislodge electrons. Strong, high-frequency (short-wave length) photons are too energetic and although they dislodge electrons, some of their energy is left over. The maximum theoretical efficiency of solar cells, is around 10 percent. Efficiency is defined as the ratio of electric power output of the cell, module, or array to the power content of sunlight over its total exposed area.

Actual efficiences are much lower, however, because part of the solar energy is reflected back to sky, absorbed by non photovoltaic surfaces or converted to heat. Cells are usually laboratory rated at 100 W/m and 28° C but normally operated at 50°, 60° C. This reduces the efficiency by 1 or 2 percent. In arrays, there are additional losses that result from the mismatch between individual cells in a module and between modules in an array.

CHAPTER 2

SERVO AMPLIFIER

2.1 Introduction (6)

In order to control the power flow to a servo system, a component which is called a power amplifier has to be used. This means that a small amount of input power controls a large amount of output power. So the function of the amplifier shown in Figure 2.1 is to amplify the deviation between the command signal and the controlled one, and to produce a defined output which causes the motor to move the load inertia, such that the error is reduced.

Rotary amplifiers, such devices as d.c generators, metadynes and amplidynes often necessary in systems which require output powers above 500 w. The fact that they rotate means that they require more maintenance than electronic and magnetic amplifiers. They also make noise and require to be driven by a prime mover.

With the advent of the thyristor, power output stages of several MVA capacity became feasible, and stages up to 10 KVA are now commonplace.

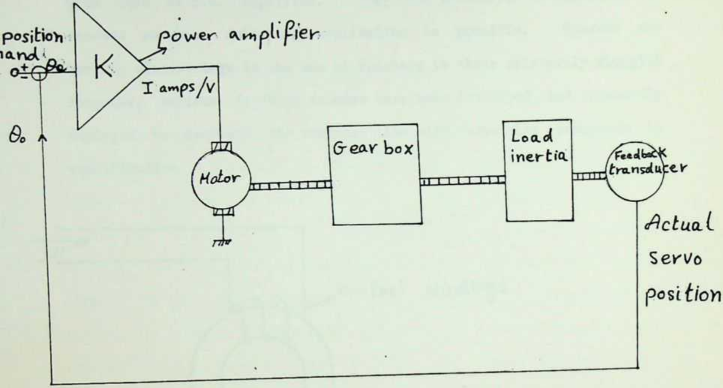


Figure 2.1 Servo Block Diagram

2.2 Magnetic Amplifiers (8)

A magnetic amplifier is a device employing saturable reactors, generally in combination with dry-type rectifiers, to active power amplification. The use of reactors for amplification purposes is not new. Recent development of high permeability magnetic materials and gapless construction of magnetic circuits have made the magnetic amplifier entirely suitable for most applications. Magnetic amplifiers are often preferred to the electronic type. Other characteristics which favor magnetic amplifiers in many applications are low maintenance, complete isolation of input and output signals, and inherently stable operation when used as d.c. amplifier. They tend themselves to operation in cascade so that multistage application is possible. However one serious disadvantage in the use of reactors is their relatively sluggish response, various feedback schemes have been developed and presently employed to decrease the response time with excessive reduction in amplification.

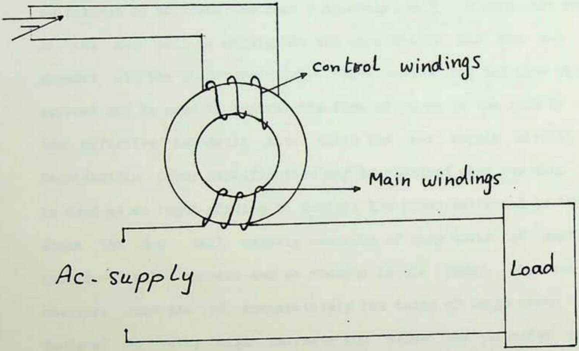


Figure 2.2 Basic Circuit of Saturable reactor

The basic circuit of a saturable reactor is shown in Figure 2.2, it consists of an iron-cored reactor in series with an a.c supply and load. A separate winding on the iron is excited from a d.c source. When no current flows in the d.c coil the magnetic core is unsaturated and so the reactance of the a.c coil is large,

$$L = \frac{d\Phi}{di} \Rightarrow x = 2\pi f \frac{d\Phi}{di}.$$

Thus the a-c coil absorbs almost all the a-c supply voltage. .If a d-c current is allowed to flow through the control winding the core tends to become saturated $-\frac{d\Phi}{di}$ is decreasing $\Rightarrow$ x is decreasing -, decreasing the effective inductance of the a.c winding so that more of the a-c supply voltage appear across the load. When the direct current is sufficient to saturate the core completely, $\frac{d\Phi}{dt}$ = zero -the reactance of the a-c coil is negligible and essentially all the a-c voltage appears at the load terminals. Thus controlling the flow of direct current may be used to control the flow of power to the load by varying the effective impedance into which the a-c supply circuit works. Considerable power amplification may be obtained when the d.c. winding is used as an input winding to control the power delivered to the load. Since the d-c coil usually consists of many turns of small wire, carries little current and so absorbs little power, the a-c coil, however, consists of comparatively few turns of large cross section, designed to carry high currents and allow the transfer of large quantities of power to the load. Actually the simple saturable reactor is not a good amplifier because it has relatively slow response, due to the existence of high inductance in the control winding, the shortcomings of the reactor are due largely to the fact that the d-c coil must supply more ampere turns than the a.c coil in order to maintain saturation. This can be shown from Figure 2.3 . Overall response time for magnetic amplifiers vary from 0.1 sec. to several seconds. Most of the delaying contributed by the control field inductance to decrease the amplifier time lag, several feedback methods may be used, all of which allow the use of a d-c control winding of fewer turns, this cutting down the field time constant, and at the same time reducing the input power requirements.

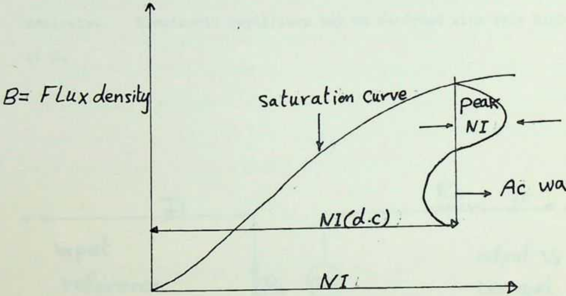


Figure 2.3 Magnetic Requirements of a Saturable Reactor

2.3 Electronic Amplifiers (2)

It is convenient to represent an electronic amplifier by an approximate equivalent circuit as shown in figure 2.4. The representation is not precise but is useful approximation when the input signals are small and changes do not take place very quickly. It is less exact for transistor circuits than it is for vacuum tube circuits. Vi is the input voltage and Vo is the output voltage. It can be imagined that the box has a generator with induced voltage equals to GVi, where G is the open-circuit `gain' of the amplifier. The voltage GVi will only appear at the output terminals when they are not connected to an external load. When a load is connected a current Io will flow and the voltage Vo = GVi - Io Ro, usually Ri is designed to be as high as possible in order not to absorb a significant input current Ii from the source. If Ri is very high compared with external resistances the input can be regarded as an open circuit in order to simplify the analysis. Electronic amplifiers may be designed with very high values of G.

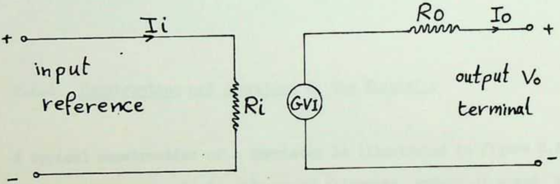


Figure 2.4 Equivalent Circuit of Electronic Amplifier

2.4 Thyristor Applications (6)

2.4.1 Introduction

In order to fully understand the action of the thyristor as a power amplifier, it must be appreciated how the amplification occurs. The reference power source of the servo - which may be either d-c or a-c - lies outside the servo loop, therefore amplification occurs from the fact that a low level error signal, is used to trigger or turn on a thyristor or bank of thyristor, by which a large power is controlled. Since a thyristor is in effect an electronic switch, so the energy source is connected to the motor. By switching the voltage across the motor armature, the desired mean voltage can be generated across the motor armature terminals. It follows that a low power signal has allowed a much larger power which is only limited by the current and voltage ratings of the thyristors to be applied to the motor armature. Consequently large power amplification has occured. The thyristor, therefore, is a mean of switching large currents electronically with a low power signal without having any moving contacts.

2.4.2 Construction and Operation of the Thyristor

A typical construction of a thyristor is illustrated in Figure 2.5. It is seen that the unit is made up of alternate wafers of p and n type silicon. Thus the device may be thought of consisting of a cascaded pair of pnp and npn transistors with a common collector junction.

The operation of the thyristor may be explained by refering to Figure 2.6, if a positive voltage is applied between anode and cathode, then in the

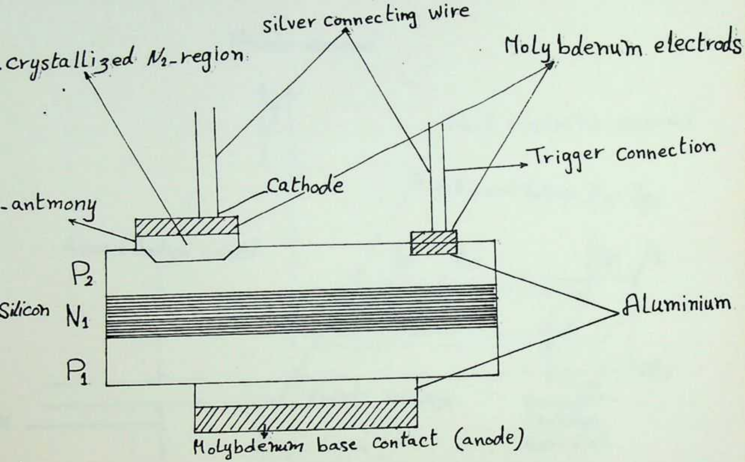


Figure 2.5 Cross Section of a Thyristor

absence of any current in the gate a very small leakage current flows until the anode voltage reaches a critical value called the break over, Vbo, when the applied voltage is equal or greater than Vbo, at this point the anode to cathode voltage drops to approximately 0.7 V, but the anode current is only limited by the external load. Thus the thyristor has been turned on by breaking it over, i.e. by increasing the anode voltage above Vbo in the forward or positive direction with no trigger current being supplied.

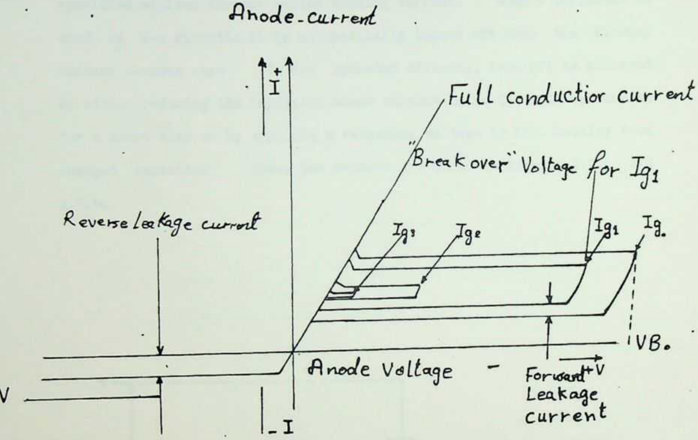


Figure 2.6 Anode Current Voltage Characteristic of a Thyristor

When a small control current Ig is applied to the gate, the corresponding value of the break over voltage Vbo will be reduced from that needed to produce breakover with zero control current. In general the higher the control current applied to the gate lead the lower anode voltage at which breakover occurs. If the trigger current is sufficiently large, the breakover voltage is reduced virtually to zero and the thyristor current-voltage characteristic will be that of an ordinary diode. The major problem associated with the application of the thyristor is that once the anode current is initiated it will continue to flow even after the trigger signal has been removed, provided the current passing through the thyristor is not less than the specified minimum current called holding current. When a thyristor is used in a-c circuits it is automatically turned off when the flowing current becomes zero. In d-c operated circuits, turn off is achieved by either reducing the thyristor anode current below the holding current for a short time or by applying a reversing voltage to it, usually from changed capacitor. These two methods are shown in Figures 2.7.a and 2.7.b.

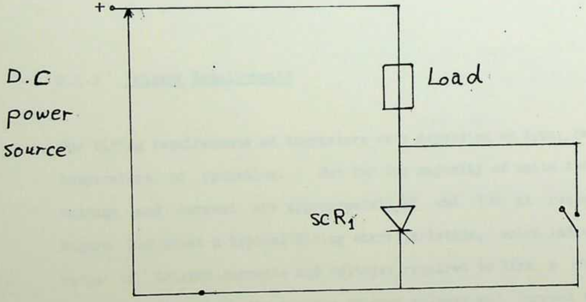


Figure 2.7.a Turn off by reducing thyristor holding current

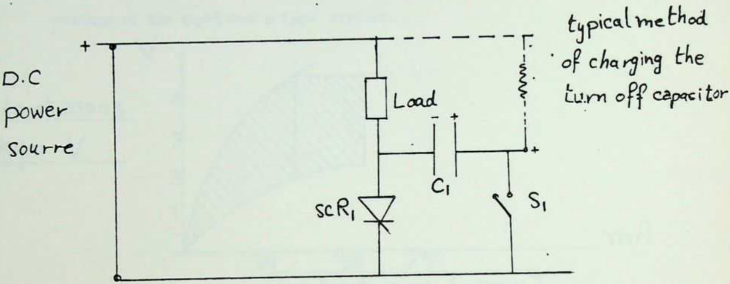


Figure 2.7.b Turn off by applying severe voltage to the thyristor

2.4.3 Trigger Requirements

The firing requirements of thyristors vary depending on type, rating and temperature of operation. But for the majority of units the firing voltage and current are approximately 3V and 100 mA respectively. Figure 2.8 shows a typical firing characteristics, which indicates the range of trigger currents and voltages required to fire a thyristor. Further it also shows the maximum trigger voltage and current that may be applied to the thyristor. It will be noticed that, as the junction temperature of the device increases the necessary current to "fire" or turn on the device, decreases. For reliable firing, under all temperature conditions, the trigger signal source should be designed to produce voltages and currents in excess of the value indicated in the shaded area, without exceeding peak voltages, current and wattage ratings of the thyristor trigger circuit.

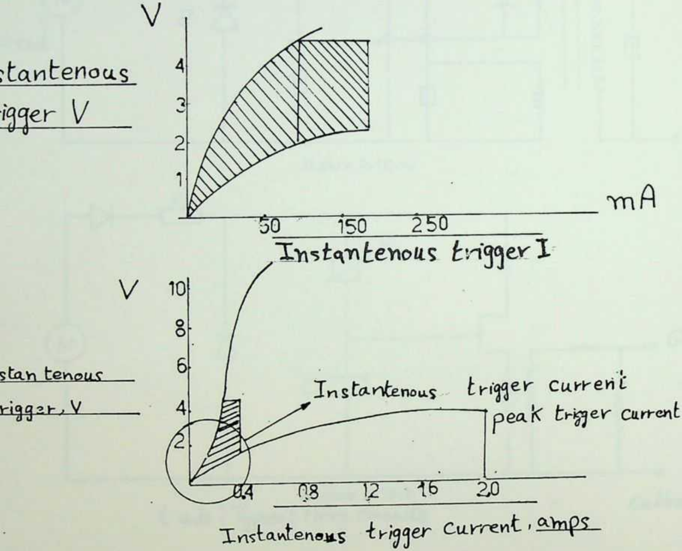


Figure 2.8 Typical Trigger Characteristics for Thyristors in the range 10-150 Amp

2.5 Typical Firing Circuits (9)

Figure 2.9.a shows a circuit firing arrangement, the object of which is to control the load voltage to the wave form shape in 2.9.b. The gate current $I_g \cong \frac{V_s}{R}$, and as the sinusoidal voltage rises from zero, the gate

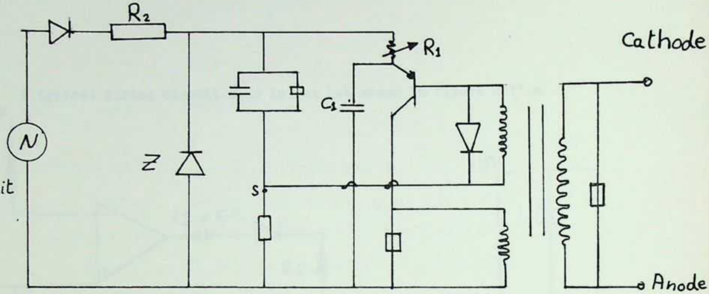


Figure 2.10.a.

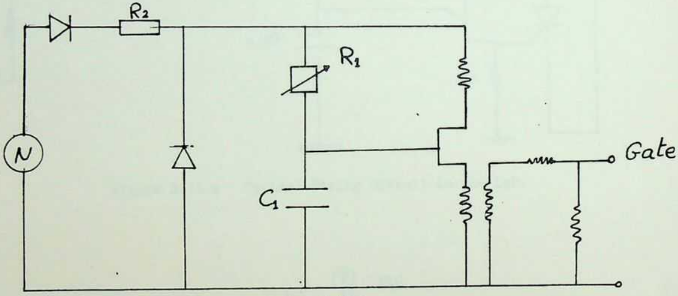


Figure 2.10.b

(a,b) Typical firing circuits

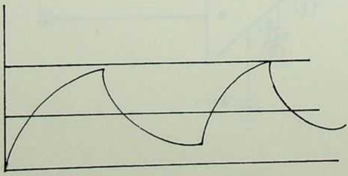


Figure 2.10.c

A typical firing circuit made in the lab shown in Figure 2.11.a

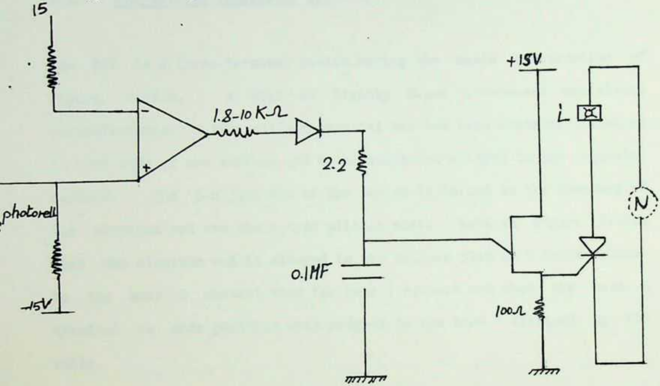


Figure 2.11.a Typical Firing Circuit in the Lab.

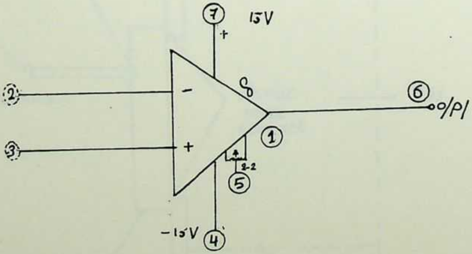


Figure 2.11.b

2.5.1 Unijunction Transistor UJT (10)

The UJT is a three-terminal device having the basic construction of Figure 2.12.a. A stab of lightly doped (increased resistance characteristic) n-type silicon material has two base contacts attached to both ends of one surface and an aluminum rod alloyed to the opposite surface. The p-n junction of the device is formed at the boundary of the aluminum rod and the n-type silicon slab. Note in Figure 2.12.a that the aluminum rod is alloyed to the silicon slab at a point closer to the base 2 contact than the base 1 contact and that the base 2 terminal is made positive with respect to the base 1 terminal by VBB volts.

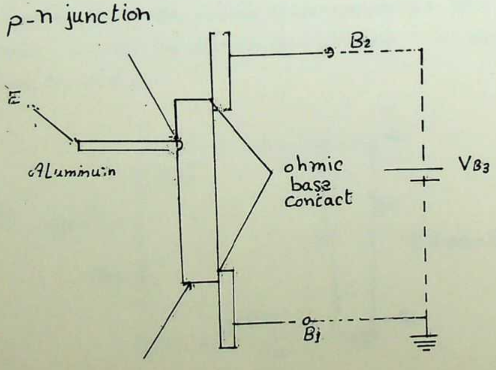


Figure 2.12.a

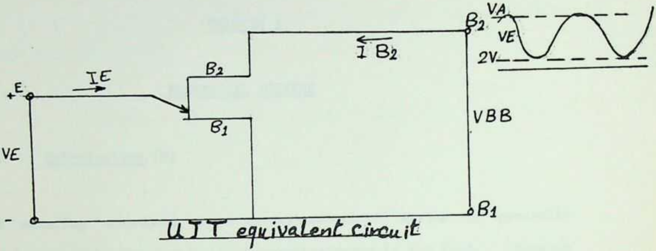


Figure 2.12.b

The symbol for the unijunction transistor is provided in Figure 2.12.b.c The arrowhead is pointing in the direction of conventional current (hole) flow when the device is in the forward based, active or conducting state. The peak point voltage of UJT varies in proportion to the interbase voltage VBB according to the equation Vp = VBB + VD, the parameter is called the intrinsic stand off ratio. The value of lies between 0.51 to 0.82.

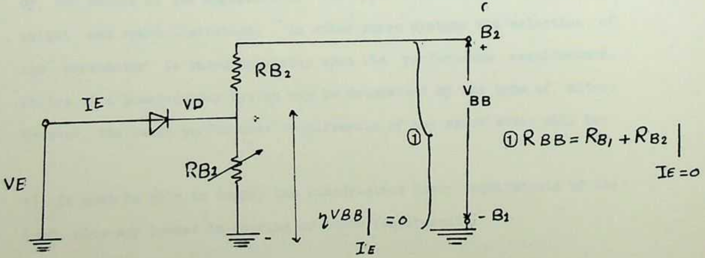


Figure 2.12.c

CHAPTER 3

ELECTRICAL DRIVERS

3.1 Introduction (8)

The motoring component in an automatic-control system is generally considered to be the device which supplies power to the load. However the motoring device is a specific piece of equipment such as an electric, hydraulic, or penumatic motor. Electric motors are generally rotational devices, but can be used to produce linear motions by means of proper linkages. Hydraulic motors and penumatic motors are available in rotational types and in cylindrical types, which produce linear displacements directly.

In many control systems, the physical nature of the servo motor is set by the nature of the application, the type of power available, or by weight and space limitation. In other servo systems the selection of the servomotor is based primarily upon its performance requirements. Choice of a power-supply system may be determined by the type of motor. However, the basic performance requirements of any servo motor will be:

1) It must be able to supply the steady-state power requirements of the load, plus any losses in gearing or other requirements.

2) It must be able to accelerate itself and the connected load in accordance with given acceleration specifications.

3) It must be able to supply the peak power demand during possible transient conditions.

4) It must operate at a given velocity or over a given range of velocities.

Both ac and dc control motors are manufactured. Speed-torque characteristics of both types, to a first approximation, are represented ideal curves shown in Figure 3.1 .

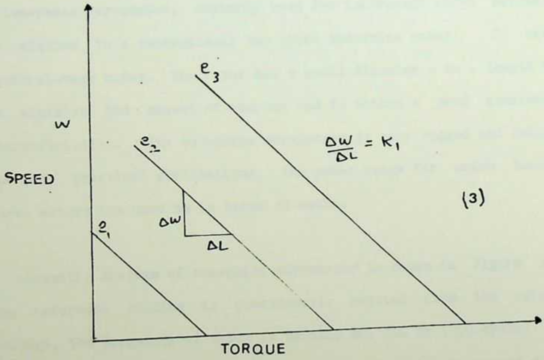


Figure 3.1 Linearized Speed-Torque characteristics for a (3) Control Motor

3.2 Servo Motors (5)

The servomotors which are considered here are classified into

a. Two-phase servo motors

b. DC servo motors which can be divided into

  1. Armature control

  2. Field control

3.2.1 Two-Phase Servo Motors

A two-phase servomotor, commonly used for instrument servo mechanisms, is similar to a conventional two phase induction motor. It uses a squirrel-cage rotor. The rotor has a small diameter - to - length ratio to minimize the moment of inertia and to obtain a good accelerating characteristics. The two-phase servomotor is very rugged and reliable. In many practical applications, the power range for which two-phase servo motors are used is in terms of watts.

A schematic diagram of two-phase servomotor is shown in Figure 3.2.a. The reference winding is continuously excited from the reference voltage, the frequency of which is usually 60, 400 or 1000 cycles. The control winding is driven with the control voltage (a suppressed carrier signal) which is 90 phase-shifted in time with respect to the reference voltage. (The control voltage is of variable magnitude and polarity).

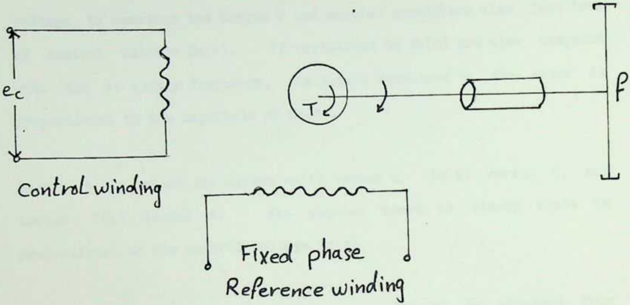


Figure 3.2.a Schematic diagram of a two-phase servometer

The two stator windings are normally excited by a two-phase power supply. If a two-phase power supply is not available. Then the fixed phase winding may be connected to a single phase power supply through a capacitor, which will provide the 90 phase shift. In the two-phase servo motor, the polarity of the control voltage determines the direction of rotation. The instantaneous control voltage ec(t) is of the form

$$ec(t) = Ec(t) \sin wt \text{ for } Ec(t) > 0$$

$$= \backslash Ec(t) \backslash \sin(wt + \pi) \text{ for } Ec(t) < 0$$

This means that a change in the sign of Ec(t) shifts the phase by π radians. Thus, a change in the sign of the control voltage Ec(t) reverse the direction of rotation of the motor. Since the reference voltage is constant the torque T and angular speed $\dot{\theta}$ are also functions of control voltage Ec(t). If variations in Ec(t) are slow compared with the ac supply frequency, the torque developed by the motor is proportional to the magnitude of Ec(t).

Figure 3.2.b shows the curves ec(t) versus t, Ec(t) versus t, and torque T(t) versus t. The angular speed at steady state is proportional to the control voltage Ec(t).

The transfer function of two-phase servo motor may be obtained from torque-speed curves, if they are parallel and equidistant straight lines, generally, the torque-speed curves are parallel for a relatively wide speed range but they are not equidistant.

Figure 3.2.c shows a set of torque-speed curves for various values of control voltages. The torque-speed curve corresponding to zero control voltage passes through the origin.

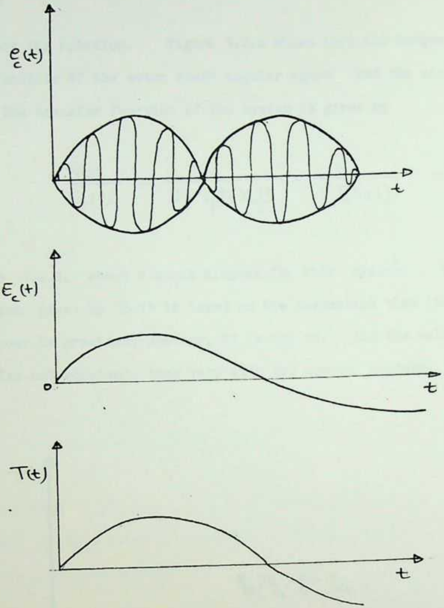


Figure 3.2.b Curves showing ec(t) versus (t)
Ec(t) versus (t) and
T(t) versus t

Since the slope of this curve is normally negative, if the control phase voltage becomes equal to zero, the motor develops that torque necessary to stop the rotation. Figure 3.2.c shows that the torque T generated is a function of the motor shaft angular speed and the control volatge Ec. The transfer function of the system is given by

$$\frac{\theta(s)}{E_c(s)} = \frac{K_c}{JS^2+(f+K_m)S} = \frac{K_m}{s(T_mS+1)} \quad \ldots \text{ 3-1}$$

Figure 3.2.d, shows a block diagram for this system. The transfer function given by "3-1" is based on the assumption that the servomotor is linear in practice, however, it is not so. And the values of Km, Tm are also not constant, they vary with the control voltage.

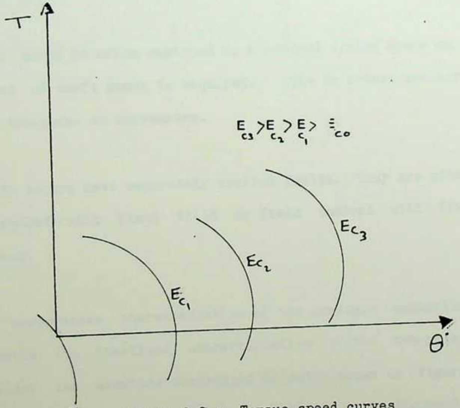


Figure 3.2.c Torque speed curves

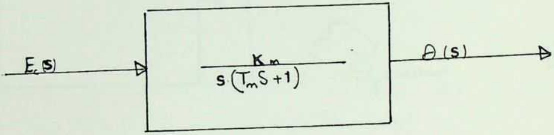


Figure 3.2.d Block diagram of a two-phase servomotor

3.2.2 Armature Controlled dc Motors

A dc motor is often employed in a control system where an appreciable amount of shaft power is required. The dc motors are more efficient than two-phase ac servomotor.

The dc motors have separately excited fields. They are either armature-controlled with fixed field or field control with fixed armature current.

The performance characteristics of the armature controlled dc motor resemble the idealized characteristics of the two-phase ac motor. Consider the armature controlled dc motor shown in Figure 3.3.a the transfer function of this system is obtained as in figure 3.3.b (5)

$$\frac{\theta(s)}{E_a(s)} = \frac{K}{s\left[L_a J s^2 + (L_a f + R_a J) + R_a f + K K_b\right]} \quad \ldots \text{3-2}$$

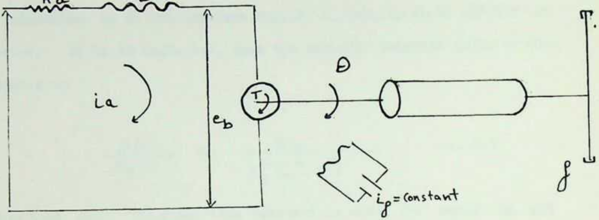


Figure 3.3.a Schematic diagram of an armature Control dc motor.

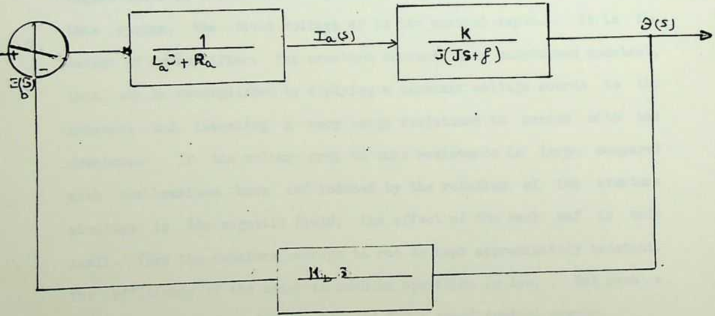


Figure 3.3.b Block Diagram

The inductance La in the armature circuit is usually small and may be neglected. If La is neglected, then the transfer function given by (3-2) reduces to

$$\frac{\theta(s)}{E_a(s)} = \frac{K_m}{s(T_m s+1)} \qquad \ldots 3\text{-}3$$

In equation 3-3, the motor time constant is small for small Ra and smalle J with small J, as the resistance Ra is reduces, the motor time constant approaches zero, and the motor acts as an ideal integrator.

Field-Controlled dc Motor

Figure 3.4.a is a schematic diagram of a field-controlled dc motor. In this system, the field voltage ef is the control input. It is the output of an amplifier. The armature current Ia is maintained constant, this may be accomplished by applying a constant voltage source to the armature and inserting a very large resistance in series with the armature. If the voltage drop in this resistance is large compared with the maximum back emf induced by the rotation of the armature windings in the magnetic field, the effect of the back emf is made small. Then the armature current ia can be kept approximately constant. The efficiency of the motor in such an operation is low. But such a field-controlled dc motor may be used for a speed control system.

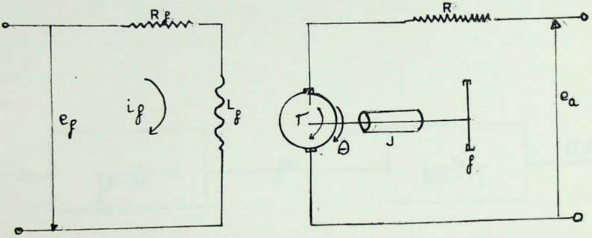


Figure 3.4.a Schematic diagram of a field-controlled dc motor

Note that maintaining a constant armature current ia is more difficult than maintaining a constant field current if, because of the back emf in the armature circuit.

Considering Ef(s) as the input and θ(s) as the output, the block diagram is shown in Figure 3.4.b. From this block diagram the transfer function of this system is obtained as

"5"

$$\frac{\theta(s)}{E_f(s)} = \frac{K_2}{s[L_f s+R_f][Js+f]} = \frac{K}{s[T_f s+1][T_m s+1]} \quad \ldots 3\text{-}4$$

where Km = (k2/R f) = motor gain constant

T_f = Lf/Rf = time constant of field circuit

Tm = J/f = time constant of inertia-friction element

Since the field inductance Lf is not negligible, the transfer function of a field-controlled dc motor is of the third order.

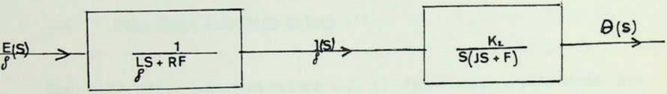


Figure 3.4.b Block Diagram

3.3 Comparison of the Performance of the Armature-Controlled dc Motor with the Field-Controlled dc Motor

An advantage of the field control of a dc motor is that the required amplifier can be simplified of the low power requirement in the field circuit. The requirement of a constant armature current source is, however, a serious disadvantage of field-controlled operations providing a constant current source is much more difficult than providing a constant voltage source. The field controlled operation has a few more disadvantages over the armature controlled operation of the dc motor. In the armature-controlled dc motor, the back emf acts as a damping, this is not the case in the field control, and necessary damping must be provided by the motor and load. Because of the low efficiency of field-controlled operations, the heat generated in the armature may cause a problem.

The time constants of the field-controlled dc motor are generally large compared with the time constant of a comparable armature- controlled motor. In making a comparison of time constants between field-controlled operations and armature operations, the time constant of the power amplifier is considered.

3.4 Poly Phase Induction Motors (11)

The poly phase induction motors used in industrial applications are practically without exception three phase. In conventional induction motors the stator windings are connected to the source and the rotor winding is short-circuited for many applications, or it may be closed through external resistance - wound-round roter -. The poly phase induction motor, however requires no means for its excitation other than the ac line. It is economical to build. The wound-rotor motor type, lends itself to a fair degree of speed control. The induction motor runs below synchronous speed and is known as an asynchronous machine. As the load increases the motor speed decreases. The full-load speed of poly-phase induction motor is, in most cases within 90% of synchronous speed. Since the induction motor has no inherent means for producing its excitation, it requires reactive power and draws a lagging current. While the power factor at rated load is generally above 80%, it is low at light loads, which has the disadvantages of incurring a less favorable price rate for electric power when the power factor (current lagging) falls below a certain value in commercial and industrial insulation.. The stator windings of poly phase induction motors are fundamentally the same as the stator windings of poly phase synchronous machines. However, poly phase induction motor fall into two general catagories, depending on the kind of rotor used - the wound-rotor and the squirrel cage rotor. The stator iron as well as the rotor iron is laminated and slotted to contain the windings. The wound-rotor has three phase winding similar to that in the stator and is wound for the same number of poles as the stator winding. The rotor winding terminals are connected to slip rings which are mounted on the rotor shaft. Brushes ride on the slip rings of the wound-rotor motor. At starting, they are connected externally to three equal resistances one in each phase, connected in Y that are short-circuited simultaneously in one or more steps as the motor comes up to speed. Instead of containing a winding, the slots in the squirrel-cage rotor occupied by bars of copper or of aluminum, known as rotor bars, short-circuited by rings of the same material as the rotor bars. The rotating magnetic field produced by the poly phase voltages applied to the stator winding induces currents in the squirrel-cage rotor circuit that develop the same number of rotor poles as stator poles. The rotor poles react upon the stator flux, thus developing torque in the same direction of rotation as that of the stator flux. As long as the rotor rotates below or above synchronous speed, there is relative motion between it and the rotating stator flux, and voltage is induced in the rotor circuits. At synchronous speed there is no relative motion between rotating field and the rotor, so the induced voltage in the rotor = zero. At this case the developed torque equal to zero.

3.4.1 Induction Motor Slip

Suppose that the rotor circuit is open and that the rotor is made to rotate at a speed n r.p.m. by some external means in the direction of rotating flux φ_M, if ns is the synchronous speed in r.p.m. (i.e. the rotational speed of φ_M), the slip is defined by

$$S = \frac{n_s - n}{n_s} \qquad \ldots \text{3-5}$$

when the rotor is rotating at a slip s; the speed of the stator flux relative to the rotor is no longer equals the synchronous speed but is the slip speed sns. The rotor frequency must therefore be

$$f_r = s f_s \qquad \ldots \text{3-6}$$

3.4.2 Equivalent Circuit of the Polyphase Induction Motor

At stand still, S = 1, the developed mechanical power is zero and all the real power transferred across the air gap from the stator to rotor is converted to heat. At zero slip the rotor represents an open circuit, because the induced voltage in the rotor circuit is = zero, so the rotor current equals zero, s = 0. r2/s is infinite - when the effects of harmonics are neglected whether the rotor is actually open circuited or whether it is short circuited and running at zero slip, part of the voltage applied to the stator winding, E2, produces the mutual flux that requires an exciting current. The magnetizing component of the current is given by Ie = $\frac{E_2}{jx_m}$. The core loss component of the exciting current or iron loss current Ife. The exciting current

IM is the sum of these components.

Im = Ie + Ife.

Figure 3.5.a shows the equivalent circuit and Figure 3.5.b the approximate equivalent circuit of the poly phase induction motor. In both circuits the noninductive resistance $\left(\frac{1-S}{S}\right)r_2$ represents the mechanical load.

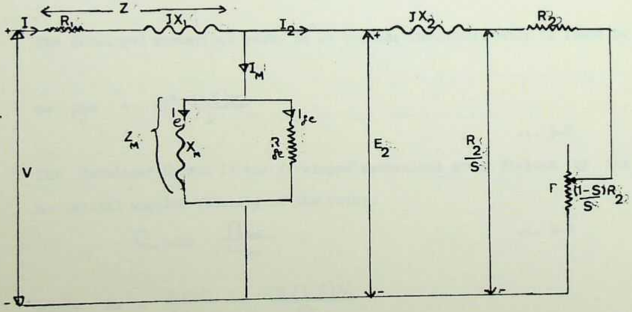
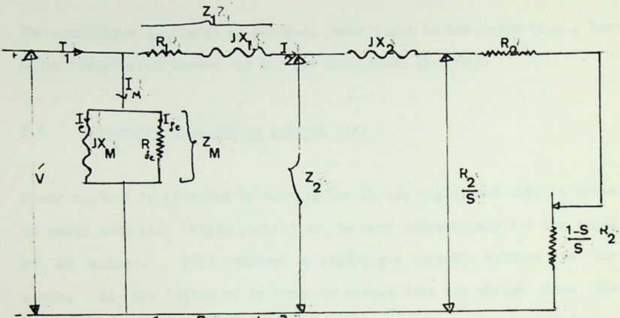


Figure 3.5.a Equivalent Circuit



$V' = V[1 - (X_1/X_M)]$

Figure 3.5.b Approximate Equivalent Circuit

3.4.3 Mechanical Power and Torque

The developed mechanical power in an m-phase induction motor is found to be

$$p_{em} = m I_2^2 \frac{(1-S) r_2}{S} \qquad \dots 3\text{-}7$$

The developed torque is the developed mechanical power divided by the mechanical angular velocity of the rotor.

$$T_{em} = \frac{P_{em}}{W_m} \qquad \dots 3\text{-}8$$

where $W_m = \frac{2\pi N}{60} = \frac{2\pi(1-S)N_s}{60}$

torque is expressed in terms of slip and rotor current

$$T_{em} = \frac{m\, 60\, I_2^2 r_2}{2\pi N_s} \qquad \dots 3\text{-}9$$

The quantity m I_2^2 (r2/S) is the real power input to the rotor (i.e., the power transferred across the air gap into rotor winding).

3.5 Induction Motor-Speed Control (12)

Power control is obtained by varying the firing angle, and this is knows as phase control. Phase control can be very conveniently for the speed of AC motors. This achieved by applying a variable voltage to the motor. As the speed of synchronous motors does not change when the input voltage is varied. This method is useful only for commutator or induction motors. Figure 3.6.a shows the schematic arrangement for the speed control of three-phase induction motors. By controlling the firing angle, the RMS input voltage can be changed.

Two SCRS connected in antiparallel are prefered to one triac since the motor is an inductive load. The input current wave form is shown in Figure 3.7.a . The motor winding will experience open-circuits in any half cycle if the angle of conducting β is less than π. During this period, the rotor currents will induce a voltage in the stator phase winding.

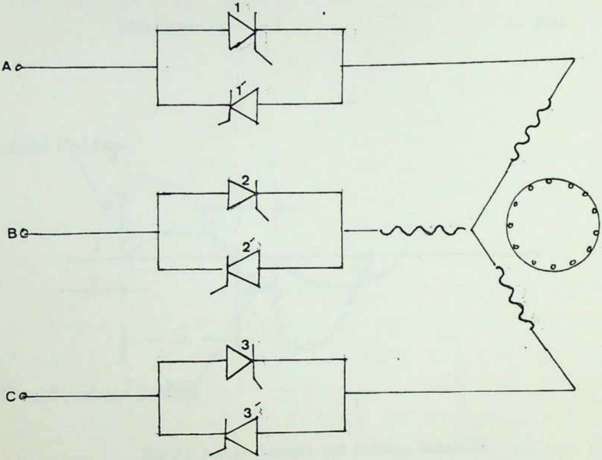


Figure 3.6.a Phase control of an AC motor

As the firing angle increases, the RMS value of this voltage decreases. The characteristics of an induction motor with variable applied voltage are shown in Figure 3.7.b. This method of control is very simple and economical. It provides a wide range of speed control. The points indicated by circles on Figure 3.7.b show several speeds that are possible by varying the voltage. If the load torque is constant, the speed deviation is very much limited as shown by curve 2. Another drawback of this method of control is that efficiency falls off with decrease in speed. For an induction motor, the power output is given by

mechanical power output = power input to rotor x (1 - S) therefore

$$\text{efficiency} = 1 - S \qquad \ldots\ 3\text{-}10$$

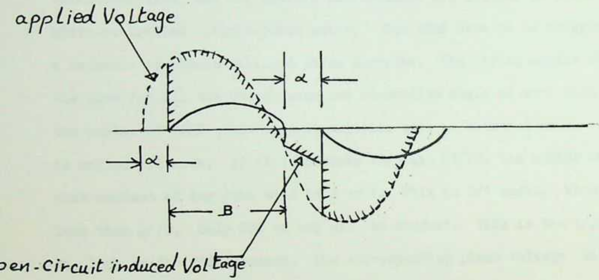


Figure 3.7.a Current and Voltage Waveform

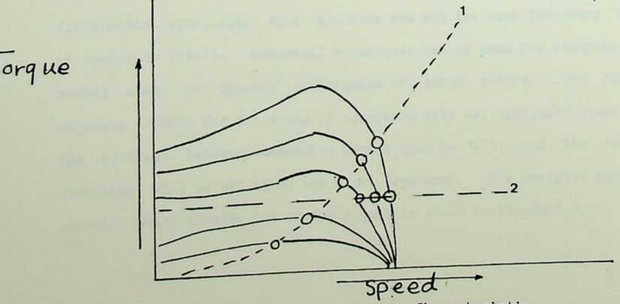


Figure 3.7.b Speed-Torque Characteristic

3.5.1 Phase Control of three-phase Induction Motors

The schematic diagram of phase-control circuit for controlling the speed of a three-phase induction motor is in Figure 3.6.a. The speed torque characteristics and the overall perrformance are similar to those for a phase-controlled single-phase motor. The SCRS have to be triggered in a sequence to obtain balanced phase currents. The firing angles must be the same for all the phases when the conduction angle is more than $2\frac{\pi}{3}$, the number of SCRS conducting at any time will be either 3 or 2. This is called 3/2 mode, if it is between $\pi/3$ and $2\pi/3$, the number of SCRS that conduct at any time will be 2 or 1. This is 2/1 mode.. When it is less than $\pi/3$, only SCR or non will be conduct. This is the 1/0 mode. As long as the SCRS conduct, the corresponding phase voltage will be known. When the phase gets open-circuit the corresponding voltage across the phase will be the induced voltage due to current flowing in the other stator and rotor windings. The procedure for obtaining the steady-state current waveforms requires the solution of the motor differential equations; such equations are not the same for every mode of operation (12-1). Numerical techniques can be used for studying the steady state or dynamic performance of three motors. The firing sequence of SCRS for all modes of operation will be, 1,3',2,1' 3 and 2'. The interval between successive firing will be $\pi/3$, and the firing frequency will be six times the input frequency. The designed control circuit, which provide the firing signal is shown in figure 3.8.

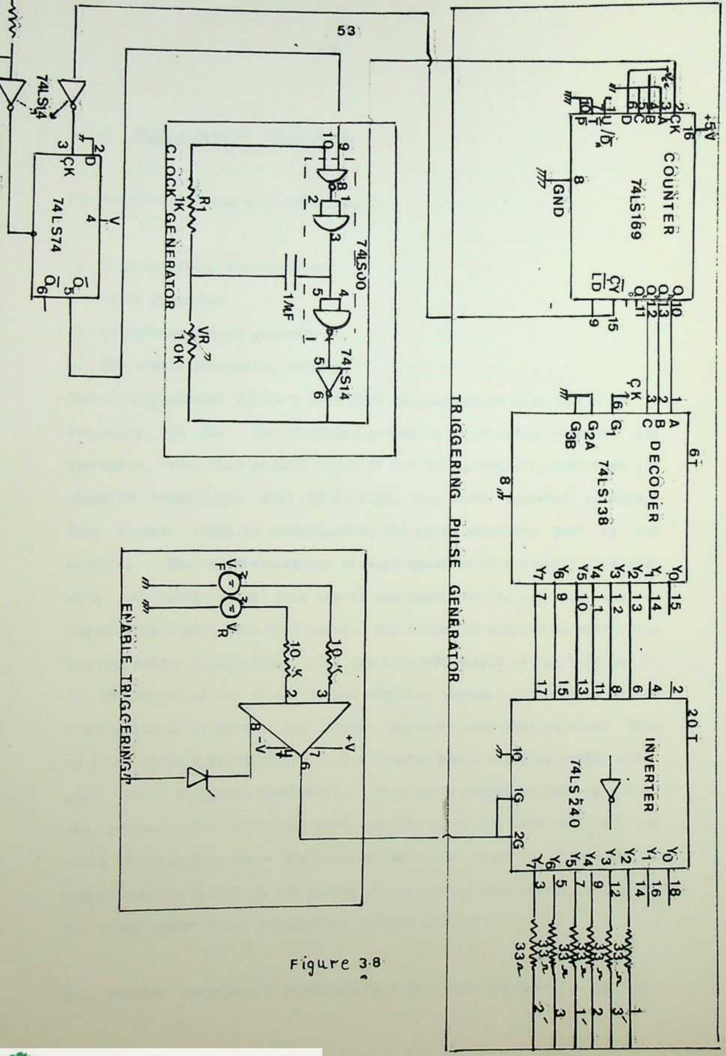

COUNTER
74LS169
+5V
16
CK
U/D
GND
8
CY
LD
DECODER
74LS138
G1
G2A
G3B
A
B
C
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
INVERTER
74LS240
1G
2G
20T
33Ω
TRIGGERING PULSE GENERATOR
74LS00
74LS14
1µF
R1
1K
VR
10K
CLOCK GENERATOR
ENABLE TRIGGERING
VF
VR
10K
10K
+V
-V
74LS74
CK
D
Q5
Q6
74LS14

Figure 3.8

3.5.2 Firing Circuit Description

The circuit consists of 4 sections,

1) line frequency synchronizer
2) clock generator
3) triggering pulses generator
4) the enable triggering section.

The clock generator consists of a free running square wave generator of frequency 300 Hz. The clock has an enable input which controls its operation, when this control input is low the clocking is inhibited (no clocking occurs),and when it is high, the clock operates normally. This control input is controlled by the synchronization part of the circuit. The synchronization circuit consists of a schmitt inverter with 5.0 volts (peak) from one of the phases as its i/p when the ac signal goes higher than 0.45 volts, the output of schmitt inverter goes low and sets a D flip-flop. The non inverted output of the D-FF (Q) is fed to control of the clock so that clocking begins. The clock drives a universal 4-bit counter (74 LS/169), which is connected to count from 10 to 15 (A to F hexadecimal). The counter has a carry up output which goes low as the count reaches 15. This carry output is used to reload the counter with 10 for the next cycle to reset the D-FF and so the clock is inhibited, while the counter remains at count 15. When the ac signal reaches 0.45 V on the rising phases later, the D-FF is set again, the clock operates and reloads the counter with 10.

The counter outputs are connected to 3 to 8 line decoder (74 LS 138) which generates a sequence of low pulses on the outputs $\overline{Y2}$ to $\overline{Y7}$ sequantially with each clock cycle. These low pulses are inverted by an octal inverter (74 LS 240) to drive the six SCR's connected to the 3-phase - 33Ω resistors are connected to the actual inverter outputs to minimize the negative overshoot on the gates of the SCR's.

Figure 3.9 shows the various signals of the circuit. The control signal of the firing circuit is provided by the last part of the circuit. This part consists of a comparator which compares between the voltages of two identical solar cells fitted on the tracking table. One cell serves as a reference signal and the other as a feedback signal. The reference cell is connecting to the non-inverting input of the comparator and the feedback one is connected to the inverting input. The difference of the quantity of sun rays falling on these two cells creates different voltage on them. If the voltage on the reference cell is greater than that on the feedback one, the comparator saturates and produces about on its output. If the voltage on the reference is less than the feedback then the output of the comparator will be about (0). This output is used to control the firing of the SCR's. It is connected to thc gate inputs of the actual buffer inverter. So that when the comparators output is high (+5) the firing signals are blocked and when it is low (0), the firing signals are enabled to fire the SCR's.

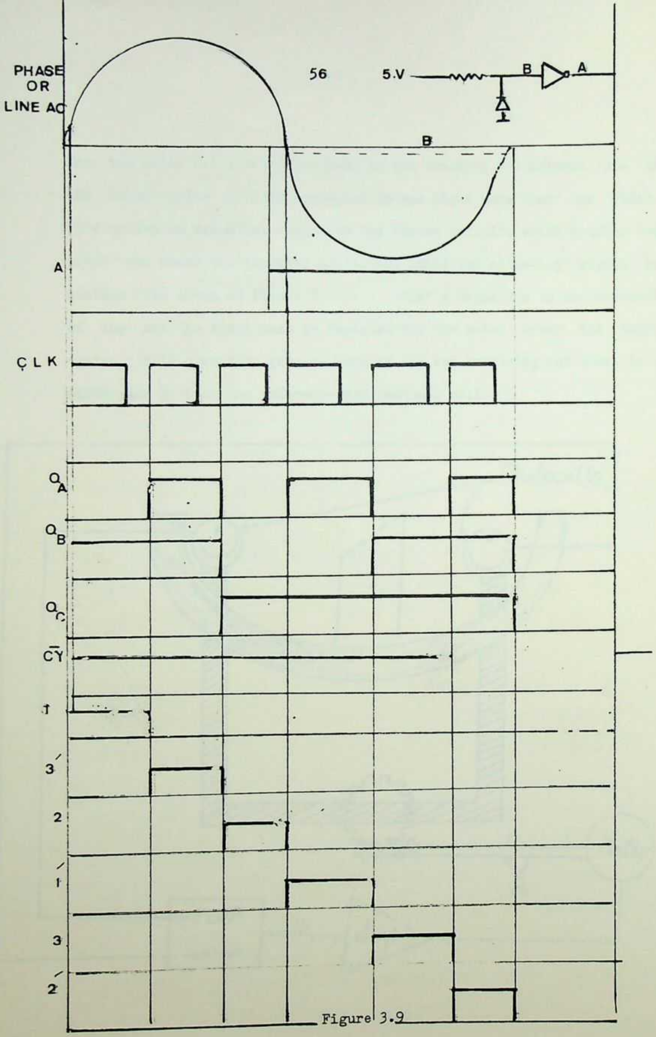


Figure 3.9

The two solar cells are positioned on the tracking collectors. One of the solar cells will be subjected to sun light more than the other.. This causes an actuation signal to the firing circuit, which rotates the motor and hence the tracking collectors until the actuating signal be minimum (as shown at Figure 3.10). After a while due to the movement of the sun the first case is repeated and the motor moves the table again. This operation goes as long as the sun is rising and there is a difference between the reference and feedback cells.

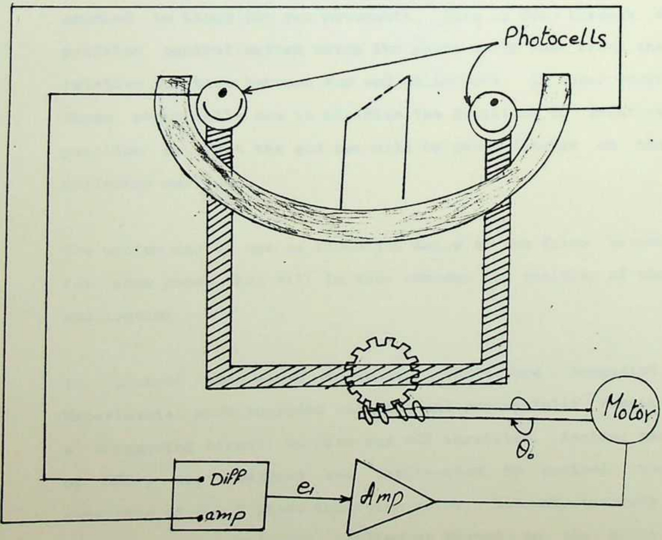


Figure 3.10

CONCLUSION

The problem of energy is subjected to supply and demand. Every year there is an increased demand for energy to satisfy the needs of growing industry, household needs, traffic and other electrical categories.

Sun is an unlimited source of energy. So, utilizing this energy might solve a lot of problems facing us every day. To collect a large amount of light energy, collectors should be mounted to track the sun movements. This is done through a position control system using two photo cells that track the relative position between sun and collectors. In other words these photo cells are to minimize the deviation in relative position so that the sun ray will be perpendicular on the collector surface.

The choice was to use an induction motor as the drive system for some gears that will in turn correct the position of the sun tracker.

To control the motor movement, SCR's are suggested. Experimental work included building and successfully testing a triggering circuit to fire one SCR thyristor. Another set of SCR's was designed and implemented to control the operation of the 3-phase induction motor, but unfortunately, it was not practically applied or tested on the motor, although it was theoritically proved to operate well.

In fact, a lot of tests should be carried out to achieve a proper performance and arrive at an efficient and relatively economical system.

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12. An Introduction to Thyristors and Their Applications, by M. Ramamoorty

12.1 From page 94 section 66.1

Figure 6.13 shows current wave forms for phase controlled three phase induction motor.