CHAPTER - 5

ELECTRICAL EQUIPMENT

5.1 POWER SUPPLY

In Sri Lanka the normal power supply is 400V 3 phase four wire. Frequency of the supply is 50 Hz. However the transmission of power supply is done at high voltage (Eg: 132,000V) to minimise transmission losses. High voltage is achieved by step-up transformers and is later stepped down for utilisation.

5.2 POWER AND POWER FACTOR

Voltage and current are in phase in resistive loads, in inductive loads (Eg: Motor) the current lags the voltage and in capacitive loads current leads the voltage.

When the alternating current in a circuit is $I \angle^{\alpha}$ and the Voltage is $V \angle^{\beta}$, the power is equal to the product of the effective values of V and I multiplied by the cosine of the phase angle between them.

Power P = $\sqrt{3}$ VI sin $(\beta - \alpha)$ Watts

The reactive Power (Volt-amperes) is given by

Q = $\sqrt{3}$ VI sin $(\beta - \alpha)$ Vars

When α is less than β the current is lagging and the factor Cos $(\alpha - \beta)$ which is the cosine of the phase angle between V and I is called the Power factor.

That is Power = $\sqrt{3}$ VI Cos θ

Where θ is the phase angle between V and I

Cos θ = Power Factor

When the power factor is low, useful power becomes low, hence power factor should be corrected.

For inductive loads capacitors are connected parallel with the supply mains to improve the factor.

Some Electricity boards penalise their consumers for having a bad power factor by charging according to the KVA demand. Improving the power factor to 0.95 is the general practice from economical point of view.

5.3 STARTERS

Induction motors of small out puts can be designed to start at full supply line voltage. This method is called the direct on line method or DOL. However if larger motors are directly switched on to the mains they will draw a very high initial starting current 4 to 5 times the full load current and this will affect the voltage regulation of the supply system and is also harmful to the motor. Therefore to reduce this starting current different starting methods are adopted. DOL method is recommended up to 5 kW. However this figure can vary with the reliability of the power supply.

5.3.1 AUTO TRANSFORMER STARTER

This type is suitable for both Star or Delta connected motors. Initially only a part of the supply voltage is applied to the motor through the auto-transformer winding. This reduces the starting torque. Full supply voltage is applied only after the motor has gathered the full speed. This is done by means of contactors. The korndorffer starter is a modified auto-transformer starter and is arranged in such a way that the progression from start to the run position is achieved without removing the electricity supply from the motor. This method is recommended for motors above 30 kW other than bore hole pumping sets.

5.3.2 STAR-DELTA STARTER

In this type of starters for a 400V motor, only 230 V is initially applied to a phase windings of the motor (Star Position). When the motor gathers the speed connections are moved to Delta position by increasing the voltage per phase to 400V. This can be done by manually or automatically connected contactors. This method is recommended for motors between 5 kW and 30 kW. However depending on application these circuits can change. Star-delta starters are not used for bore hole type submersible motors.

5.3.3 ROTOR RESISTANCE STARTING

This method of starting is applied to slip Ring or Wound Rotor Induction motors. This method involves the introduction of an external resistance to the rotor circuit. Initially the resistance applied to the rotor will be at its maximum and is reduced gradually and slip rings are short circuited after achieving the maximum speed. This type of motor and its starter is more expensive than other types, but gives the least starting currents. However maintenance of this type of motors is more troublesome than the squirrel cage type.

5.4 DRIVERS

There are two types of drivers namely ,

* Direct Current or DC Drivers
* Alternating Current or AC Drivers.

Only AC drivers are dealt with in this chapter.

5.4.1. SINGLE PHASE INDUCTION MOTORS

These type of motors are manufactured for small driving loads. The characteristics of single phase induction motors are similar to that of three phase induction motors. The only difference is single phase motors are not self starting. However by modifying the single phase induction. self starting tecthnics can be introduced. This modification is achieved by splitting the phase.

Synchronous speed N of the single phase induction motor is given by the equation.

$N = 120 \times f/P$

Where.

f = Supply frequency.

P = Number of poles.

The method of starting of this type is Direct on Line (DOL).

The other motors under single phase induction motors are

* Permanent Capacitor Start Motor : Eg. For Table fans and ceiling fans.

* Capacitor start Capacitor Run motor : Out of the two capacitors one capacitor is taken out after attaining the speed. The other remains in the circuit.

* Capacitor start motor : In this type capacitor is disconnected by means of centrifugal switch after attaining the speed.

5.4.2 THREE PHASE SQUIRREL CAGE INDUCTION MOTOR

These type of motors are widely used in water industry drive pumps. The rotor of this type of motor is constructed with Aluminium or Copper bars embedded in the rotor slots and the ends are short circuited by two end rings. Double cage construction is popular because its starting torque is better than the single cage type.

5.4.3. THREE PHASE WOUND ROTOR (SLIP RING) INDUCTION MOTOR

In this type of motors, the rotor is wound similar to the starter windings. The rotor windings are generally star connected and their ends are brought out via slip rings and brushes to a starting Rheostat. In this type the starting torque is improved by adding resistors to the rotor circuit and after starting the resistors are disconnected gradually and short circuited.

5.5 MOTOR SPEED

Synchronous speed is given by the equation,

$N = 120\ f/P$

Where,

f = Supply frequency

P = Number of Poles

Number of poles	2	4	6	8	10
Synchronous Speed (RPM)	3000	1500	1000	750	500

Table 5.1 - Motor Speeds

5.6 TORQUE OF MOTOR

The Motor torque T is given by the equation

Torque $T = S \times E_r^2 \times R / [R^2 + (SX_r)^2]$

Where,

E_r = Rotor Voltage

R = Rotor Resistance

X_r = Rotor Reactance

S = Slip $= (N - N_r)/N$ OR $N_r = (1-S)N$

N_r = Rotor Speed

N = Speed of Flux

$\therefore$ If E_r (or V) is reduced Torque is reduced and when $R = SX_r$ Torque is maximum. On start up S is large, therefore R should be large. This is the reason for introducing resistance in the rotor of a slip ring motor.

The figure overleaf shows how the motor torque varies with the slip.

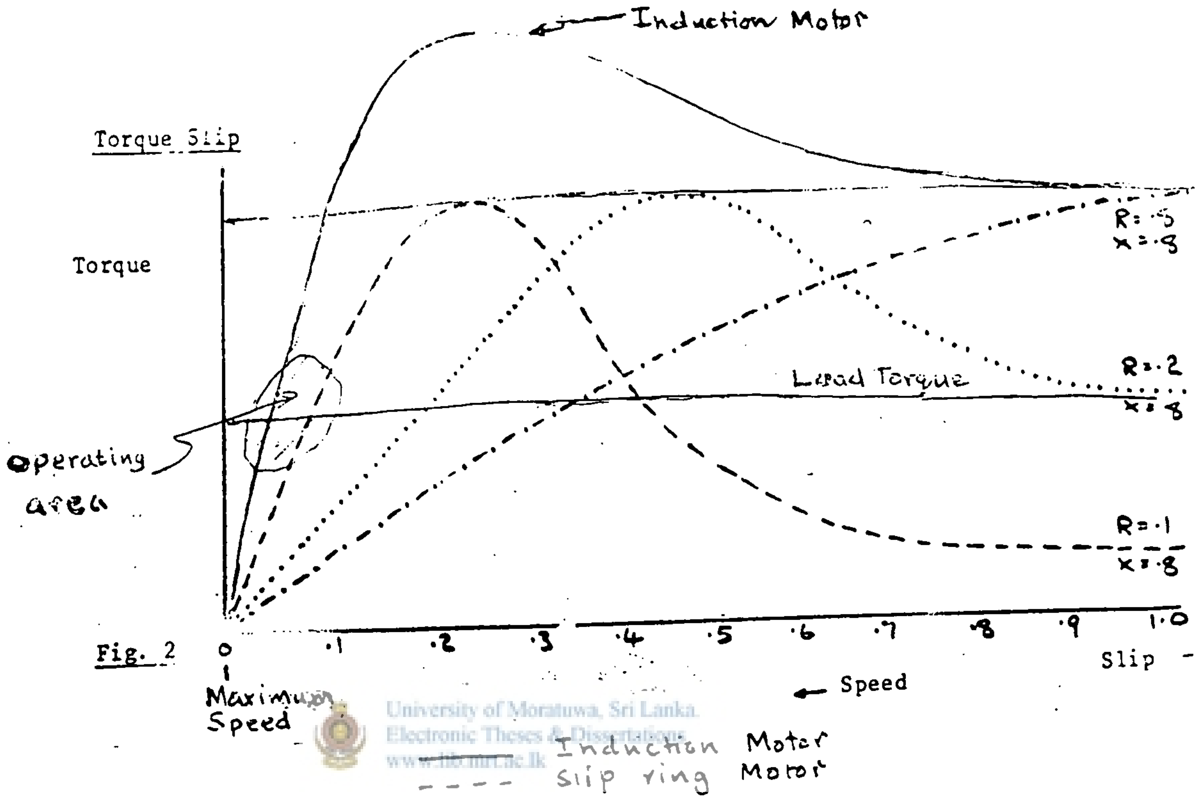
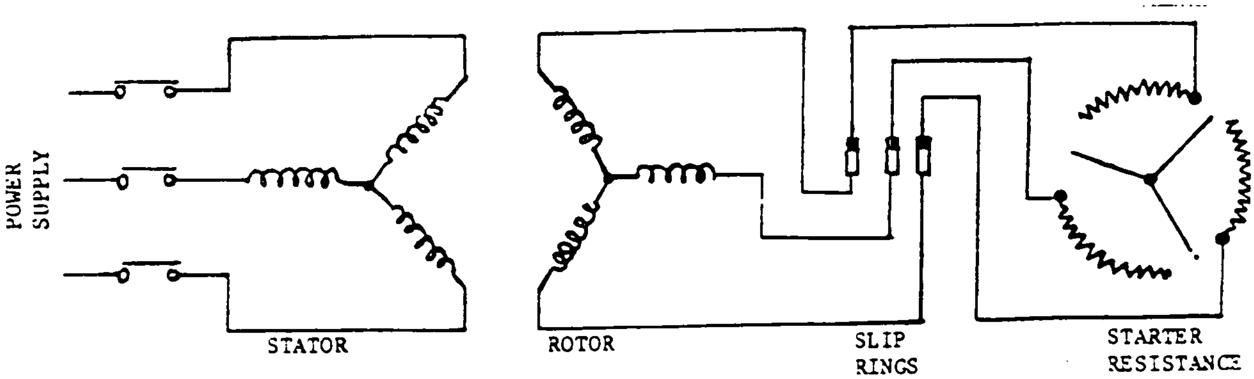


Fig. 2



(Source: Water Industry Training Association UK)

Note : $N_r = (1\text{-}S\ )N$

If the slip varied then the rotor speed will vary. Therefore from the above figure it can be seen that by varying the rotor resistance the speed can be varied. The disadvantages of this method are

(i). Heat lost in regulating the resistance.

(ii) The dependence of the speed variation on the load torque.

5.7 RATINGS AND SELECTION OF MOTORS

5.7.1 RATING

Electric machines are rated in terms of their output capacities. Motors are rated in shaft power (kW) at rated speed, full load current, and applied voltage subjected to the condition that the temperature rise is not excessive and that the machine will not overheat.

5.7.2 NAME PLATE DATA

Not all motors show of the possible information that can be shown on a name plate. In some instances. data not shown on a name plate can be obtained from manufacturer's publications. Any of the following information can appear on the motor name plate.

* **Motor Type.**
* **Frame size.**
* **Enclosure.**
* **Number of Phases or (DC).**
* **Out put Power (kW).**
* **Frequency.**
* **Rated speed.**
* **Voltage rating.**
* **Current rating.**

* **Allowable temperature rise.**
* **Duty cycle.**
* **Class of Insulation.**
* **Thermal protection.**
* **Manufacturer's Model Number.**
* **Manufacturer's Serial Number.**

5.7.3 TEMPERATURE RISE AND AMBIENT TEMPERATURE STANDARD

All machinery insulation is tested on a basis of a temperature rise above 40^0C. Motors rated on this basis of a 40^0C ambient temperature should be capable of continuous operation at rated load without damage to the insulation provided.

* The ambient temperature does not exceed 40^0C

* The altitude does not exceed 1 Km.
* Proper ventilation
* Applied voltage does not vary ± 10% the rated value

Most 40^0C rise motors are capable of a continuous 115% overload when operated at 40^0C ambient temperature.

5.7.4 EFFECT OF TEMPERATURE ON LIFE OF MOTORS

Empirical studies show that for every 10^0C increase in continuous motor operating temperature over the recommended hottest - spot temperature limit which depends on the class of insulation. the winding life is cut in half. The table below gives details for different classes of insulation.

Class of insulation	Allowable temperature rise for 40 ^{0}C standard temperature (^{0}C)	Hottest spot maximum limiting temperature (^{0}C)
A	50	90
O	65	105
B	90	130
F	115	155
H	140	180
N	160	200
R	180	220
S	200	240

Table 5.2 Class of insulation vs Temperature rise

The converse above statement is for every 10 ^{0}C of reduction in motor operating temperature below the recommended limit. the winding life is doubled. Hence the life of a machine is only good as its insulation.

The empirical exponential relation to describe above can be put in the form as given below:

(Source : Kosow 1992).

E or R Factor = $2^{\Delta T/10^\circ}$

Where.

E = Extension of life of motor

R = Reduction of life of motor

An average motor life (of a 40°C ambient temperature motor operating continuously within its maximum limiting temperature) may be assumed to be 10 years.

EXAMPLE

A motor with class 'A' insulation is operating continuously at its rated load at an elevated ambient temperature such that its embedded detectors record a temperature of 125°C calculate the life reduction factor and reduced life expectancy or the motor (Assume a standard life of 10 years).

$$R = 2^{\Delta T/10°}$$

$$= 2^{(125 - 105)/10}$$

$$= 4$$

===

Life = Original Life/R

= 10/4

= 2.5 Years

=======

5.8 FRAME SIZE vs SPEED AND POWER RATING

In general, we can say that for the same kW rating, as the rated speed of a motor is increased, the frame size is decreased. In other words, high speed motors of the same power rating are always smaller than low speed motors. Further, at the same speed, the larger frame size can tolerate a higher current and kW out-put without excessive overheating and final temperature rise.

5.9 TYPE OF ENCLOSURES

There are different types of motor enclosures. Both cost and physical size for totally enclosed motors are higher than that of open motors of the same power rating, duty cycle. Correct enclosures must be selected depending on the application. Different types of enclosures are indicated below:

5.9.1. Open Enclosure

An enclosure having a ventilating opening that permit passage of external cooling air over and around the winding of the machine. Motors with this type of enclosures can be used only where the atmosphere and surrounding are free from contamination and the surrounding air is completely dry.

5.9.2. Totally enclosed enclosure

This enclosure prevents free exchange of air between the inside and outside of the enclosure but not sufficiently enclosed to be called air tight.

5.9.3. Drip Proof

This enclosure has ventilating openings in such a way that drops of liquid or solids falling onto it are prevented from entering inside. Motors with this enclosure are used in where there is high humidity in the atmosphere.

5.9.4. Splash Proof

In this type the ventilating ducts are provided in such a way that jets of water falling on it would not enter inside. This type is used in pump houses where water can splash on machines.

5.9.5. Weather - Protected Enclosure

This type of enclosure is so designed as to minimise the effect of climatic conditions on it.

5.9.6. Explosion Proof

The enclosure of this type is designed to withstand explosions which may occur due to inflammable gas surroundings.

5.9.7. Water Proof

The enclosure is totally enclosed to exclude water applied in the form of stream from a hose.

5.10 FACTORS AFFECTING MOTOR SELECTION

Factors that should be considered in motor selection can be summerised as follows:

* **Power supply.**
* **Out Put Power.**
* **Speed.**
* **Duty Cycle.**
* **Ambient Temperature.**
* **Allowable Temperature rise.**
* **Type of Enclosure.**
* **Type of Insulation.**

The author wishes to point out that energy efficient Motors, Transformers and distribution boards are available and the operating cost gains will out weigh the extra capital cost on them. Annexes 5.1 and 5.2 give the performance of ordinary and energy efficient motors.

5.11 SYSTEM FAULTS

System faults can cause damages to electric motors. Three common faults are;

* **Phase failure (when one phase is dead).**
* **Unbalanced voltage.**
* **Low voltage.**

These faults generally bring about decrease in motor torque, efficiency and increase in noise and slip and over heating.

If protections are not provided, these faults can cause the motor windings to burn.

5.12 MOTOR PROTECTIONS

* **Thermal overload.**

A temperature sensitive device, usually a bi-metal strip bends when heated, opens a contact and trips the motor out.

* **Magnetic over load.**

The load current passes through a coil, coil produces a magnetic effect to pull an iron core attached to a piston far enough to unlatch a contact which stops the motors.

* **Earth Leakage.**

A relay is connected so that it detects any currents flowing to the earth and opens the circuit breaker.

* **Thermistors.**

A set of six member thermistors in series are embedded into each phase of the stator windings, they are temperature-dependent semi conductor devices, which, used in conjunction with a suitable control device, protect electric motors against accidental burn-out. Thermistors detect excessive temperatures before damage can occur to motor windings.

They provide protection against;

- Excessive overload.
- Stalled rotor conditions.
- Phase failure.
- Excessive ambient / motor temperature.
- Overheating due to supply faults.
- Operator abuse-excessive starting/stopping.

5.13 PROTECTION OF ELECTRICAL EQUIPMENT FROM CONTACT WITH PERSONS, FOREIGN BODIES AND WATER

Different classes of protections have been defined to ensure:

- * The protection of persons from contact with electrically live or moving parts inside the housing and the protection of the equipment from the entry of solid foreign bodies.
- * Protection of the equipment from entry of water.

Different classes are designated by the letters IP (International Protection) followed by two code digits

First Number **Degree of Protection** **against Contact and Foreign Bodies**	**Second Number** **Degree of Protection against water**
0 No Protection	0. No Protection.
1. Against large foreign bodies	1. Against vertically falling water drops
2. Against medium sized foreign bodies	2. Against obliquely falling water drops
3. Against small bodies	3. Against Splashed water
4. Against granular foreign bodies	4. Against water spray
5. Against deposited dust	5. Against water jets
6. Against entry of dust	6. Against hosing down
	7. Against Temporary immersion
	8. Against submersion

Eg. <u>I P</u> <u>4</u> <u>3</u> (Source : SIHI Manual 1988).

For electrical machines, additional letters are given as required.

R - For machines, with conduit connections

W - For machines with weather Protection

S - For machines which are tested for protection from water entry when they are at rest.

M - For machines which are tested for protection from water entry with the machine running

The letters R and W are placed between IP and two code digits.

The letters S and M are placed behind two code digits.