Lecture Note

Principal of electrical machinery and optimization of electrical power

SuthipongThanasansakorn

Southeast Asia Fishery Development Center, Training Department Thailand

June 2010

Part 1

Direct current generator

By

Suthipong Thanasansakorn

1/6/2010

Southeast Asia Fishery development center
Training Department
Thailand

DC GENERATOR

The direct current (DC) generator (Dynamo) is only used for special application or local power generation. The limited of implementation is weaken on commutation required to rectify the internal generated AC voltage to DC voltage; thereby the operating characteristics of DC generators are still importance, because most concept can be applied to all others electrical machine.

We can classify the generator machine into two parts.

1. The stationary part generally called “stator”.
2. The rotating part usually called “rotor” or the armature referred to a DC machine.

1. Field winding connection

The four brushes ride on commutator. The positive brushes are connecting to terminal A_1 and negative brushes are connecting to A_2 of the machine the brush are positioned approximately midway under poles.

The four-excitation or field poles are usually join to produced a magnetic path in series and their ends to terminal F_1 and F_2 They are connected such that they produced north and south poles

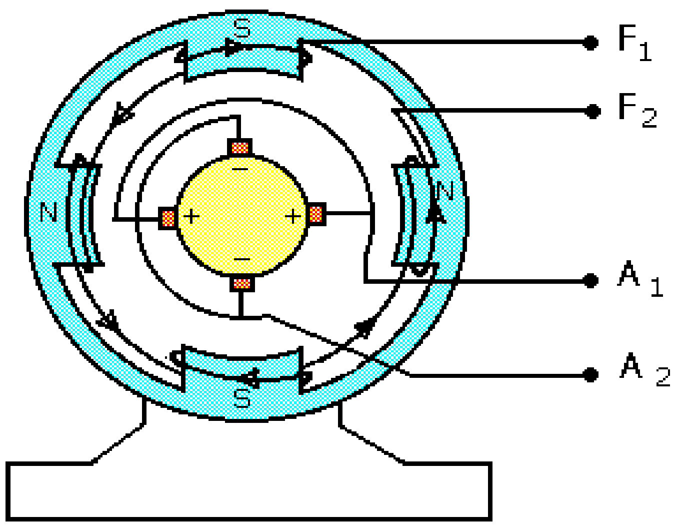


Fig. 1 The general arrangement of brushes and field winding of four-pole DC generator

2. Type of DC generator is characterized by the manner in which field excitation is provided. In general the method employed to connect field and armature winding has classify into two groups.

2.1 Separately excited generators. These kind of generators has provided field exciter terminals which are external DC voltage source is supplies to produce separately magnetic field winding (shunt field) for magnetize of the generator as illustrated in figure 2 as below.

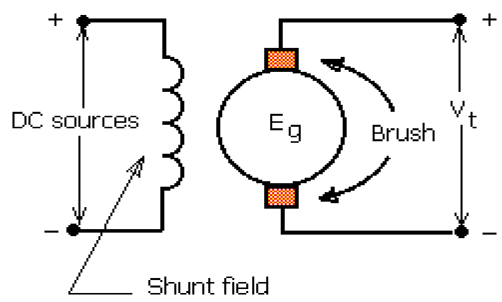


Fig. 2 Separately excited generators.

2.2 Self excited field generators. This type of generator has produced a magnetic field by itself without DC sources from an external. The electromotive force that produced by generator at armature winding is supply to a field winding (shunt field) instead of DC source from outside of the generator. Therefore, field winding is necessary connected to the armature winding. They may be further classified as

a) Shunt generator.

This generator, shunt field winding and armature winding are connected in parallel through commutator and carbon brush as illustrated in the figure 3

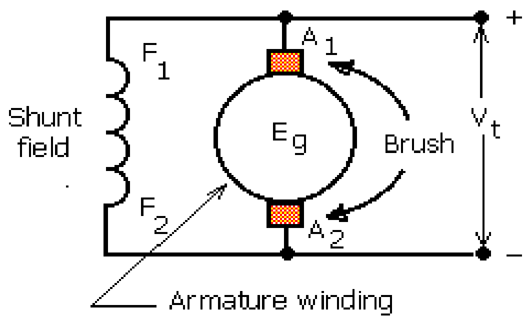
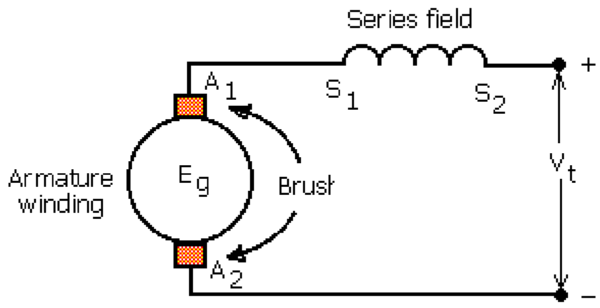


Fig. 3 Shunt generator

b) Series generator

The field winding and armature winding is connected in series. There is different from shunt motor due to field winding is directly connected to the electric applications (load). Therefore, field winding conductor must be sized enough to carry the load current consumption and the basic circuit as illustrated below.



c) Compound generator

The compound generator has provided with magnetic field in combine with excitation of shunt and series field winding, the shunt field has many turns of fine wire and caries of a small current, while the series field winding provided with a few turns of heavy wire since it is in series with an armature winding and caries the load current. There are two kinds of compound generator as illustrated in figure 5 and 6.

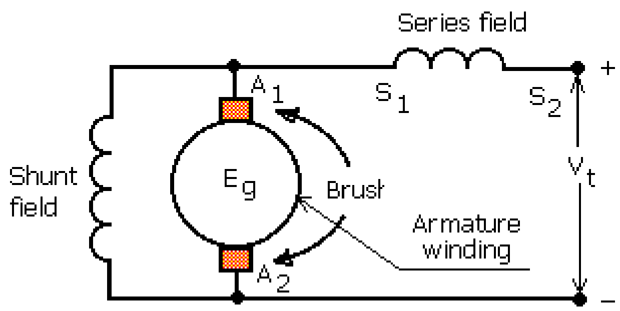


Fig. 5 A short-shunt compound generator

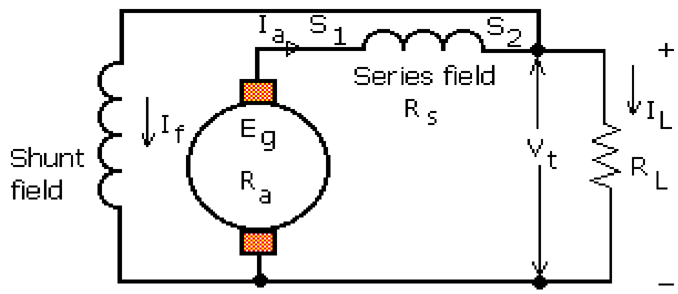


Fig. 6 A long-shunt compound generator

3. Characteristic of separately excited generator

The generated electromotive force (EMF) is proportional to both of a magnetic density of flux per pole and the speed of the armature rotated as expression by the relation as following.

$$E_g = \kappa \phi n$$

Where

K	=	Constant for a specific machine
ϕ	=	The density of flux per pole
n	=	Speed of the armature rotation
E_g	=	Generator voltage

3.1 By holding the armature speed (n) at a constant value it can show that generator voltage (E_g) is directly proportional to the magnetic flux density. Which, flux density is proportionately to the amount of field current (I_f). The relation of field current and generate voltage as impressed by figure 7.

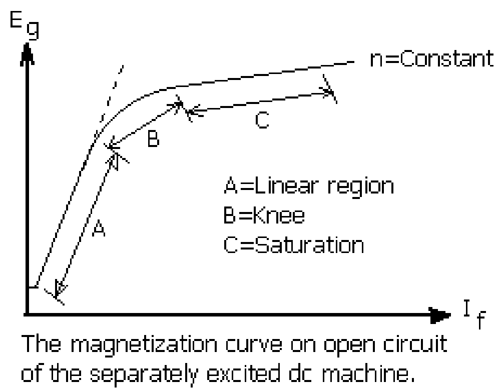


Fig. 7

From the figure 7 when the field current (I_f) is become zero a small generate voltage is produce due to a residual magnetism.

As the field current increases cause to increase generated voltage linearly up to the knee of the magnetization curve. Beyond this point by increasing the field current still further causes saturation of the magnetic structure.

3.2 Generator voltage (E_g) is also directly to the armature speed. The formula and a magnetization curve can be both impressed about this relation.

$$E_g' = E_g \times \frac{n'}{n}$$

Where

E_g	=	Generator voltage or the value of EMF at speed n
E_g'	=	Generator voltage or the value of EMF at speed n'
n	=	Speed of the generator armature ($n' \neq n$)

Example:

The open circuit terminal voltage versus the field current for a separately excited DC generator with provided the following test data at revolving speed 1400 rpm as show by the table1 below.

Voltage (V)	6	30	58	114	153	179
Ampere (A)	0	0.1	0.2	0.4	0.6	0.8

Table 1 No-load characteristic for 1400 rpm and 1000 rpm

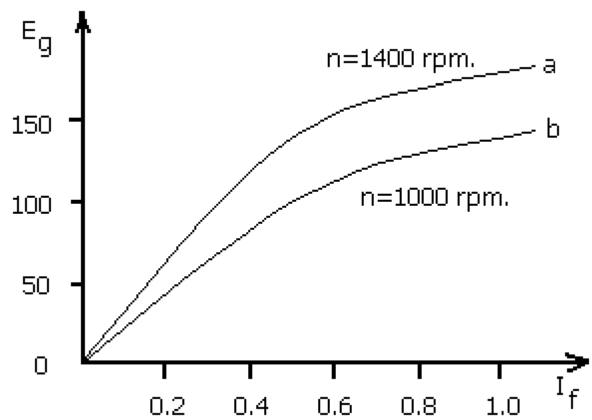


Figure 8 Magnetic curve for example 3.1

Solution

Curve (a) in figure 8 shows the characteristic at revolving speed 1400 rpm obtained by the data as show in table 1. To obtain the characteristic at 1000 rpm, is made of the relation as $E_g = K\phi n$

For instance, at a field current of 0.4 Amp the terminal voltage is 114 volts, when the speed is reached to 1400 rpm and kept its field current constant at this value, the open circuit voltage at 1000 rpm becomes.

$$E_g = 114 \times \frac{1000}{1400} = 81.40 \text{ Volts}$$

4. Voltage Regulation

When we add load on the generator, the terminal voltage will decrease due to

4.1 The armature winding resistance is mainly of armature resistance. It is cause directly decrease in terminal voltage as following relation.

$$V_t = E_g - I_a R_a$$

Where

V_t	=	Terminal or output voltage
I_a	=	Armature current or load current
R_a	=	Armature resistance

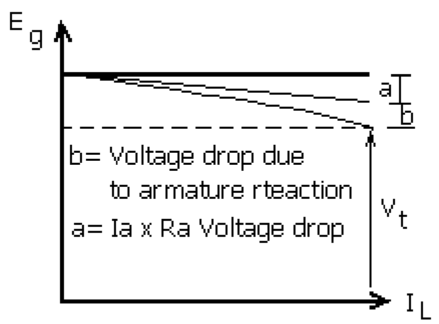


Figure 9 (a) Load characteristic of a separately excited DC generator;

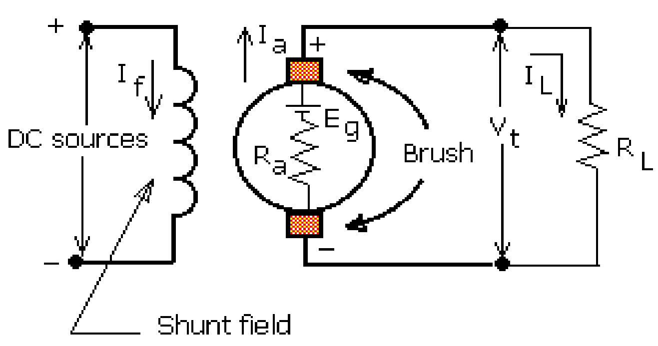


Figure 9 (b) Circuit diagram

4.2 The decrease in magnetic flux due to armature reaction. The armature current establishes a magneto motive force (MMF), which it distorts to main flux, and makes result in weakened flux. We can put inter-pole between main field poles to reduce the armature reaction.

To have some measure by how much the terminal voltage change from no-load condition and on load condition, which is called “voltage regulation”.

$$\text{Voltage regulation} = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100 = \%$$

Where

V_{nl} = No-load terminal voltage

V_{fl} = Full-load terminal voltage

Remark:

A separately excited generator has disadvantage of requiring an external DC source. It is therefore used only where a wide range of terminal voltage required.

Example 2

The separately excited generator of example 1 is driven at revolving speed 1000 rpm and the field current is adjusted to 0.6 Amp. If the armature circuit resistance is 0.28 ohm, plot the output voltage as the load current is varied from 0 to 60 Amp. Neglect armature reaction effects. If the full-load current is 60 Amp, what is the voltage regulation?

Solution

From example 1, E_g = 153 volts when the field current is 0.6 Amp, which is the open circuit terminal voltage. When the generator is loaded, the terminal voltage is decreased by internal voltage drop, namely.

$$V_t = E_g - I_a R_a$$

For a load current of, say 40 Amp.

$$V_t = 153 - (40 \times 0.28) = 141.80 \text{ Volts.}$$

This calculation is for a number of load currents and the external characteristic can be plotted as show in fig. 10 at full load the terminal voltage.

$$V_t = 153 - (60 \times 0.28) = 136.20 \text{ Volts.}$$

Therefore the voltage regulation is

$$\text{Voltage regulation} = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100 = \%$$

$$= \frac{153 - 136.2}{136.2} \times 100 = 12.3\,\%$$

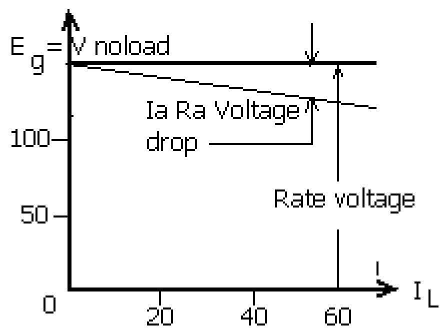
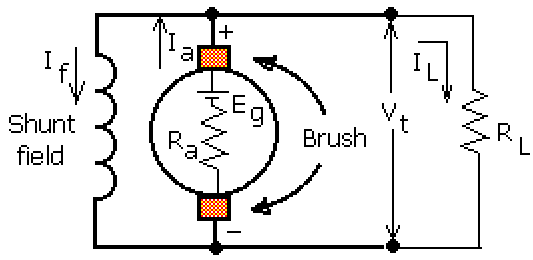


Figure 10 Calculated load characteristic of an example 3.2

5. Load characteristic

5.1 Self excited DC shunt generator

A shunt generator has its shunt field winding connected in parallel with the armature so that the machine provides it own excitation. For voltage to build up, there must be some residual magnetism in the field poles. There will be a small voltage (E_r) generated.



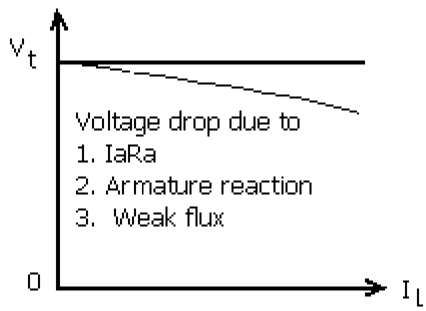


Figure 10a Shunt generator circuit

Figure 10b Shunt generator load characteristic

If the connection of the field and armature winding are such that the weak main pole flux aids to the residual flux, the induced voltage will become larger. Thus more voltage applied to the main field pole and cause to the terminal voltage increase rapidly to a large value.

When we add load on the generator, the terminal voltage will decrease due to.

a) The armature winding resistance

b) The armature reaction

c) The weakened flux due to the connection of the generator to aids or oppose to the residual flux.

Example: A shunt generator has field resistance of 60 ohms. When the generator delivers 60 kw the terminal voltage is 120 volts, while the generated EMF is 135 volts. Determine

a) The armature circuit resistance

b) The generated EMF when the output is 20 kw and the terminal voltage is 135 volts.

Solution

a) The circuit diagram when delivering 60 kw is as show in figure 11 the load current is

$$I_L = \frac{60{,}000 \text{ watts}}{120 \text{ volts}} = 500 \text{ Amperes.}$$

The field current supplied by the armature is

$$I_f = \frac{120 \text{ volts}}{60 \text{ ohms}} = 2 \text{ Amperes}$$

Therefore,

$$I_A = I_f + I_L = 500A + 2A$$

$$= 502 \text{ Amperes.}$$

Since,

$$V_t = E_g - I_a R_a$$

$$R_a = \frac{E_g - V_t}{I_a} = \frac{135 - 120}{52} = 0.28 \text{ Ohms.}$$

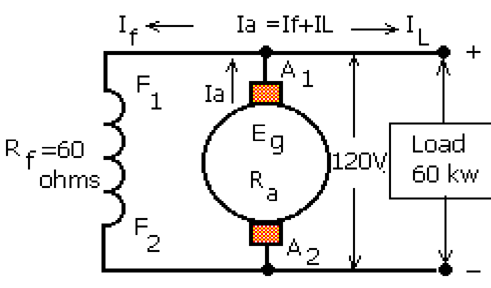


Figure 11 Circuit diagram for the solution of example 3

b) For a load of 20 kw when the terminal voltage is 135 volts, therefore the load current is

$$I_L = \frac{20{,}000 \text{ watts}}{135 \text{ volts}} = 148.1 \text{ Amperes.}$$

And the field current is

$$I_f = \frac{135 \text{ volts}}{60 \text{ ohms}} = 2.25 \text{ Amperes}$$

$$I_a = 148 + 2.25 = 150.25 \text{ Amperes}$$

$$E_g = V_t + I_a R_a$$

$$= 135 + (150.25 \times 0.28)$$

$$= 177.07 \text{ volts}$$

5.2 Series generator

The field winding of a series generator is connect in series with the armature winding. Since it carries the load current, the series field winding consists of only a few turns of thick wire. At no-load, the generator voltage is small due to residual field flux only. When a load is added, the flux increase, and so does the generated voltage.

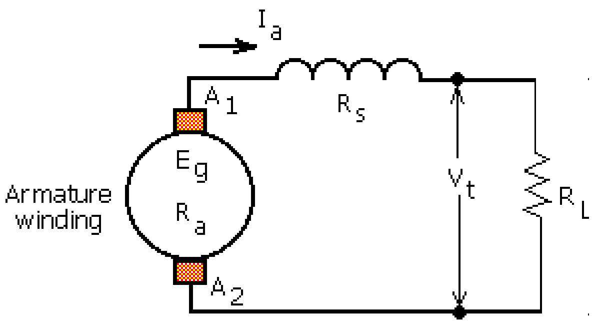


Figure 12a. Circuit diagram of a series generator

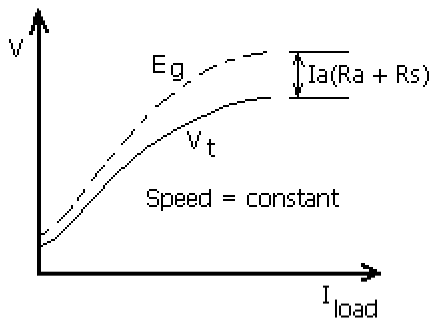


Figure 12b. Load characteristic of a series generator

Figure 12 shows the load characteristic of a series generator driven at a certain speed. The dash line indicated the generated EMF of the same machine with the armature open-circuited and the field separated excited. The different between the two curves is simply the voltage drop (IR) in the series field and armature winding.

$$V_t = E_g - I_a(R_a + R_f)$$

Where

R_f = The series field winding resistance

R_a = The armature winding resistance

The series generators are obviously not suited for applications requiring good voltage regulation. Therefore, they have been used very little and only in special applications for example, as voltage booster. The generator is placed in series with a supply line. When the current consumption is increase, the generated voltage of the series machine goes up because the magnetic field current is increases.

5.3 Compound generator

The compound generator has both a shunt and a series winding. The series field winding usually wound on the top of a shunt field. The two winding are usually connected such that their ampere-turns act in the same direction. As such the generator is said to be cumulatively compound.

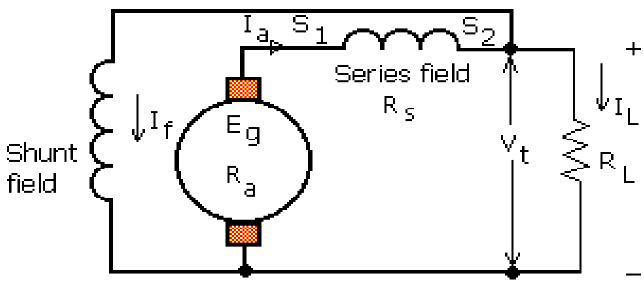


Figure13 A simply circuit of compound generator

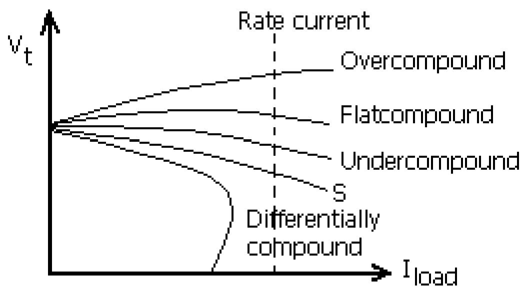


Figure 14 Terminal voltage characteristic of compound generator

- Curve s is represent the terminal voltage characteristic of shunt field winding alone.

- Under-compound, this condition the addition of series field winding too short it is cause the terminal voltage no rise to certain value and reduce while increasing in load current
- Flat compound by increasing the number of a series field turns. It is cause to rise up in terminal voltage and when no-load and full load condition a terminal voltage is made nearly same value or equal.
- Over-compound, if the number of series field turns is more than necessary to compensated of the reduce voltage. In this case while a full load condition a terminal voltage is higher than a no-load voltage. Therefore over-compound generator may use where load is at some distance from generator. Voltage drop in the line has compensated by used of an over-compound generator.
- If a reversing the polarity of the series field occur this cause to the relation between series field and shunt field, the field will oppose to each other more and more as the load current increase. Therefore terminal voltage will drop, such generator is said to be a differentially compound.

The compound generator are used more extensively than the other type of dc generator because its design to have a wide variety of terminal voltage characteristics.

Example 5 Determine the number of series turn required on each pole of a compound generator to enable it to maintain the voltage at 240 volts between no load and full load of 20 kw. Without the series winding, it is found that the shunt current has to be 4 amps. On no load current and 5 amps at full load, to maintain the terminal voltage at 240 volts The number of turns per pole on shunt field winding equal 600 turns.

Solution. Figure 15 gives the circuit diagram of the compound generator. A long shunt connection is assumed. On no load the field excitation current is supplied by the armature. The resulting MMF of a shunt field pole is

$$= n1 = 600 \times 4 = 2400 \text{ At}$$

The small voltage drop across the series field winding will be assumed negligibly small.

On full load the shunt field current is 5 Ampere used to maintain the terminal voltage at 240 V. In other words, the required MMF is taken = n1 = 600 x 5 = 3000 At/pole. It is the difference in MMF that would have to be supplied by the series field winding to give flat compounding while keeping the shunt field at he initial value of 4 A. Thus the MMF series field is 3000-2400 = 600 At/pole. The full load-current which also flows through the series field winding is

$$I_{FL} = \frac{P_L}{V_1} = \frac{20,000}{240} = 83.3 \text{ A}$$

Therefore, the number or turns required on the series field to provide an MMF of 600 At is

Series field turns = 600 At / (83.3 + 4) = 6.9/pole

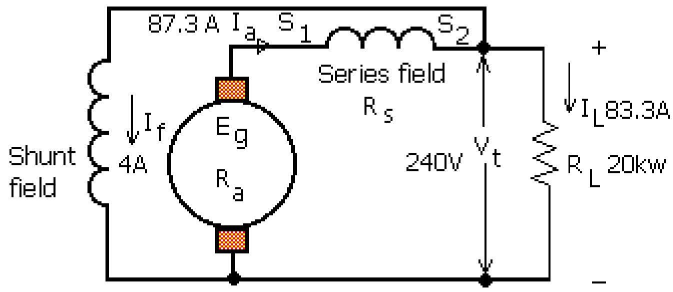


Figure 15 Compound generator at full load for Example 5

Or we can solve by

$$N_s = \frac{N_f \ \Delta I_f}{I_s \ (\text{rated})}$$

Where

N_s = number of series turns required

N_f = number of shunt field winding

ΔI_f = the increase in shunt field current required to maintain the terminal voltage from no-load to rated –load without the series field

I_s = rated load or armature current flowing through the series field winding

Machine Efficiency

The efficiency of any machine is the ratio of the ratio of the output power to the input power. The input power is provided by the prime mover to drive the generator. Because part of the energy delivered to the generator is converted into heat, it represents wasted energy. These losses are generally minimized in the design stage; however, some of these losses are unavoidable.

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100\% \quad \text{or}$$

$$\text{Efficiency} = \frac{\text{Output power} \times 100\%}{\text{Input power} + \text{losses}}$$

The losses of generators may be classified as

1) Copper losses

The copper losses are present because of the resistance of the windings. Currents flowing through these windings create ohmic losses. The windings that may be present in addition to the (I^2R) armature winding are the field windings, inter-pole and compensate windings.

2) Iron losses

As the armature rotates in the magnetic field, the iron parts of the armature as well as the conductors cut the magnetic flux. Since iron is a good conductor of electricity, the EMF s induced in the iron parts courses to flow through these parts. These are the eddy <u>currents.</u>

Another loss occurring in the iron is due to the Hysteresis loss is present in the armature core.

3) Other rotational losses consist of

3.1 bearing friction loss

3.2 friction of the rushes riding on the commutator

3.3 windage losses

Windage losses are those associated with overcoming air friction in setting up circulation currents of air inside the machine for cooling purposes. These losses are usually very small.

Example 6 A 10 kW 125 V compound generator has rotational losses amounting to 580 W. The shunt field resistance is 62.5 Ω , the armature resistance 0.12 Ω , and the series field resistance 0.022 Ω . Calculate the full-load efficiency.

Solution The full-load current is

$$I_L = 10{,}000 / 125 = 80 \text{ A}$$

Assuming a long-shunt connection, the field currents is

$$I_F = 125/62.5 = 2 \text{ A}$$

Then IA = 80 + 2 = 82 A, which is the current through the series winding. The $I^2 R$ losses can now be determined:

Armature $82^2 \times 0.12$ = 807 W

Series field $82^2 \times 0.022$ = 148 W

Shunt field : $2^2 \times 62.5$ = 250 W

Rotational loss = 580 W

Total loss = 1,785 W

Hence

$$\eta = P_{out} / (P_{out} + P_{loss}) = 10{,}000 \times 100 / 11{,}785$$

$= 84.9\%$

An alternative way to solve for the efficiency is as follows:

$$E_G = V_1 + I_A (R_s + R_A)$$
$$= 125 + 82(0.022 + 0.12) = 136.6 \text{ V}$$

the power developed by the armature is

$$p_d = E_g I_A = 136.6 \times 82 = 11.205 \text{ W}$$

Therefore, the power input at the shaft is p_d + rot = 11.785 W and

$$\eta = (10{,}000 / 11{,}785) \times 100 = 84.9\%$$

as above

Part 2
Direct current motor

By

Suthipong Thanasansakorn

1/6/2002

Southeast Asia Fishery development center
Training Department
Thailand

Direct Current Motor (DC motor)

DC motor is similar to dc generator; in fact the same machine can act as motor or generator. The only difference is that in a generator the EMF is greater than terminal voltage, whereas in motor the generated voltage EMF is less than terminal voltage. Thus the power flow is reversed, that is the motor converts electrical energy into mechanical energy. That is the reverse process of generator.

DC motors are highly versatile machines. For example, dc motors are better suited fore many processes that demand a high degree of flexibility in the control of speed and torque. The dc motor can provided high starting torque as well as high decelerating torque for application requiring quick stop or reversals.

DC motors are suited in speed control with over wide range is easily to achieve compare with others electromechanical.

Counter EMF in DC motor

When voltage is applied to dc motor, current will flow into the positive brush through the commutator into the armature winding. The motor armature winding is identical to the generator armature winding. Thus the conductors on the north field poles are carry current in one direction, while all conductors on the south field poles carry the current in opposite direction. When the armature carry current it will produce a magnetic field around the conductor of it own which interact with the main field. It is cause to the force developed on all conductors and tending to turn the armature.

The armature conductors continually cut through this resultant field. So that voltages are generated in the same conductors that experience force action. When operating the motor is simultaneously acting as generator. Naturally motor action is stronger than generator action.

Although the counter EMF is opposite with the supplied voltage, but it cannot exceed to applied voltage. The counter EMF is serves to limit the current in an armature winding. The armature current will be limited to the value just sufficient to take care of the developed power needed to drive the load.

In the case of no load is connected to the shaft. The counter EMF will almost equal to the applied voltage. The power develops by the armature in this case is just the power needed to overcome the rotational losses. It's mean that the armature current I_A is controlled and limited by counter EMF therefore.

$$Ia = \frac{VL - Ea}{Ra}$$

Where:

VL	=	Line voltage across the armature winding
R_a	=	Resistance of the armature winding
E_a	=	Induced EMF or generated voltage
I_a	=	Armature current

Since, E_A is induced or generated voltage it is depend on the flux per pole and the speed of the armature rotate (n) in rpm. Therefore

$$E_a = K \phi n$$

Where:

K	=	the constant value depending on armature winding and number of pole of machine.
ϕ	=	Rotation of the armature

And,

$$K = \frac{Z \times P}{a}$$

Where:

Z	=	Total number of conductor in the armature winding
a	=	Number of parallel circuit in the armature winding between positive and negative brushes.

For wave wound armature "a" = 2

Lab wound armature "a" = P

Example

A dc motor operated at 1500 rpm when drawing 20 amps from 220 volts supply, if the armature resistance is 0.2 ohms. Calculate the no load speed assumed Ia = 0 amp (This amount to assuming the brushes and rotation loss are negligible)

Solution

When load condition Ia = 20 amps.

$$Ea = VL - Ia\,Ra$$
$$= 220 - 20\,(0.2)$$
$$= 216 \text{ Volts.}$$

And $Ea = k \phi n$

$216 = K\phi \times 1500$

$K\varphi = \frac{216}{1500}$

$= 0.144$

At no load condition $Ia = 0$ Amp.

$Ea = VL = 220$ Volts.

Hence $Ea = k\phi n$

$n = \frac{220}{k\phi}$

$= \frac{220}{0.144}$

$= 1528$ rpm.

Mechanical power develop in dc motor (Pd)

P_d = Mechanical power develop

T = Torque exerted on the armature

$$P_d = \omega T$$

$$= \left(\frac{2\pi n}{60}\right) T$$

Where: $T = P_d / \omega$

$$= \frac{Ea \times Ia}{2\pi n / 60} \qquad = \frac{K\varphi n \times Ia}{(2\pi n)/60}$$

Therefore: $T = K\phi\, I_A$

Example: from the motor that mentions before, determine

Solution: $P_d = E_A\ I_A$

$= 216 \bullet 20$

$= 4320$ watts.

$T = P_d / \omega$

$= 27.51\ N_M$

Classification of dc motor

There are generally three type of dc motor namely

1, Series motors

2, Shunt motors

3, Compound motor

The series motor is widely used because its excellent starting torque characteristics, but each type of dc motor has very definite operating characteristics. It is essential to know construction and requirement before a proper motor4 selection.

Starting of dc motor

At the instant of start up, the armature is not rotate, therefore the counter EMF E_A is zero because no any flux which induced to the armature winding. If we start the motor as mention before with direct across the line 220 volts supply. That armature winding tend to reach search current equivalent to 220/ 0.2 = 1100 A. This current subject to the armature to produced as mechanical shock and would blow fuse and disconnect itself from supply. It is therefore necessary to insert some resistance in series with the armature circuit to limit the current flow through the armature winding.

As The motor come up to speed, this resistance is taken out in steps because E_A rise as the motor come up to full speed. This resistance arrangement is called starter. If the resistance has induced into the motor as mention above is to be limited at 100 amps. The total resistance of the starter plus the armature winding resistance of 2 ohms, the starter circuit as illustrate below.

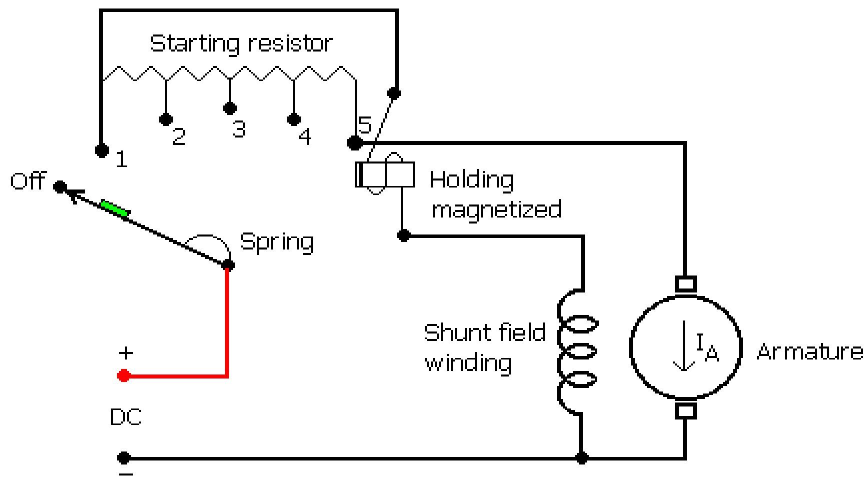


Figure 1.The starter circuit

When the main switch is turn on by starter arms is moved to contact 1 the motor is starting to rotate. The starter arm has to slowly move to the following contact until the final position. Motor is full speed condition, this whole process shout a few seconds depending on the size of motor.

The starter must be rated on horsepower, voltage and current that is used. The motor less than 1 hp. direct on line full voltage starting is allowed.

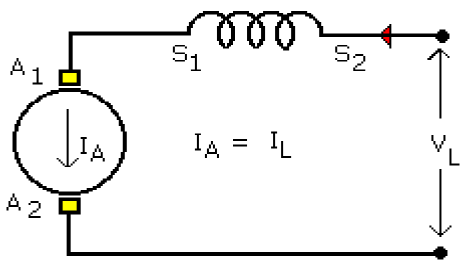
In the final position no added the external resistant connected to the armature circuit, so the current is directly apply to the armature path but the external resistant still connected to maintain the field circuit. The starter arm is continuously kept closed to the final contact by the holding coils. (Magnetized force) When there is a failure power or the field circuit is opened accidentally. The spring will return starter arm out off position, automatically shut down. The amount of current consume with starter connection becomes.

$$I_{start} = \frac{V_{source}}{R_A + R_{starter}}$$

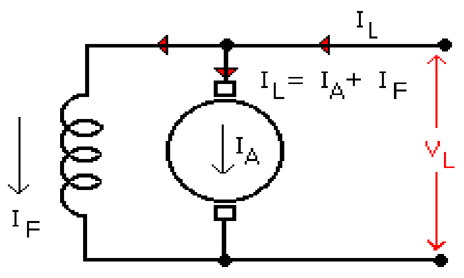
In the separately excited machine the field winding is connected to a different supply. If the field winding is connected in parallel with the armature winding we called a shunt machine. The series machines has a field winding is caries the load current, It is necessary to capable the winding to carry the load current without the excessive heat loss in its.

In case of compound motor it has both of winding conductors. This field winding may be connected so that the field aid one another, depending on flux oppose. Thus, the compound motor may have long-shunt or short shunt field winding. It is arrangement, whether the shunt field is connected before or after the series field winding.

When the motor is loaded the speed tends to slow down. This is known from practical experience. The amount which speed is slows down at full-load, as compare with no-load condition will depend on type of connection employed.



Series motor



Shunt motor

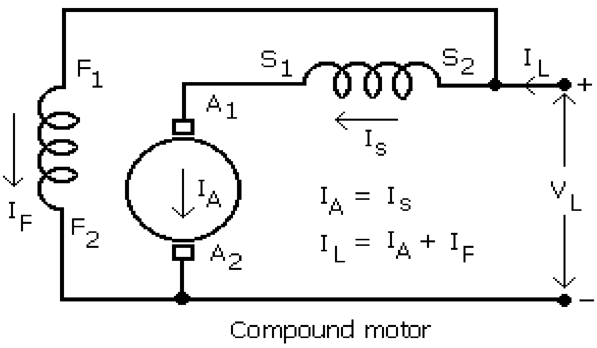


Figure2. Illustrated the current on different kinds of dc motor

The armature current on the starter position 1 is can be define as following.

$$I_1 = \frac{V_{supply}}{R_A + R_{starter}}$$

Since torque is directly proportion to the armature current and flux it is cause accelerated to the start up of the armature. During the acceleration period the counter electromotive force is increase (E_c) but the armature current tendency to decrease to some value. When the starter arm is moved to position 2 with sufficient resistance the current that flow into the armature is rise approximate to I_1 again. This operation is continued until the last contact is reach, assume that the motor is steady-state speed and current.

Example

Calculate the require resistance for a four-step starter to limit the starting current of a DC shunt motor to 150% 0f rate current. Assume that all four steps have an equal resistance value. The motor has rating as 25 Hp, 240 Volts, 860 rpm. And armature resistance is 0.08 Ohms, the overall efficiency 90%. Determine at each speed of the starter resistance must be take into the starting circuit to maintained the rate value during start up period. Assume that the field current is negligible compared to rate armature current.

Solution:

Motor starting circuit. At full load the motor input power is as computed by the following.

$$P_{in} = \frac{Hp \times 746}{\eta} = \frac{10 \times 746}{0.9} = 8{,}288 \text{ watts}$$

And the line current is

$$I_L = \frac{8{,}288}{240} = 34.53 \text{ Amps.}$$

The designed rate current is limited at 150% of nominal rating, the maximum current will be

$$I_{max} = 1.5 \times 34.53 \text{ Amps.}$$
$$= 51.79 \text{ Amps.}$$

The current-limiting resistance at startup is

$$I_{max} = \frac{V_{supply}}{R_A + 4R} = \frac{240}{0.1 + 4R} = 51.79 \text{ A}$$

$$240 = 51.79 \times (0.1 + 4R)$$

$$240 = 5.17 + 207.16R$$

$$240 - 5.17 = 207.16R$$

$$R = \frac{234.84}{207.16} = 1.13\,\Omega$$

Furthermore, at rated speed and current,

$$E_c = V - I_A R_a = k\Phi n$$
$$= 240 - (51.79 \times 0.1)$$
$$234.8 = k\Phi \times 860$$
$$k\Phi = 0.273$$

Therefore, $k\Phi = 0.273$ which is constant under stated assumptions. On the startup period, since n = 0 rpm there are four resistors connected in series with the armature winding then the total resistance and current will be.

$$I_{max} = I_R$$

Then

$$240 = I_A (0.1 + 4R)$$

The motor will accelerate and the current decay until $I_A = I_{A\,rated}$ at this point the starter is place in the contact 2 there are 3 resistors in series with the armature-winding and $I_A = I_{A\,max}$ Then

$$240 = 51.79\,(0.1 + (3 \times 1.13)) + E_c$$
$$= (51.79 \times 3.49) + E_c$$
$$= 180.6 + E_c$$
$$E_c = 59.4$$

Where : $E_c = k\Phi n$

$$59.4 = 0.273\,n$$

$$n = \frac{59.4}{0.273} \approx 218 \text{ rpm.}$$

At time t_1 the motor has produce counter EMF 59.4 volts and accelerate up to 218 rpm.

Similarly on contact 3 with 2 resistors connected in the circuit.

$$240 = 51.79\,(0.1 + (2 \times 1.13)) + E_C$$
$$= 122.22 + E_C$$
$$E_C = 117.78 \text{ volts}$$
$$n = \frac{117.78}{0.273} \approx 431.42 \text{ rpm.}$$

At time t_2 Ec = 118 volts and n = 431 rpm.

On contact 4, with a single resistor connected in the motor circuit

$$E_c = 181 \text{ volts and } n = 664 \text{ rpm. at time } t_3.$$

At contact 5, the final position the starter-arm connected without resistor no additional resistance in the motor armature circuit. Motor is directly across to the sources.

$$E_c = 235 \text{ volts and } n = 860 \text{ rpm. at time } t_4$$

When the motor has reach to a steady condition. The time interval of the revolution reach to full speed condition is depending on motor plus load inertia the variation of armature current and time will somewhat similar to the curve as giving.

Automatic starter of DC motor

The apparent disadvantages of manual starter of DC motor are.

- Bulkiness of the starter.
- Lack of remote operation.
- Possibility of improper operation.
- Non-uniform acceleration.

An automatic starter has covered all these disadvantages in order to providing other reliable control feature such as over and under voltage protection, over speed protection.

To illustrate these matters let refer to a simple automatic starter connected to a dc shunt motor as illustrate as following

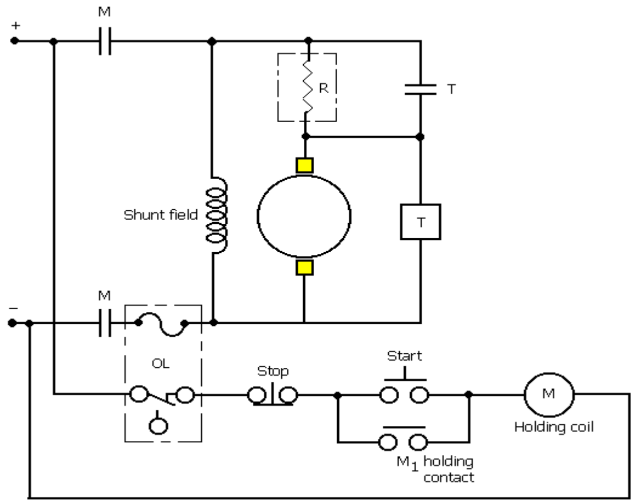


Figure3. Illustrated an automatic starter connected to a dc shunt motor

This starter circuit is called a "counter-EMF starter". The starting resistance is added to cut out the current in a single step; the contact M is a magnetic contact. The magnetic is an electrical switch which has a holding coil placed on an iron armature core. When the current flows through the holding coils, the coils become magnetize. This attracts to move iron armature that carries a set of contacts, which has an electrically insulated from each other. Thereby closing the circuit the holding coil energized, contact M are closes and complete the circuit by pressing the start button and disconnect the circuit after pressing the stop button, which together the start and stop button may be remotely located from the motor.

When the magnet is energized contacts M and M_1 close, contact M_1 is called " maintaining or holding contact" it function is keeps magnetic contact energized after the start button is released the motor continue operates until the stop button is pressing.

It is cause to the motor connected to power supplied with the starter resistor R connect in series with the armature winding because at the standstill the counter EMF is zero, the starter resistor is provided for limited the starting load current. The contact T is called "accelerating contact"

When the motor is speed up the counter EMF is increase as the voltage across the armature (E_c). Whenever E_c reach about 80% of supply voltage contact A closes and associated short out the starter resistor R. The contact T is controlled by a definite time presetting called timer-delay relay, because the counter EMF is relate to the acceleration of the motor. So now the motor is directly cross to the supply voltage. To obtain smoother accelerate and high performance.

In the starting circuit overload protection has provided by the thermal overload relay, there are two types basically both are operate by the heat generate in the heating element which is connect in series with the motor cause the amount of motor current flow through its. One type is bimetallic strip and the other is melting a strip of solder. Both types act to open the motor circuit when the over current is produced.

To stop the motor under normal operation, the stop button is presses thereby open the control circuit. This is cause by the stop button is disconnect the holding coil, the holding coil is de-energized cause the contact M are disconnect, thereby motor is separated from the sources.

Speed characteristic of DC motors.

When the mechanical load is removing from the motor, the motor speed will increase. The amount by which it increases depends on the type of motor. The speed of shunt motor increase about 8%, for a compound motor it rise approximately 15 to 20%. And for the series motor it would rise rapidly and it is for this reason the series motors must always drive a load. To make clear and understand why this happens let consider the relation as following.

$$n = \frac{V - I_A R_A}{k\varphi}$$

In shun motor the flux is only slight affected by the armature current, while the I_A R_A drop rarely exceed 5% of line voltage. Therefore the maximum change in speed must be the same order as I_A for a shunt motor. Shunt motor is fairly constant machine as indicated by a curve as following.

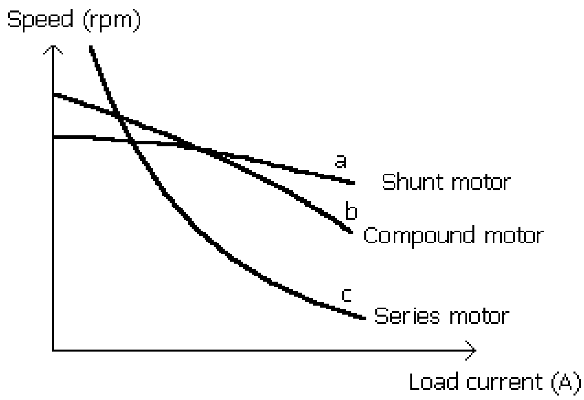


Figure 4. Illustrated shunt motor current characteristic

For a compound motor, when the load is removed there are two factors affected the speed and flux. Unlike the shunt motor, the effect of series field is removed under no-load condition, thereby weakening the overall of field flux. The result is larger increase in speed, since the speed is inversely proportional to the flux as indicated as the above formula. This is representing by curve b. We can now see why the series motor will run at danger high speed when the load is removed. There would not be any flux because the flux is depend upon load current The curve c illustrated a load current behavior of the series motor. For this reason the series motor is not used in instance where the load can be disconnected by accidentally such as belt-coupling drive should never be used with series motor drive.

In similar the torque-load characteristic for the shunt, compound and series motor can be compare the figure as illustrated below shows for the 3 different type of dc motors. In series motor, the developed torque depends on the load current and fluxes; because the flux in turned depend on the current under this condition.

$$T = k\varphi \ I_A$$

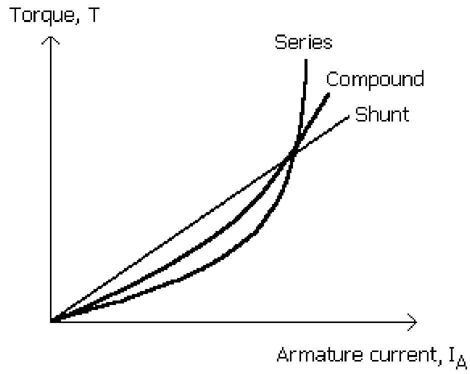


Figure 5. Illustrated DC motor speed characteristic

If magnetic saturation is considered, the graph will become a straight line at heavy load, since the flux will not change with increase loading. Figure 5 it is evident that for a given current below full-load value, the shunt motor develops the largess torque. For currents exceeding rated current, the series motor develops the largess toque. It is for this reason that in applications requiring large starting current. Such as for hoist, electric trains, and so on, the series motor is the most suitable machine.

Example

A 240-Volt shunt motor has an armature current of 0.25 ohms. Under load, the armature current is 20 A. Suppose that the flux is suddenly decrease by 2.5%, what would be the immediate effect on the develop torque?

Solution. When the current is 20 A

$$T = k\varphi I_A = K\varphi \times 20$$

and

$$E_c = V_L - I_A R_A$$
$$= 240 - (20 \times 0.25)$$
$$= 235 \text{ volts}$$

If ϕ is suddenly decreased by 2.5%, E_c is also decrease, since $E_c = K \phi n$ and the speed cannot change instantaneously, thus

$$E_c = 235 - (235 \times \frac{2.5}{100}) = 235 \times 0.975$$
$$= 235 - 5.87$$
$$= 229.13 \text{ volts.}$$

The new armature current is

$$I'_A = \frac{V_L - E_c}{R_A} = \frac{240 - 229}{0.25} = 44 \text{ Amps}$$

The new value of develop torque is

$$T = k(1 - 0.025\,\varphi)\,I_A$$
$$= K(0.975\,\varphi)\,44$$
$$= 40.7\,K\varphi$$

This is corresponding to an increase in torque as

$$\frac{T'}{T} = \frac{40.7\,K\varphi}{20\,K\varphi} = 2.035 \text{ times}$$

Thus slight decrease of flux almost doubles the torque. This increased torque causes the armature to accelerate to higher speed. At that point the counter EMF limits the armature current just enough to carry the load at this new speed.

Speed regulation.

The motor classification on the basis of speed change with load is particularly important in the selection of motor. If the speed of motor is relatively constant over it normal range, the phenomenon of motor as having good speed regulation. Speed regulation is usually expresses ass a percentage as found as following.

$$\text{Speed regulation} = \frac{\text{no-load speed} - \text{Full-load speed}}{\text{full-load speed}} \times 100 \quad \%$$
$$= \frac{N_{nl} - N_{fl}}{N_{fl}} \times 100 \quad \%$$

Where:

n_{fl} = Full-load speed

n_{nl} = No-load speed (Both express in r/min, rpm.)

Note. Speed changes cause by loading condition, there are no resulted by speed adjustment made by manually or by personnel.

Speed control of DC motor

In order to change in speed of dc motor there are three quantities that may be considered as parameter:

- The armature resistance I_A.
- Flux ϕ density.
- And terminal voltage V.

The armature resistance method by adding resistor in series with the armature effectively increases the armature circuit resistance. Let considered the equation as follow.

$$n = \frac{V - (I_A R_A)}{k\varphi}$$

There is indicates the results in reduction of steady-state speed, since it is proportional to the counter EMF, except for no-load condition. This method is the field current is kept constant. Figure. Illustrate the characteristic of different value of armature circuit resistance. As apparent, this method of speed control is relatively simple and inexpensive. Anyway it has some disadvantage such as.

1. Adding resistance in the armature circuit the speed of the motor, compare to that without any resistance adding, however it is always lower

2. This method of speed control is ineffective at no load condition due voltage drop cause by I_A and R is less.

3. Adding resistance means increase in I^2 R losses, therefore waste power due to heat generated. As a rule of Thumb, the percentage reduction in speed is equals to the percentage of input power that is consumed in the added resistor.

4. The constant-speed characteristic of the motor is loss. In generals the speed control of this method is limited about 50 % of nominal rated speed.

Example. A 200 volts shunt motor run at 1000 rpm when the armature current is 60 A, the armature circuit resistance is 0.2 ohms. Find the required resistance to be added in series with the armature to reduce the speed to 800 rpm when the armature current 40 A.

Solution

$$E_c = V - (I_A R_A)$$
$$= 200 - (60 \times 0.2)$$
$$= 188 \text{ volts.}$$

Since the field current has remained constant, the counter EMF is proportional to the speed. Therefore the counter EMF at 800 rpm is.

$$E_c' = k\,\varphi\, n = 188 \times \frac{800}{1000}$$
$$= 150.4 \text{ volts}$$

Therefore, the voltage drop in the armature circuit is equal to the voltage drop at the resistor plus voltage drop by the armature resistance; they are computing as follow.

$$V_L = V_R + V_{R_A} - E_c$$
$$V_R + V_{R_A} = 200 - 150.4 = 49.6 \text{ volts.}$$

The total armature circuit resistance is obtaining by.

$$R + R_A = \frac{49.6 \text{ volts}}{40 \text{ Amps.}} = 1.24 \text{ Ohms.}$$

Therefore, the additional resistance required in the armature circuit for reduced the speed from 1000-rpm into 800-rpm compute by.

$$R = 1.24 - 0.2 = 1.04 \text{ Ohms.}$$

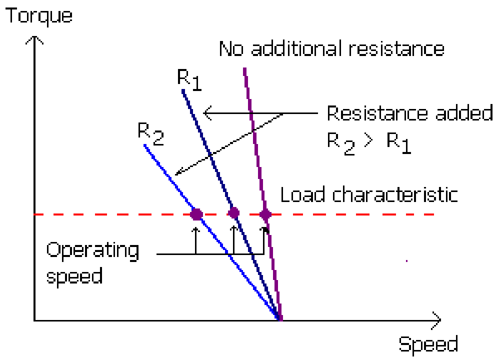


Figure 6. Illustrated shunt motor armature resistant characteristic

The second method of speed control is by changing the fluxϕ. The additional resistor is employ to connect in series with the field winding. Normally used a variable resistor and it is generally called "field rheostat" Therefore the field current is directly proportional to the field rheostat. The speed of motor is increase by reduction in flux (increase resistance value). This method has some disadvantage. One is it can only increase speed at the motor normally run at a light load. Another disadvantage is speed is increase without corresponding reduction in shaft load. The motor will overload condition. However at a light loads or under no-load condition the speed can be above nominal rating speed reach about 200%. And the field current control as shown in figure7 bellow.

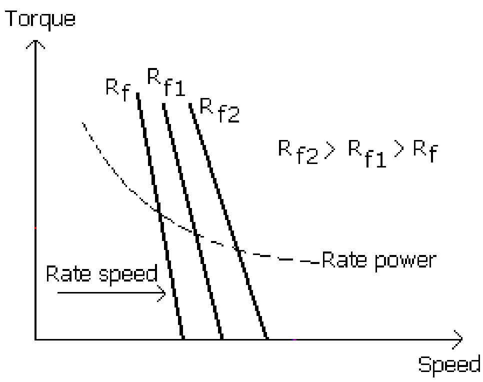


Figure 7 Illustrated DC motor field resistant characteristic

The third method of speed control is by changing the terminal voltage V of the motor. This is normally the most frequent application of control, at least for shunt motor, where the field winding is separately excited as represent by the figure 8 as bellow.

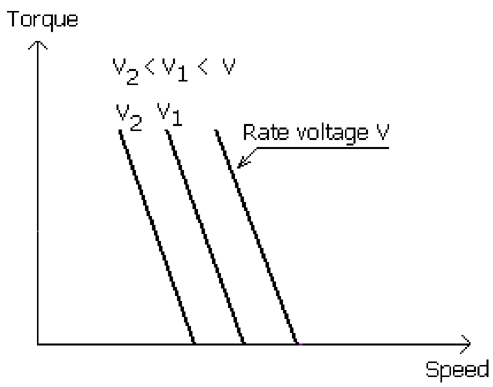


Figure 8 Illustrated DC motor terminal voltages characteristic

The voltage control method lowers the speed in a similar as the armature resistance control method; but it does not drawback. Due to the no-load and full-load speed can be reduced all the way down to zero. And there is not much power wasted. There are various ways to obtain a variable DC voltage. Some modern ways are using solid-state device.

Finally if the speed control above and below nominal speed are desired, a combination of two methods. For example, field control combined with armature voltage control would achieve this mode of control.

Solid-state controllers

The Dc speed is function of the armature and field voltages. Control and adjustment of armature voltage cause results in a constant-torque drive, while constant horsepower is obtained by field-voltage control. Therefore all DC drives essentially consist of a controlled voltage supply and a feedback network, which controls the dc voltage as a function of speed.

Recently a solid-state or computer control is used for this purpose. In this section to introduce some of concepts without going too much detail of electronic controls to electrical machines requires a sound knowledge of both electronic and machines.

Power switching principles

A wide range of speed control for dc motor can be achieved by controlling the field and armature current by adding resistance in the corresponding circuits. The easily of control is at the expense of reduced efficiency. Commercial electronic controller for dc motor is used ac line alleviating the need for a separately dc source. This controller consists of solid-state circuit and electronic components such as thyristors (SCR), diode, and choppers are essence.

They control the average current supplied to the motor. The combination of control system and motor is usually referred to as the drive system.

Figure9. Show a simple switching circuit in principle. The switch is opened and closed at specified intervals; in fact this be done by electronically. If voltmeter were connected across the load resistor R the average voltage read by a dc voltmeter would be.

$$V_R = \frac{t_1}{t_2} E \quad \text{volts.}$$

Generally, the ratio t_1 / t_2 is called "duty cycle" of the waveform and by controlling it; the amount of power consumed by R is controlled. For example as below the on time is 2ms, while off time is 3ms. Therefore the average current in the circuit is.

$$I_R = \frac{E}{R} \times \frac{t_{on}}{t_{off} + t_{on}} = \frac{12}{2} \times \frac{2}{2+3} = 2.4 \text{ Amps.}$$

For the specific switching rate of one cycle equal to 5 ms, therefore 200 of on-off operation of the switch per one second are required. It can be appreciated that a these switch rates or greater, electronic switching techniques must be resorted to for this either power transistors or SCRs are usually used to handle the required power. There are numerous varieties of circuits that accomplish. The method of speed control by controlling the duty cycle will be illustrated in the following.

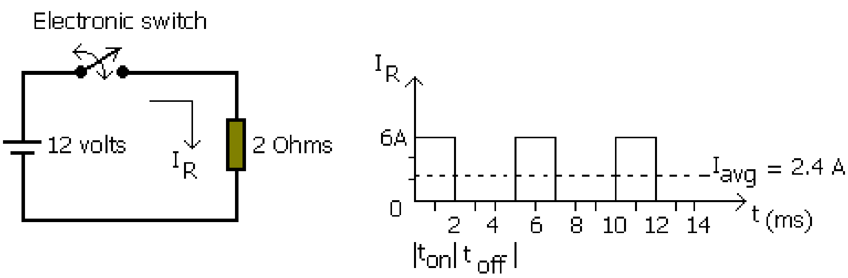


Figure 9 Show a simple switching circuit in principle

Example. A Dc motor is supplied from 120 volts dc switch source as showing. The duty cycle is 50% and the input power is 3 kW at 600 rpm. The armature circuit resistance is 0.05 ohms. Determine

a. The delivered shaft horsepower.
b. The new speed and output horsepower if the duty cycle is increased to 0.6

Solution,

a. If the duty cycle is o.5 the average motor voltage is $V_m = 0.5 \times 120 = 60$ volts

And the average input current is $I_{dc} = 3000 / 120 = 25$ Amps.

Since the average power is the same on either side of the switch, the average motor current is

$$120 \times I_{dc} = 60 \times I_A$$

$$I_A = 2 \times I_{dc}$$

$$= 50 \text{ Amps.}$$

The average counter EMF is

$$E_c = 60 - (50 \times 0.05) \text{ volts}$$

$$= 57.5 = K\phi n$$

Hence; $E_c = K\phi n$

$$K\phi = 57.5 / 600$$

$$= 0.0958$$

Therefore, the average output power is

$$W = 57.5 \times 50$$

$$= 2{,}875 \text{ watts.} = 3.85 \text{ Hp,}$$

b. When the duty cycle is adjusted to 0.6 the average motor voltage becomes 0.6 x 120 = 72 volts. With the load remaining the same, the torque will remain constant, since $T = K\phi I_A$, The field current being constant. Thus I_A remains the same.

Hence;

$$E_C = 72 - (0.05 \times 50) = 69.5 \text{ volts}$$

And the new speed

$$n' = \frac{69.5 \times 600}{57.5} = 725 \text{ rpm}$$

The output power

$$P_o = E_C\ I_A = 69.5 \times 50 = 3475 \text{ watts}$$

$$= 4.66 \text{ Hp.}$$

As example above the controlling of dc motor speed by controlling of duty cycle is rather than changing of armature resistance or field resistance. Control by electronic means results in insignificant added losses their force. High system efficiencies can be maintained at all speeds. Considering that at a duty cycle of 1.0 that is, when full voltage is applied, the speed becomes 1200 rpm. The speed of the motor can be controlled over a wide range. Of course additional control is available by changing the field current as well as.

When a high inductive circuit is interrupted abruptly, the inductance temps to keep the current flowing. It can do so only when a path provided. Therefore a diode is added in the circuit as shown, normally referred to as a freewheeling diode.

Diodes

A silicon diode is two terminal devices consisted of a thin layer of silicon, doped so as to provide a P-type layer and N-type layer. A diode allows unidirectional flow of current. That is conducts well in only one direction. The figure shows the circuit symbol and static characteristic of diode. Current flows through the diode when the voltage at the anode (P-type materials) is positive with respect to the cathode (N-type materials). The allow configuration of the symbol shows the direction of conventional current flow and the diode is then open circuited.

Thyristors (Silicon- controlled rectifiers)

A silicon-control rectifier (SCR) is a three-terminal device made from four layers of alternating P-and N-type materials. Normally, the device blocks current flow in both directions, using one of P-N junction's forms by these layers. Common N1 layer performs most of the blocking duty, so that the block capacity is symmetrical. A second layer N_2 forms the cathode and the other P_1 layer forms the anode. The gate is connected to the P_2 layer. A positive pulse of current from the gate to cathode floods junction J_2 (which is responsible for forward blocking) with carries so that it looses its blocking capability and start to conduct in the forward direction. Once start the gate signal can be removed, as this process is self-generating and forward blocking cannot be recovered without turning off the current flow. Normally with gate current applied, the thyristor will perform essential the same as a diode.

Gate pulses are of a few microseconds' duration and insignificant power compared to that controlled. Conduction ceases when the positive voltage is removed from the node, after control by the gate is reestablished.

AC rectification

In the section on power switch principles, it was shown that dc motors could be energized from dc source using electronic switching methods. As the result current or voltage waveform indicates, the ripple in the armature current will generally by high. Thus some additional filtering in the circuit is necessary to keep the motor losses to acceptable levels, although the armature inductance may provide some of this filtering.

To have some measure of ripple present, the form factor is used. It is measure of departure from pure dc and is defined as the root-mean-square (rms) value divided by its average value of the current. For half-wave rectifier current the form factor is 1.57; for full-wave it is 1.11 pure dc has a factor of 1.0 or unity.

The form factor is an important consideration with motors designed to operate form rectified ac power supplies. The increase in motor heating for a constant out is approximately proportional to the square of the form factor. For example a motor operating from half-wave rectified dc will have about 2.5 times the heat rise of the same motor operating on pure dc voltage source.

To accommodation the increase heating effect, a larger motor is generally required for such applications. However, with motor ratings increase, larger amounts of power are needed, which are available only from ac sources. Alternating current is then converted into direct current using rectifiers, thyristors, or a combination of such devices.

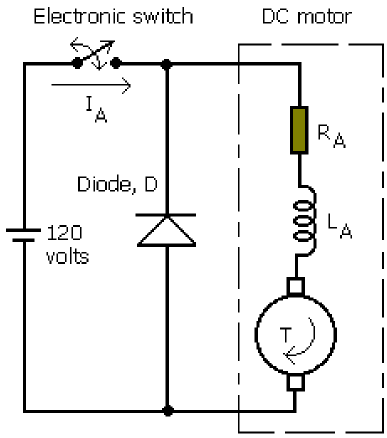


Figure 10 Show a simple electronic switching circuit in principle

Part 3

Direct current shunt motor

By

Suthipong Thanasansakorn

22/3/2001

Southeast Asia Fishery development center
Training Department
Thailand

Direct Current Shunt Motor

Introduction: The principle of dc shunt motor is the current carrying conductor in the magnetic field. The exciter field of the motor forms the magnetic field here by the exciter field of motor; the armature winding embodies by the conductor coil. The super positioning of the exciter field and magnetic fields around the conductor coil produces a force (Torque) on the moving conductor loop or armature. This torque is proportional to the magnetic field and the armature current.

$$M \sim \Phi I_A$$

The conductor or conductor rotates in a motor with two poles, the rotating motion would cease at 90°, Since at this point both force directions are indeed parallel different from the other rotation direction. For the rotation that is to proceed, one of the magnetic fields must be reversed at this moment. The collector also called commutator or current reverse carries out in this function. It continuously reverses the current direction in the armature coil so that the current direction remains constant below the north and south poles of the exciter field. This produces is continues rotating motion of the armature. The zone, where the current reverse it takes place, is described as the neutral zone.

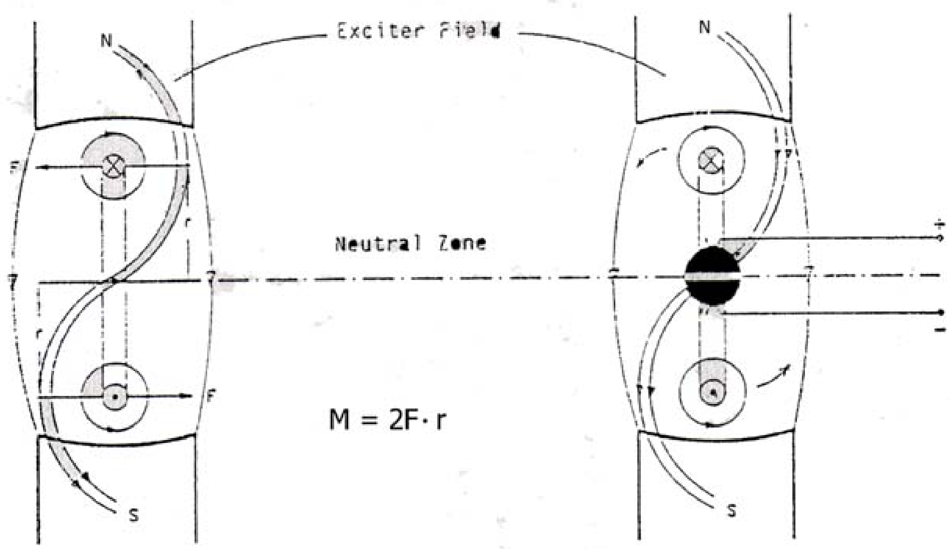


Fig.1 The current carrying conductor coil in the magnetic field

Fig. 2 the current carrying conductor coil in the magnetic field with commutator

Design

The dc machines consist of the stator and the rotor. The stator is constructed either of solid steel or in modern motors out of laminated sheet metal. It contains windings which are located on the pole pieces and which produce the exciter field. In a dc shunt motor, the exciter winding is parallel to the armature winding, that is, in shunt connection. It consists of many windings of thin wire. The exciter winding of a dc shunt wound motor can also supplies a separate voltage source. In such case one speaks of a separately exciter motor. There are also dc motors with permanent magnetic excitation up to approx. 30 KW. The armature is constructed out of laminated sheet and contains the armature winding in grooves located on the armature. The ends of the armature coils are soldered on to the bars of the collector.

The current flow to the exciter winding and to the armature is provided by making the corresponding connections on the motor terminal board, whereby the current flow to the armature during rotation is carried out via the brushes located on the commutator.

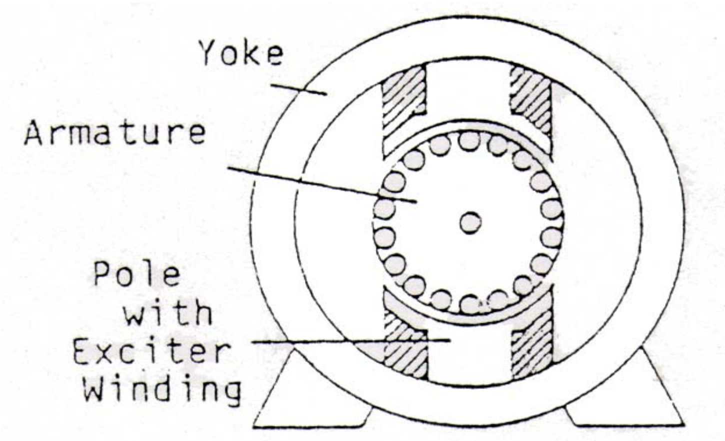


Fig. 3 Cross- section of a 2-pole dc motor

Starting and starting current

A back e.m.f. is induced in the coils of the armature winding which are rotating in the exciter field. This voltage is opposed to the applied voltage. The current in the armature is therefore determined by the difference between the mains' voltage and the induced back e.m.f. Since the armature is at a standstill at the moment of switch-on, the back e.m.f. is absent. As a result the armature current would too high when switched on directly: This could lead to damage the brush switchgear, and the commutator. Therefore a starter resistor is connected in series to the armature in order to limit the current.

Back e.m.f. is the induce voltage (VA) is produced according the law of induction. This voltage is opposed to the applied terminal voltage (V_T) in accordance with Lens's law. The induce voltage is dependent on the magnetic field and the speed of the armature.

$$V_A \sim \Phi n$$

Commutator's winding.

The magnetic field formed by the coils of the armature winding is called the armature cross-field because it is located perpendicular to the exciter field. Both magnetic fields are superposition and form the resulting total field. This effect of the cross-armature field on the exciter field is also called the armature reaction. The affect is not constant but it depends on the load. The brushes of the commutator are arranged in the neutral zones. These neutral zones alter their position with every load: this causes a shift against the rotation direction in the motor and damage to the commutator, brushes. To avoid the commutator faults, machines larger than 1 KW are equipped with commutating poles. The commutating poles are arranges in the magnet frame located in the neutral zone. The commutating pole winding consists of a few turns of thick wire and is connected to the armature winding in series. The commutating poles are connected so that they are in opposition to the armature cross field in the neutral zone and thus cancel it out.

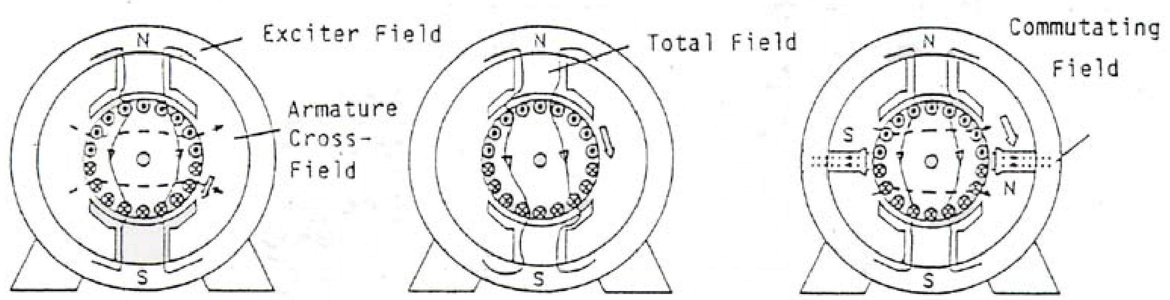


Fig. 4 Shift of the magnetic field in loaded dc motor a and b and

and cancellation by means of commutating poles

In dc motor which are subject to strong load fluctuations, and fast running machines, an additional compensation winding apart from the commutating poles may be required to cancel out the armature reaction. It is arranged along the grooves in the pole pieces of the exciter field. It is also in series with the armature winding. See Fig. 5 and Fig. 6

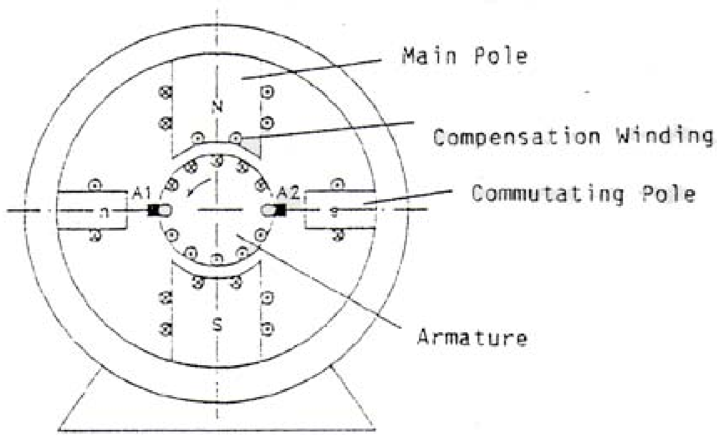


Fig. 5 Cross section of a shunt motor with main and commutating pole and compensate winding Connection and Rotation direction

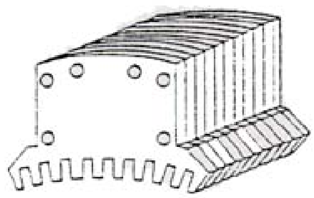
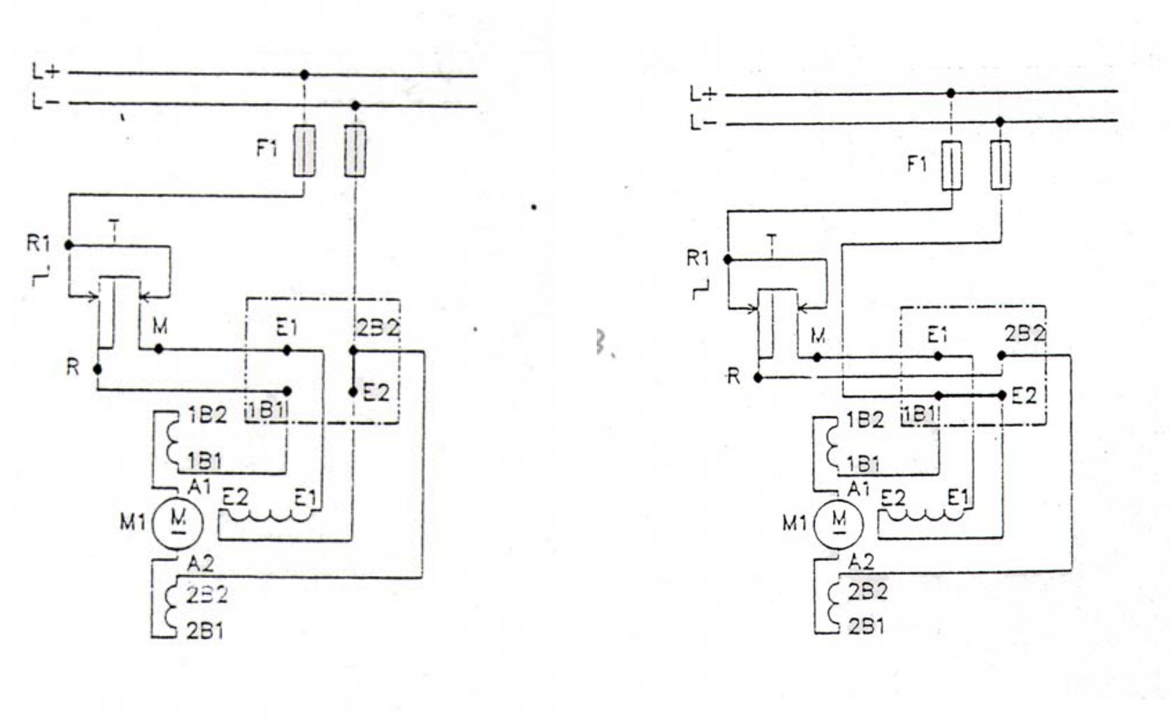


Fig. 6 Main pole with grooves for compensate winding

The connection designations and the current directions determine the rotation direction of a machine. The rotation can be determined by looking at the drive side of the motor. There are two types of rotation in machines and they are referred to as clockwise and counterclockwise. The connection of dc machine has the same designations for motors and generators.

Connection designation:

A_1 - A_2	=	Armature winding
B_1 - B_2	=	Commutating winding
E_1 - E_2	=	Shunt winding
F_1 - F_2	=	Separately excited winding



a) Clockwise rotation b) counterclockwise rotation

Fig. 7 Shunt wound motor diagram with commutating poles and starter

In this case the alphabetical numerical system for example A_1 , B_1 , E_1 , F_1 stands for the beginning of the winding, then the symbol with the same letter but the next digit for example A_2 , B_2 , E_2, F_2 stands for the end of the same winding. It has been determined that for clockwise rotation, then the current flow every winding from the beginning to the end, that is from the lower digit to the higher digit. In the shunt wound rotor, a current flows from A_1 to A_2 and from E_1 to E_2 for clockwise rotation

Reversal of the Rotation Direction

As an explanation the rotation direction of the armature is determined by the direction of the exciter field and the armature cross-field. Therefore, a reversal of the rotation direction is achieved by changing the direction of one of the two magnetic fields; or rather one of the currents that generates them. However, should the exciter current and the armature current be simultaneously reversed, then the previous rotation direction is determined. The exciter winding of dc shunt-wound motor has a high inductance because it consists of many windings. As a result, high self-inductance voltages could arise during switchover that could easily lead to damage of winding insulator. Hence, Reverse of motors rotation on the armature winding. In this case, the current direction in the commutating winding and, if necessary, the compensation winding must also be reversed.

Speed and Exciter current characteristic

The speed of dc shunt motor can be decreasing or increasing beyond the normal speed by the exciter field. In the practice this is carry out by adjusting the exciter current by using a rheostat in the exciter circuit.

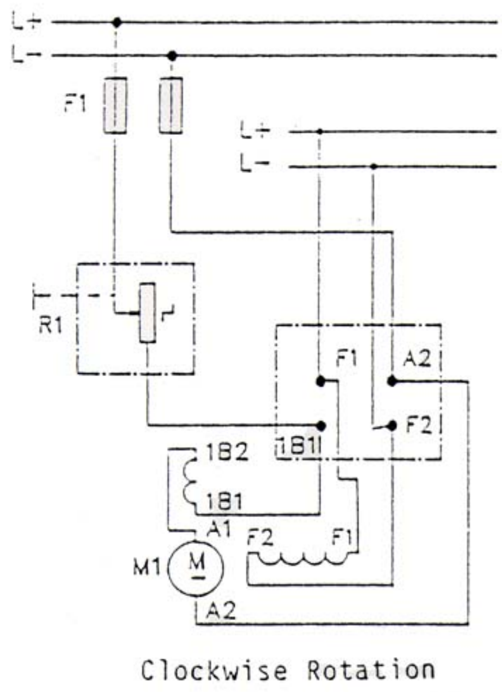
Separately excited dc shunt wound motors; the voltage source for the exciter field itself can also be change if necessary. Since the exciter fields together with the armature current generate the torque as mention the torque of dc shunt motor decreases when the magnetic field is weaken. However a reduction of power is compensated for by the increasing speed of the rotor itself. The following can be concluded for the speed of the motor:

$$N = V_T - I_A \cdot R_A \; / \; (\Phi \cdot C) \text{ Or}$$

$$N = V_A \; / \; (\Phi \cdot C)$$

Where:

I_A	=	Armature current
V_T	=	Terminal voltage at the armature
V_A	=	Induce back e.m.f. in the armature
R_A	=	Internal resistance of the armature circuit
Φ	=	Magnetic flux density of the exciter field
N	=	Revolution
C	=	Machine constant (conductor length, number of winding)



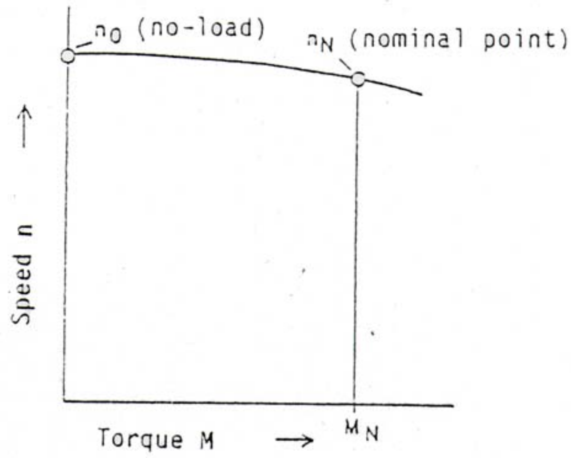


Fig. 8 The Separately excited circuit with Commutating poles, starter and field regulator.

Fig.9 Speed and exciter current characteristic of dc shunt wound motor.

Caution: Should the manufacturer of the dc shunt motor provide no special instructors concerning the field regulating range, then the increased of rotor speed caused by the weakened fields may not exceed the normal speed by more than 10%. In dc shunt wound motor operating at no-load, a field that has been weakened too severally can lead to an extremely high rotor speed, the motor " races ". As a consequence the motor is destroyed by the centrifugal force that is generated.

For special applications, however, the dc shunt wound motor can be completely adapted for speed setting ranges of 1: 3 and more under load with constant power. A very weakened field, for example a break in the armature circuit, also causes extreme damage in dc shunt wound motors under load. The load torque does indeed prevent the racing of the motor but the lack of large portion of t he excitation results in a very small back e.m.f. in the armature. A slight armature resistance and increases to a very high value only limit the armature current. If the motor is not immediately switch off, the commutator, the brushes and also the winding are damaged.

Speed and armature voltage characteristic of dc shunt motor

A second possibility to alter the speed of a dc shunt wound motor is offered by the reduction of the armature voltage V_{T} , the change of terminal voltage at the armature circuit can be realized using a rheostat connected to the armature circuit (starter) as well as using a variable dc voltage.

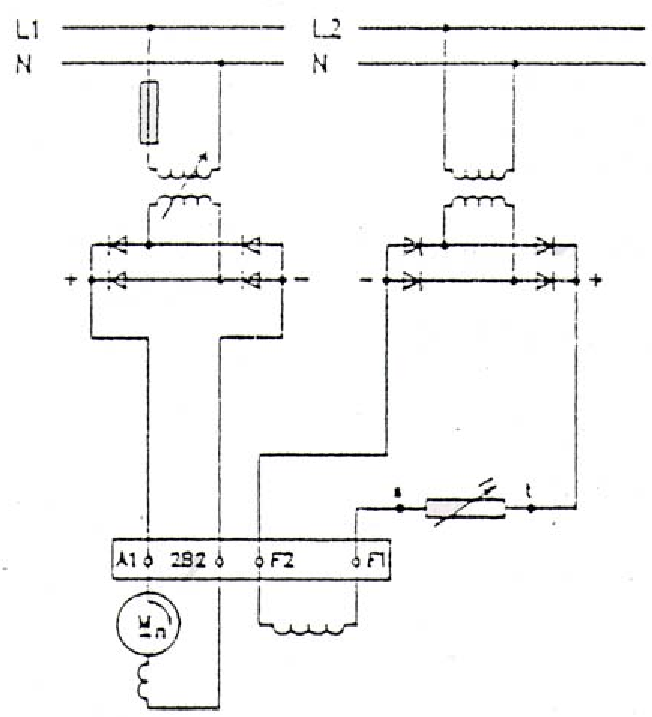


Fig. 10 Speed changing of a separate excited of dc shunt motor using variable transformer in the armature circuit to below nominal speed and separate field regulator.

For this the rheostat must be suitable for continuous operation below nominal load. In this fashion, the speed can be basically reduced from the nominal speed to zero. Since the excitation remains unchanged here, the motor can produce its nominal torque, however at that point the power reduces because of the reducing speed.

. Naturally, as the motor speed decrease, the ventilation of the motor decreases in relation to the square of speed, and the rotation of the armature is dependent on the construction of the motor - number of grooves, laminations of the commutator. These aspects could reduce the speed setting range and motor application possibilities in the range below the normal speed. Assistance is here found by proving separate ventilation and special armature construction.

Difference between the methods

Speed controlled with variable voltage source, an armature voltage may be set independently from the load of the motor. This results in a separate speed-torque characteristic with definite no-load speed and shunt characteristic for each armature voltage setting: the decrease in speed between no-load and nominal load is only relatively slight. The dc shunt wound motor.

$$V_A = V_T - V_R$$

$$V_R = I_A \cdot R_A$$

Where: V_A = Voltage across armature circuit.

V_R = Voltage drop across the resistance.

I_A = Current in the armature circuit

R_A = Armature series resistance.

V_T = Terminal voltage of the DC source.

The smaller load caused the lower voltage drop across series resistor and smaller speed changing effect. The opposite is also true, the greater load and the greater voltage drop across the series resistor, which reduces in motor speed.

Consumed power (P_I)

The consumed power P_I is calculated from the measured values of VT, I_A , and I_E as following formula:

$$P_I = V_T (I_A + I_E)$$

Delivered power (P_O)

$$P_O = M \cdot \omega$$

Where: P_O = Delivered power in watt

M = Torque in NM.

ω = Angle velocity

= 1/ s

= $2 \Pi n / 60$

Part 4

Alternating current generator

By

Suthipong Thanasansakorn

1/6/2000

Southeast Asia Fishery development center
Training Department
Thailand

GENERATOR

Introduction:

The brush-less ac generatoris the output current of an armature type ac exciter mounted on the shaft of the main generator to excite the field system of the main generator through a rotary rectifier, thus generating ac power.

Types of generator

(1) The types of generator are available for the kind of current:

DC generator such as Shunt, compound, series generators

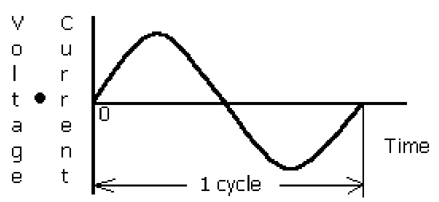
AC generator as Shingle phase, three-phase, multi phase generators

(2) Generators are classified as follows depending upon the kind of prime mover, or power turning them: Water-wheel generator, Steam turbine generator, Motor-generator, Diesel generator (light fuel oil, heavy fuel oil), Gasoline generator, Wind-wheel generator, Atomic power generator.

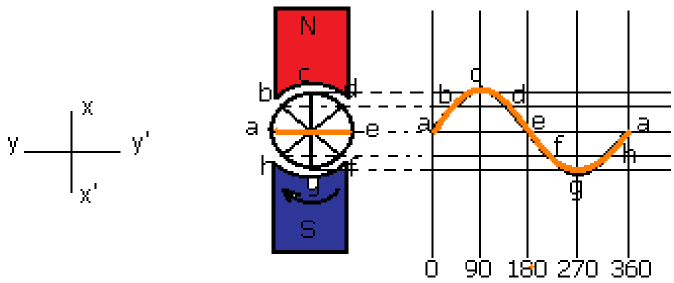
As AC sources for civil engineering construction work, small gasoline generators are used in smaller work, and diesel generators in larger work. In general, diesel generators are use as auxiliary or emergency power sources. (AC generators in particular). Formerly, DC generators were used for marine power generation and in special power plants, but recently DC generators owing to expensive costs for wiring, protective equipment, etc have replaced these. Many DC generators are used for welding machines, and AC generators are also in use. Depending upon on the applications, they are divided into the two generator types: with a diesel engine and with a gasoline engine.

Principle of alternating current

Alternating current alternately varies its magnitude and direction with time.



If a conductor is placed between the north and south poles as illustrated on the next page, and turned clockwise, electricity is generated with respect to the position to the position of the conductor as shown in the following illustration.



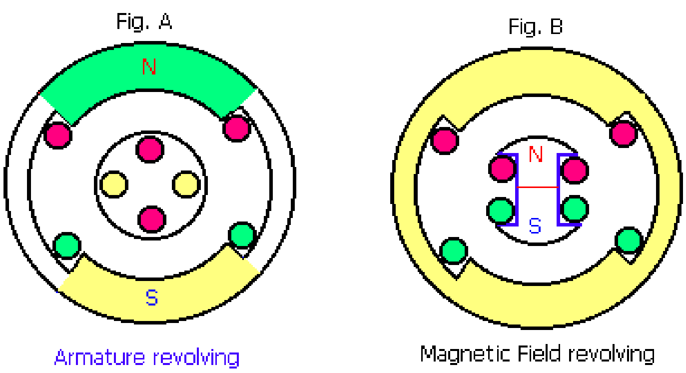
Illustrate the direction of current alternately changes

When both ends A and B of the conductor are on the axis X – X′, they cross the flux at a right angle to cut the flux. When both ends are on axis Y – Y′, they do not cut the flux at all. Thus, when ends A and B are rotated clockwise, the direction of the current alternately changes and the magnitude also varies as illustrated.

Such electromotive force is called "Voltage" The alternating of electric power and a machine producing alternating electromotive force is called an "AC generator".

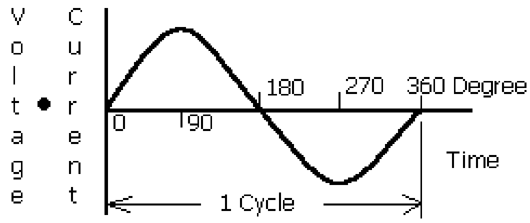
Types of AC generator

The types of Ac generator are revolving-field type, revolving-armature type, and inductor type. The generator illustrated in the following figure is called revolving-armature type because the armature revolves. To induce electromotive force, a coil is only required to cut the flux. Therefore, when a field is revolved with a coil fixed as in Fig. (b), an electromotive force is induced. Such a generator is called revolving-field type. The revolving-armature type is mainly used for generators with a smaller capacity, but it is difficult to insulate the armature winding of this type of generator, so the revolving field type is used instead.



Revolving speed of and frequency

If an armature or a field makes one revolution (360°) per second, a wave form of alternating current is drawn.50 revolutions per second called "50 cycles" (Hz)60 revolutions per second called "60 cycles" (Hz) The number of cycles per second is called frequency



Generator frequencies

The electromotive force moves via one cycle per turn in a two-pole alternating current generator, but via two cycles per turn in a four-pole generator. That is, electromotive force of generators with P number of poles will go through cycles per revolution. If Ns(synchronous speed) is the number of revolutions per minute, the frequency of the electromotive force will be given by the following formula:

$$\text{Frequency} = \text{Revolution per second} \times \text{Number of pole pairs}$$

$$= \frac{\text{Revolutions per minute}}{60} \times \frac{\text{Number of poles}}{2}$$

$$f = \frac{Ns}{60} \times \frac{P}{2} = \frac{(Ns \times p)}{120}$$

$$Ns = \frac{(120 \times f)}{P}$$

Where:

F	=	Frequency (Hz)
Ns	=	Number of revolutions at synchronous speed
P	=	Number of poles

RPM of the different frequencies and number of poles

Number of poles Cycles	2P	4P	6P	8P	10P	12P
60 Hz	3,600	1,800	1,200	900	720	600
50 Hz	3,000	1,500	1,000	750	600	500

rpm: unit of revolutions per minute

Capacity and current of generator

Single – phase

$$\text{Capacity (kVA)} = \text{Voltage (E)} \times \text{Current (I)} \times \frac{1}{1000}$$

$$= \text{VI} /1000$$

$$\text{(kW)} = \text{Voltage (E)} \times \text{Current (I)} \times \text{P0wer factor} (\cos\theta) \times \frac{1}{1000}$$

$$\text{KW} = \text{VI} \cos\theta /1000$$

$$\text{Current (I)} = \frac{\text{Capacity (kW)}}{\text{Voltage(E)}} \times 1000$$

Three – phase system

$$\text{Capacity (kVA)} = \sqrt{3} \times \text{Voltage (E)} \times \text{Current (I)} \times \frac{1}{1000}$$

$$= (1.732 \text{ VI}) / 1000$$

$$\text{(kW)} = \sqrt{3} \times \text{Voltage (E)} \times \text{Current (I)} \times \text{Power factor} (\cos\theta) \times \frac{1}{1000}$$

$$=(1.732 \text{ VI} \cos\theta) /1000$$

Generally, the power factor of a three – phase generator is taken for 0.8, then

$$\text{(kW)} = \text{(kVA)} \times 0.8$$

Relationship between engine output and the generator capacity

$$\text{Generator capacity} \cong \frac{0.746 \times \text{generatoe eff} \times (\text{Engine output(ps)} \times \frac{1}{k})}{\text{Power factor}} = \text{KW}$$

$$\text{Engine output} \cong K \left(\frac{\text{Generator capacity (KVA)} \times \text{Power factor}}{0.746 \times \text{Generator eff.}} \right) = \text{PS}$$

Where:

K = Allowance factor is the mechanical output power of the engine it is usually taken as follow:

K = 1.2 for diesel engine and
1.4 is for gasoline engine.

Generally, the power factor ($\cos\theta$) is 1.0 for a single-phase generator and 0.8 for a three–phase generator.

Example If a three-phase generator having an efficiency of 85% and power factor is o.8 set to a 100 PS diesel engine, how much kVA of output can be obtained?

Where:

100 PS = Engine output x K

Solution.

$$\text{Generator capacity} \cong \frac{0.746 \times \text{generatoe eff} \times (\text{Engine output(ps)} \times \frac{1}{k})}{\text{Power factor}} = \text{KW}$$

$$= \frac{0.746 \times 0.85 \times (100 \times 1/1.2)}{0.8}$$

$$= 66.05 \text{ kW}$$

$$= 82.56 \text{ KVA}$$

Consequently an output of 82.56 kVA can be obtained.

Brush-less generator

Generators with out brushes are called brush-less generators. They use a permanent magnet for excitation, rotary rectifier, etc.

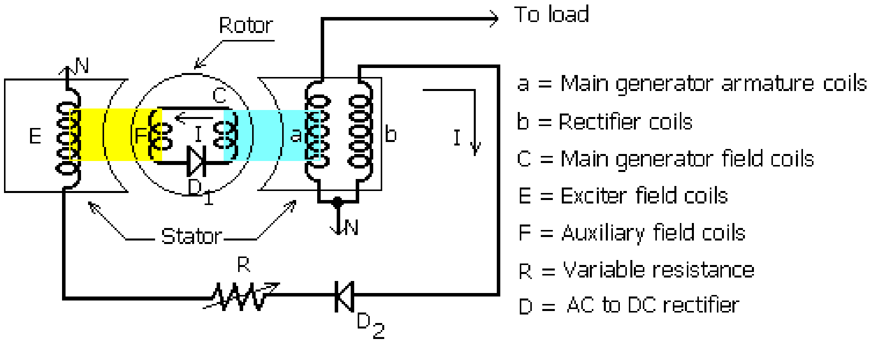


Fig. 1A the equivalent diagram of brush-less generator

The rotor is wound with the field coil of the main generator and armature coil of the main generator and the field coil of the AC exciter. Excited current rectified through the rectifier is supplied by the reactor in the generator output circuit to the field coil of the AC exciter. In addition, the armature coil of the AC exciter wound on the rotor is magnetized, and another excited current rectifier by the revolving rectifier is supplied to the field coil of the main generator. The rotor revolves and thus the armature coil of the main generator on the stator generates power.

Generator construction

The generator is composed mainly of a stator frame, stator core, stator winding, field core, field winding, shaft, bearing, ac exciter, rotary rectifier, and so forth. Cooling is take by the fan fitted to the rotor the rotor fixed on the driven side through the ventilating port on the non-coupling side, and passes over the surfaces of the field core and coil ends and through the air ducts arranged in the stator core, field core. Eeffectively absorbing the heat generated by them. The heated air is let out of the generator via the ventilating port on the coupling side.

The ac exciter over changes or is incorporated in the generator on the non-coupling side. The rotary rectifier is also mounted on the same side to supply an exciting current to the field winding of the generator.

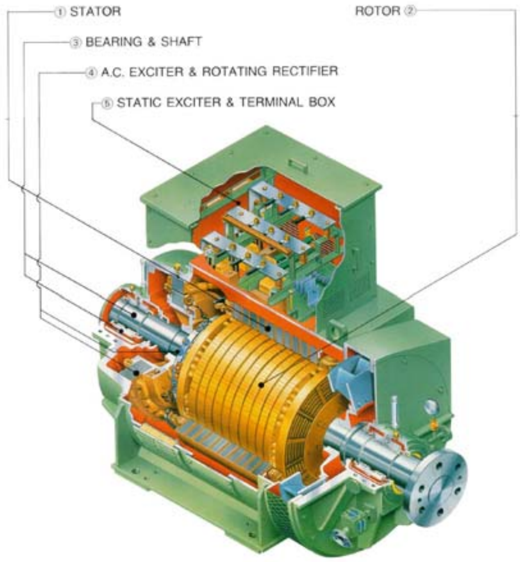


Fig. 1B the overall generator construction

Stator part

The stator frame is constructed of welded mild steel plates, being so designed as to have sufficient mechanical strength and to withstand electric shock. The stator core is provided with silicon steel plate, which is good in magnetic characteristics. And coated with an insulating varnish for prevention of eddy current is punched, and the punched plated elements are piled along the inner circumference of the stator frame from one side and equipped with air duct at each of regular pile intervals. The core thus formed is forced in fastened by stator clappers made of steel plate.

The stator winding is formed of electric wire of insulation class " B " or " F ", and placed in the slots which have been formed in the inner periphery of the stator core and protected with an insulating material of class B or F. The winding thus placed is fastened to the stator core by special wedges and then subjected to sufficient varnish impregnation and drying. The outward appearance of the stator is shown in Fig. 2

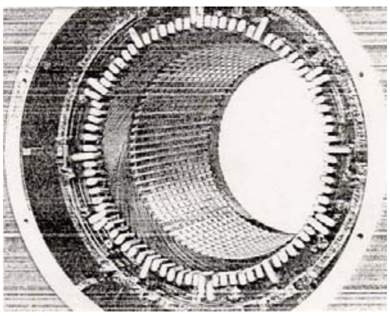


Fig. 2 The stator part

Rotor Part

The field core is made up from the laminations of material having a exceedingly high coercive force for ease of voltage self-establishment. The laminated core is fitted into the shaft (or the spider) and clamped at both ends by means of rotor clambers, and serves also to protect the winding. The field core has such cross-sectional configuration as illustrated in fig.3

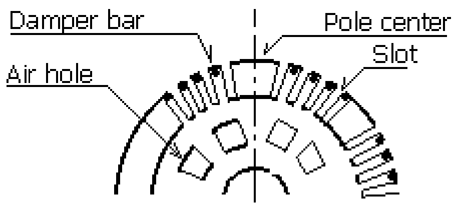


Fig.3 illustrated the laminated rotor core of a generator.

The slots in which the field coils are to be placed are formed in a number of slot groups, which corresponds to the number of poles. The pole center exists between slot groups.

The damper bars are provided only in generators for parallel running. The damper bar as illustrated in fig.2

The field winding is formed of electric wire of insulation class B or F and placed in the slots furnished with a class B or F insulating material. The coils placed in the slots are fixed firmly to the field core by special wedge and subjected to sufficient varnish impregnation and drying.

The coil ends are bound by piano wire or special tape so as not to move out by centrifugal force. The external appearance of the rotor is shown in Fig. 3 the shaft is made of an excellent forge steel material in careful consideration of mechanical strength. For the generator to be directly coupled to a diesel engine, special attention has been paid to prevention of shaft breakage due to torsion vibration.

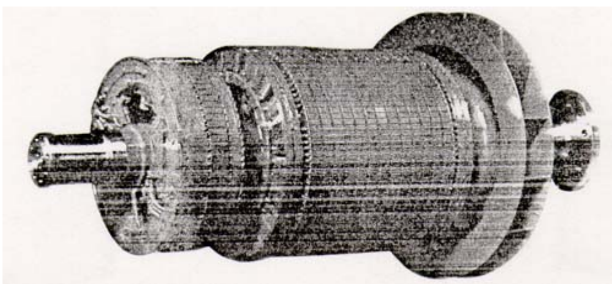


Fig. 4 External appearance of the rotor

Bearings

The bearings are either ball or sleeve bearings. The ball bearings are lubricated with grease. The sleeve bearing is each split in two for convenience of disassembly and reassembles. Supported by the lower portions of end brackets or the lower portion of pedestals and cases the bearings have sufficient strength to withstand external forces, axial load and vibration.

Lubrication system

Three lubrication systems are employed.

a) Grease lubrication
b) Oil ring lubrication
c) Force lubrication

Ventilation

In the generator of the enclosed and self-ventilation type, the fan fitted to the rotor on the non-driven side cause cooling air to be drawn in through the port on the non-coupling side and to pass over the surfaces of the stator core and the coil ends. The air effectively receives heat generated by these components and then flows out through the vent port on the coupling side.

The ventilation ports are provided with sufficient protecting for protecting of the human body and against the entry foreign solid objects.

AC. EXCITER

The ac exciter is of the rotating armature type and located on the non-coupling side of the generator, overhanging or mounted within the frame of the generator proper. The exciter is composed mainly of a stator frame, field core, field winding, armature winding.

Stator

The stator frame is constructed of welded mild steel plates, being so designed as to have satisfactory rigidity and strength.

The field core is made by placing laminations of a material having excellent magnetic characteristics in the stator frame and is fastened by clambers. In the field core, slots in which the field winding is to be placed are formed in number of slot groups, which corresponds to the number of poles. The pole center exists between slot groups. A damper winding is provided for enhancing the instantaneous characteristics and the damping effect.

The field winding is formed of electric wire of insulation class B or F and placed in the slots formed along the periphery of the field core and furnished with an insulating material of the employ classed. The winding put in the slots is subjected to sufficient varnish impregnation and drying and fastened to the field core by wedges.

Rotary rectifier

The rotary rectifier is fitted to the generator shaft end for ease of inspection. Two conductive disks are attached to a rotary rectifier boss through an insulating plate. The conductive disk carries silicon rectifiers for each phase, a silicon carbide varistor (silistor) for surge prevention and other parts. These components serve for three-phase full wave rectification of ac output of the ac exciter to supply a dc exciter current to the field winding of the generator.

Space heater

The generator windings may absorb moisture while the generator is at rest. In order to prevent this moisture absorption, it is necessary to keep the temperature within the resting generator a little higher than the ambient temperature. A space heater is provided to satisfy this requirement.

The space heater is located at the lower portion of the generator frame so that the heat air circulates in the generator to serve effectively to protect the windings and the related parts from moisture. Therefore, when it is intended to keep the generator at rest is sure to turn on the power switch for the space heater. When starting the generator is sure to cut off the power supply to the space heater. Fig. 5 shown the mounted space heater

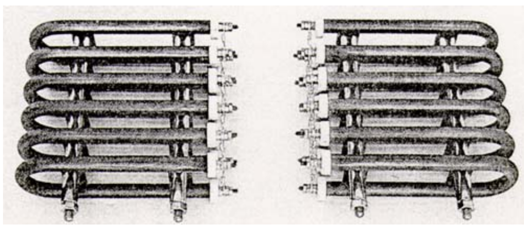


Fig.5 Show the outward appearance of the space heater

Air Filter (special specification)

A drip-proof protected type generator, the generator is equipped with an air filter, it is located at the cooling air suction port so as to minimize the entry of dust, oil vapor and other foreign matter into the generator, so that the generator interior can be kept cleaner than otherwise.

Air cooler (special specification)

In the generator of the totally enclosed, air cooling type, an air cooler is mounted on top of the main body of the generator.

a) As a rule seawater is used for cooling. The maximum temperature of seawater (the temperature at the inlet of the air cooler) is 32 °C.

b) The cooler employs double tubing. The inner into which seawater enters is a seamless copper alloy tube having cooling fins brazed around the periphery.

The advantage of employing the double tubing is that, if the cooling tube damage owing to corrosion by sea water, leaking water passes through the space between the inner and outer tubes and flows out of the cooler so that there is no danger of water intrusion into the generator. Also, the leaking water discharged out of the cooler flows through a drainpipe and detected by a water leakage detector.

c) In the cooler, about 5% of the whole cooling tubing is intended for auxiliary use and equipped with blind plugs. In case a normal cooling tube is damaged, an auxiliary tube can be used, with the damaged normal tube clogged with blind plugs.

d) The tolerance of the cooling capacity is determined to meet the case in which the cooling efficiency of the cooling tubes including the auxiliary tubes lowers by about 20% of the designed overall efficiency owing to dirt attached to the cooling tubes.

e) The tube plate is made of naval brass, and the water chamber is formed of cast iron. A rubber coating is applied on the inside surface of the water chamber, and also zinc or mild steel is used for prevention of electrolytic corrosion.

Exciting operation

The understanding of the operation principle is very important for proper handling of the generator and quick troubleshooting. Refer to the basic circuit arrangement show in Fig. 1A The output of the rotary armature type ac exciter coupled to the generator rotor shaft serves to excite the field system of the main generator through the rotary rectifier fitted to the end of the generator shaft. The ac. exciter has two separate field windings, that is, the first field winding F_1 and second controlled field winding F_2

The second field winding is a control winding for stabilizing the generator voltage, and the AVR output currents through the second field winding to excite the same winding so as to keep fine regulation of the generator voltage.

The reactor and the current transformer are set to pass exciting currents for over-compensation as compared with the exciting current required both to maintain the desired generator terminal voltage and to compensate for the voltage drop due to the load current armature reaction. As a result, the automatic voltage regulator (AVR) supplies its output current differentially to the control winding to offset part of the excitation of the first field winding, thereby keeping the generator terminal voltage constant.

Silicon rectifier and protecting device

The silicon rectifier elements as shown in Fig.6   Role of rectification, the current passes the rectifier elements only in one direction or half circle of the sine wave and no current in the opposite direction. The silicon rectifier has a peak voltage and would be damaged by applies of over-voltage which exceeds the peak reverse voltage. Therefore, the silicon rectifier must be used together with a protecting device against over-voltage.

The silicon rectifier is connected to the silicon rectifier on the dc side which is used for protecting the over-voltage when the generator is short-circuited the silicon input voltage might become an over-voltage nearly 10 times as high as the rating. The silistor is the varsity made of silicon carbide, when the voltage applied to the silistor decreases, its resistance increase non linearly, and vice versa so that its serve effectively for over-voltage absorption

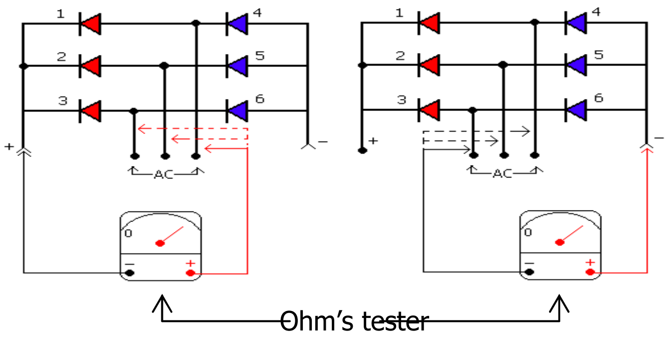


Fig.6 illustrated the measurement procedure of silicon

Operation of the generator

When operating the generator, practice the following items completely in order to ensure safety and to elongate the lifetime of the generator and machine.

Check foe any matter, iron fragments loose screws etc. should this check be neglected, there might occur serious damage to the generator during operating conditions.

Preparation for running

a) Installed condition:

-Check if the coupling has been done at the proper position.

-Check if the clamping bolts are fully tightened.

b) Terminal section:

-Inspect the lead wires for any flaw or crack in their coatings.

-Check for sure that terminal treatment and correct terminal codes and phases.

-Check for looses bolts and nuts in the terminal section.

c) Insulation resistance

Measure the insulation resistance between each winding of the generator and ground with 500 V megger. It is desirable that the measure resistance is above one MΩ.

-In order to avoid applying the megger voltage to the AVR is sure to disconnect or short the terminals.

d) Air cooler

-Check the cooling tube for deposition of scales.

-Check if oil and dust is attached to the cooling tube fins.

-Check for water accumulation in the water leak sensor.

-Examine the degree of wear of the zinc or mild steel used for prevents of electrolytic corrosion.

e) Bearing section

-In case of oil ring lubrication system makes that the lubricating oil is supplied up to the red mark of oil gauge.

During running

When operating a new generator, do so under no load at low speed. Meanwhile, inspect components as to temperatures, vibration, sound, etc.

a) Sleeve bearing oil ring rotation

b) Abnormal sound in the bearing section

c) Abnormal vibration

d) Temperature rises in the bearing section.

f) Rapid temperature rises.

Monitoring of the generator panel

At the time of testing at factory, adjustments are made in relation to power factor change, rotating speed change, load variation, etc., so that, when the rated rotating speed is approached, the voltage will build up within ±1.0% of the rate voltage. There fore, there is no need to control the voltage regulator.

Others

a) Temperature rise in the components (refer to the test record)

b) Check to confirm that the readings of the meters on the switchboard are always below the values specified on the name plates especially, output voltage and current.

c) Check the bearings are properly lubricated.

Parallel running

For parallel running of generators, when both generators are matched in frequency and phase and brought into parallel running, any frequency difference and phase difference are completely eliminated because a synchronizing force acts on both generator as soon as they are connected in parallel. If there is any voltage difference, a reactive crosscurrent will flow. Therefore, unless there is any means for controlling the wattles crosscurrent, no stable parallel run can be affected. For this reason, a crosscurrent compensation system employing a differential current transformer for each generator serves for stable operation.

a) Independent operation. During independent operation of one generator, the secondary winding B of the differential current transformer (DCT) is short by ACB auxiliary contacts of the other generator, so that the condition is equivalent to the assumed one in which the secondary winding of the cross compensating current transformer (DCT) is shorted. Therefore, during the single running, this circuit has no influence upon the AVR.

b) Operate with respect to reactive crosscurrent during parallel running. During parallel running, the ACB auxiliary contacts of both generators are opened. So, if a reactive cross current (Ic) flows between both generators, current tends to flows, corresponding to the cross current component, through the secondary windings of DCT_1 and DCT_2 show in Fig. 7. The circuit of the DCT secondary windings B is equivalent to the circuit shown in Fig. 8

If we consider that the DCTs are constant current sources, since their secondary windings B are connects in a crossing manner, the circuit is equivalent to a circuit in which two constant current source of the same capacity are connected in series in opposite directions as shown in Fig. 8. In this case, therefore, the DCT secondary current by reactive cross current does not flow through the secondary windings, and acts on the AVRs through the secondary winding A. That is, with respect to reactive crosscurrent, the DCT secondary windings B can be regarded as not connected, and across the crosscurrent compensation resistor in the AVR there occurs the same voltage as in the case of no DCT provided. The crosscurrent compensating effect is approximately the same as with no DCT.

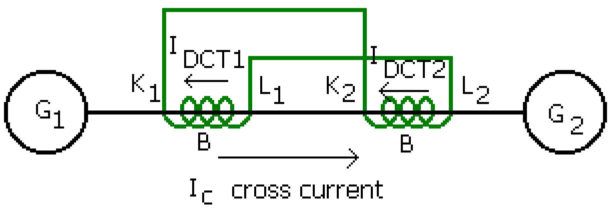


Fig. 7 Cross current in the parallel generators

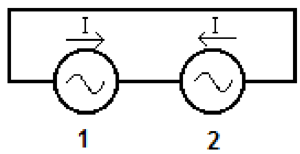
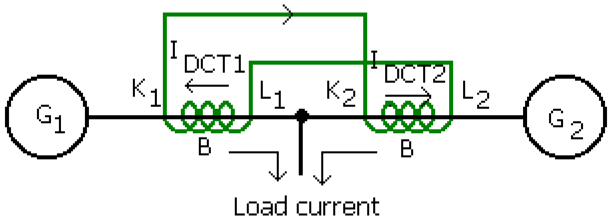


Fig. 8 the equivalent circuits

c) Load current during parallel running. With regard to load current, the circuit of the DCT secondary windings B in Fig.9 is equivalent to the circuit shown in Fig. 10 and further to the circuit shown in Fig. 10 in which two constant current sources are connected. Then the DCT secondary currents with respect to the load current become identical and the condition is equivalent to the assumed one in which the DCT secondary windings B are shorted.



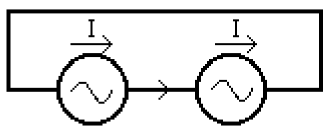


Fig. 10 equivalent during parallel running

Fig. 9 load current during parallel running

Accordingly, the DCT secondary current due to the load current exerts no influence upon the AVR. In the case of current compensation circuit with no DCT, when the generators are for example, under full load at a lagging power factor of 80%, the dropping characteristic is about 3.5 % as shows by curve B in Fig.11. Meanwhile, a crosscurrent compensating circuit including DCTs shows almost the same characteristic as during independent running, as represented by curve A in Fig. 11

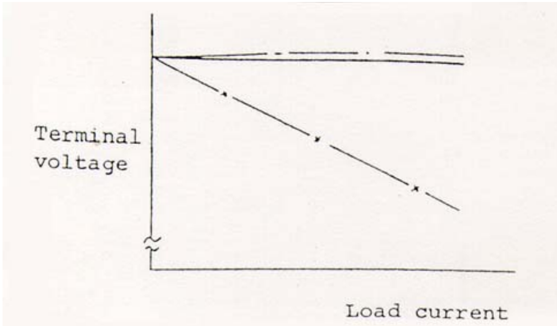


Fig. 11 Load current characteristic of the generator.

As described above, the crosscurrent compensating circuit-incorporating DCTs serves, when the loads are balanced. To discriminate between reactive crosscurrent (90° lagging current) and lagging current by load and exhibits the drooping characteristic only with respect to the reactive current (90° lagging current) so, the voltage regulation during parallel running is markedly improved as compares with the case when no DCT is used. On the generator load sharing are unbalanced, if we assume that the first generator operating under full load (lagging power factor of 80 %). And the second generator operating under no load, are brought into parallel running.

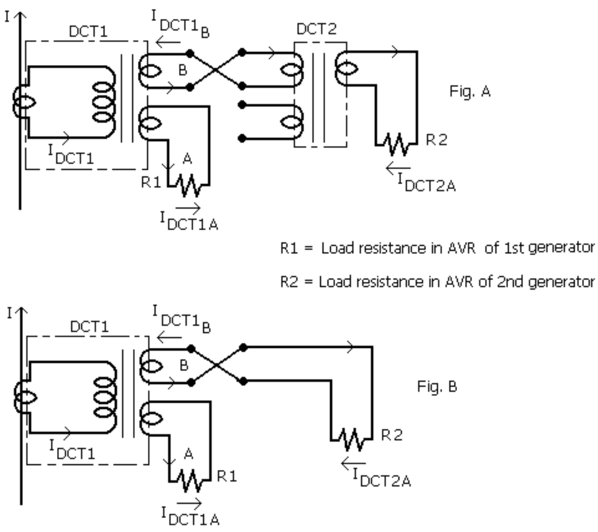


Fig. 12 The direction of current flow between two generators

Both generators have difference DCT secondary currents due to load current, so that there cause no such operation as described before. In this case, a half of the secondary current of CCT_1 of the first generator flows through the winding A of DCT_1 to the load resistance R_1 in the AVR. While the remaining half through the winding B of DCT_1 to the winding B of DCT_2, and through the winding A of DCT_2 to the load resistance R_2 in the AVR of the secondary generator. At the same time, the impedance of the secondary winding of DCT_2, as viewed from the primary winding side of DCT_2, is very large, so that the condition is equivalent to the assumed one in which the primary of DCT_2, is opened. Thus, the circuit of $DCT_{1,}$ and DCT_2 is equivalent to the circuit $_A$ or B

In Fig.12 that is the first generator has its voltage lowered by the flow of lagging current. While the voltage of the second generator is increased since the current $I_{DCT\ 2\ A}$ flowing through the winding a Of DCT_2 via the winding B of DCT_1 acts as current 180° out of phase with the current $I_{DCT\ 1\ A}$ flowing through the winding A of $DCT_{1.}$ So that there occurs the same operations as if the second generator were supplied with a leading current.

All winding A and B of DCT_1 and DCT_2 are identical in the number of winding turns, and AVR load resistance R_1 and $_{R2}$ have almost identical values. So, if we assume that DCT is an ideal current transformer, current $I_{DCT\ 1A}$ is substantially the same as current $I_{DCT\ 2A}$ and the voltage drop percentage of the first generator is almost the same as the voltage rise percentage of the secondary generator. This voltage difference cause a current flow from second to first generator, and through such operation with respect to cross current as described, both generators are stabilized at an intermediate voltage. Accordingly, also for unbalanced loads of lagging power factor, the voltage is approximately equal to the voltage setting of both generators.

Requirement for parallel running

1, In order to operate a generator in parallel with another generator in operation, it is necessary for both generators to satisfy the following conditions:

a) There be identical in frequency.

b) Both generators are equal in voltage magnitude.

d) There are corresponding in phase.

2, Conditions required of prime movers.

a) Both of prime movers have a uniform angular velocity

b) Too adequated in speed regulation.

In case the above-mentioned conditions are not satisfied, the following undesirable phenomena and situations will take place.

a) In case there is no matching in phase, much cross current will flow, and closing for parallel running will be impossible.

b) Any difference in voltage magnitude will cause a flow of cross current between the generators, so that the generators with higher and lower voltages will have lagging and leading currents respectively, and thus reactive power shedding will be impossible.

c) If the generator load characteristics do not include a drooping characteristic with respect to reactive power, stable shedding of reactive power is impossible, and this may give rise hunting or step-out.

d) In case the angular speed is not uniform, load shedding can not be performed. The prime mover is provided with an adequately sized flywheel for angular velocity uniformity.

e) Without governor speed characteristics do not include stability or quick response, just as in the case of (E) load shedding is unstable or hunting or step-out may result.

Synchronizing

1, Carry out governor adjustment on the prime mover side until the frequency of the generator to be connected in parallel with the forerunning generator is approached.

2, While watching the synchronizing lamps, or synchro scope, finely adjust the governor, and close the circuit breaker at the point of synchronism.

a) As to the synchronizing lamps, the time when one of the lamps has gone off and the two others have become brightest is the phase coincidence point.

b) As to the synchro scope, the time when the needle has come to the top center is the phase coincidence point.

c) It is a proper method to start the closing operation with the closing time of the circuit breaker taken into account, and to close the circuit breaker just at the point of synchronism

(The needle of the synchro scope has come to the top center).

Load shedding.

After completion of synchronizing, while paying attention to frequency, operate to governor on the forerunning generator side in the speed lowering direction and operate the governor on the after-running generator side in the speed raises direction. By so doing make a gradual load shift for load shedding.

Release from parallel operation.

When disconnecting one of generators running in parallel from the bus, take the following steps:

1, operate the governor of the driver for the generator to be release in speed lowering direction and operate the governor of the driver for the generator on the bus side in the speed raising direction for load shifting.

2, When the load on the generator to be release become zero, trip the circuit breaker for the same generator.

Temperature rises.

The monitoring of the temperature of devices is an effective means for finding faults. Check the temperature rise in components by referring to the table allowable temperature rise limits as:

Mechanical parts	Measuring method	Insulation class B °C	Insulation class F °C
Armature winding (stator winding)	By thermometer By resistance	60 70	75 90
Field winding of cylindrical rotor	By resistance	80	100
Core or other mechanical parts adjacent to insulation winding	By thermometer	70	90

Note: 1. Where the standard ambient temperature is 45 °C or 40 °C instead of 50 °C, the difference between them should be added to the temperature rise limits specified in the table

2. When LR, GL and NV standards are applied, the standard ambient temperatures shown in the table are for the standard ambient temperature of 45°C.

3. For the generator with an air cooler, allowable temperature rise limits should be obtained by adding (50 °C temperature of cooling seawater of the limits specified in the given table. Generally, the temperature of cooling seawater is 30 °C, so that 20°C should be added to the values in the table.

Insulation resistance

Insulation resistance is an important index for judging the performance of an electric machine to be good or not.

Insulation material changes with time under influence of, independently or in combination, heat, moisture, vibration, mechanical damage, dust, chemical change by acid or alkali, salt content, air, and so forth.

a) Insulation resistance provides excellent data for judging insulating conditions So, measure it periodically during shunt-down, and record also the ambient temperature, relative humidity, etc.

b) For insulation resistance measurement, use 500 V. DC mega ohms.

c) Precaution for insulation resistance measurement:

Component (AVR etc.) which include semiconductors such as transistors and thyristors must be subjects to circuit disconnection or shorting for prevention of application of abnormal voltage, prior to insulation resistance measurement.

d) Judgment of measured resistance. The resistance measured by 500 V megger is acceptable if it is above the value calculated by the following formula.

$$\text{Insulation resistance} = \frac{3 \text{ x Measure voltage of main line (volts)}}{\text{Rated output (KW or KVA) +1000}}$$

The best way for judging the insulation good or not is to compare the newly measured resistance with the value obtained by previous measurement. The variation from the preceding measurement result is significant so that insulation resistance measurement should always be continually carried out with recording.

e) The minimum allowable insulation resistance varies depending upon the machine model, size, etc. and is therefore difficult to determine at a particular value. However, as a simple measure for routine maintenance, one MΩ is considered to be a minimum safe value.

Inspection of exciting equipment and AVR

A. For grounding and conductor connections check once about every six months. When maintenance work is to be done, make sure that no voltage is applied to the exciting system before starting the work. When subjecting the exciting system to insulation resistance measurement or dielectric strength test, do so after shorting the terminals of the silicon rectifier and AVR or disconnecting them.

B. How to check the silicon rectifier

a) The silicon rectifier may become faulty if an over-voltage is applied or if an over-current flows. When the silicon rectifier becomes faulty, almost no generator voltage will be produced. The silicon rectifier is composed of six elements which have such outward appearance as shown in Fig. 13

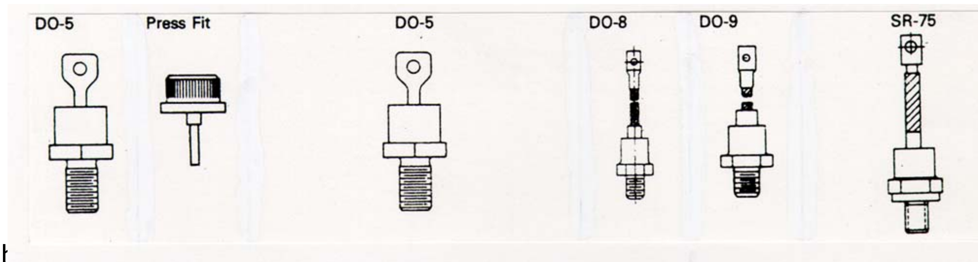


Fig. 13 Heavy duty silicon rectifier type

[illegible] sing a tester by the procedure

(1) Disconnect all wires connected to the silicon rectifier stack.

(2) Using the resistance measuring range of the tester, measure the forward and reverse resistance of each rectifier element.

The forward resistance is acceptable if it is below 10Ω, while the reverse resistance is acceptable if above 100 kΩ. Any rectifier element that is conductive in both forward and reverse directions is defective.

If a faulty element has been found by the above measurement, replace it with a good element.

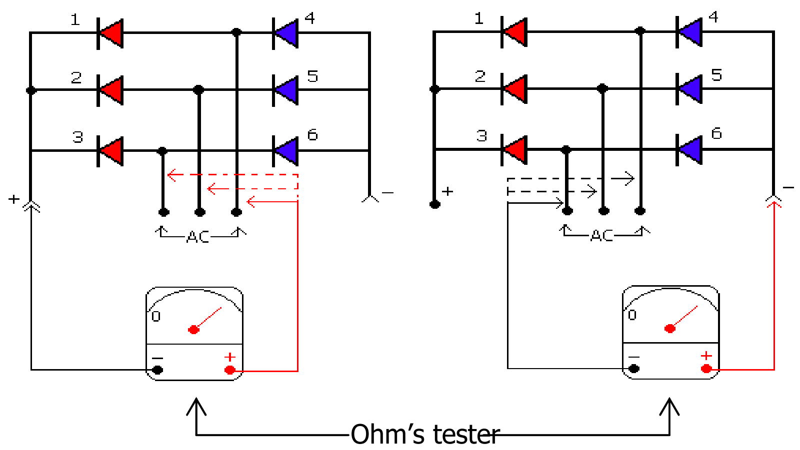


Fig.14 illustrated the measurement procedure of silicon rectifier.

Rotary rectifier

The rotary rectifier exhibits stable performance with excellent mechanical and electric characteristics. So, correct operation and maintenance will allow the rotary rectifier to be used without hindrance for a long time.

a) The rotary rectifier is incorporated in a three-phase full-wave rectifying circuit as shown in Fig.15 As shown a varistor is connected for sure protection of the silicon rectifiers.

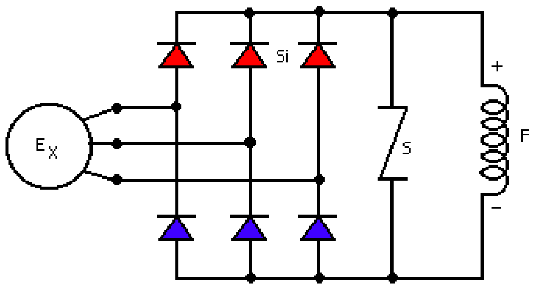


Fig.15 the equivalent rotary silicon rectifier with an over-voltage protector

b) It is important to keep the rotary rectifier and the surroundings clean just like the stator and rotor windings of the main generator and exciter. Carry out cleaning periodically just as for the winding. Also at the same time as cleaning check for any grounded terminal or lead wire and any loose bolt or nut around the rotary rectifier.

c) Implement list of trouble shooting guide line.

symptom	Cause	Remedy
Abnormal voltage decrease	1. Short-circuited elements of the silicon rectifier of the exciting system 2. Reactor disconnection. 3. Current transformer secondary short circuit. 4. Short-circuited thyristor in the AVR. 5. Printed circuit board out of order with resultant control failure. 6. Abnormal rise in the field temperature of the main generator.	Replace the good elements. Replace thyristors or the AVR.Replace the printed circuit board Decrease the load on the generator.
Abnormal voltage rise **Incessant voltage change or hunting**	1. Print circuit board out of order, or thyristor gate circuit disconnection. 2. Detecting transformer disconnected. 3. Disconnection or shorting of the circuit to the control winding. 4. Broken wire or faulty contact in the rheostat for voltage regulation 5. Abnormal in rotating speed. 6. Disconnection or short circuit of the power transformer secondary winding. 1. Faulty contact in the rheostat for voltage regulation. 2. AVR. Damping circuit out of order.	Replace a circuit board or The AVR. Replace the rheostats. Make a regulation or replace the rheostat. Replace The AVR.

Part 5

Optimization of electrical power

By

Suthipong Thanasansakorn

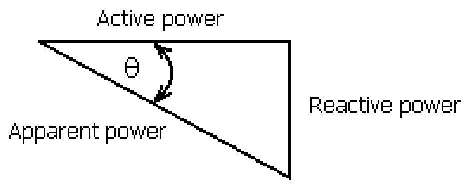
1/6/2000

Southeast Asia Fishery development center
Training Department
Thailand

Key to electrical energy reduction

By understanding power basic is one can reduce the electrical energy. The total requirement is comprised of two components, as in the power triangle as illustrate in fig.1

This diagram had shown the resistive portion or kilowatt (KW). It is ninety degree out of phase with the reactive portion (KVAR). The reactive power is necessary to build up the magnetic field of the inductive device such as motors and coils. But otherwise it is non-usable. The resistive portion is also known as the active power, which is directly converted to useful work.



The hypotenuse of the power triangle is referred to as the kilovolt ampere or apparent power (KVA). The angle between Kw and KVA is the power factor angle.

KW = KVA cos.θ

KVA = KW / cos.θ

KVAR = KVA sine θ

Relationship between power, voltage and current

For the balance three phase load.

Power in watt = $\sqrt{3} V_L I_L \cos\theta$

$$= \frac{\sqrt{3} V_L I_L \cos'}{1000} \text{ Kilowatt}$$

For single phase load

Power in watt = $V_L\ I_L \cos.\theta$

$$= \frac{V_L I_L \cos\theta}{1000} \text{ Kilowatt}$$

Motor loads.

Each electrical load in the system has own an inherent power factor. The motor loads usually specified by horsepower such as 2 HP., 3 HP.. These may be convert to apparent power(KVA) or active power(KW) by use of:

$$KVA = \frac{HP \times 0.746}{eff_M \times PF}$$

And

$$KW = \frac{HP \times 0.746}{eff_M} \quad \text{Kilowatt.}$$

Where:

eff_M = Motor efficiency.

PF = Motor power factor.

HP = Motor horsepower

Example

A plant of load is comprise of:

1. 40 kW of lighting operated at unity power factor.
2. 10 sets of 20 HP motors running at full load.
3. 5 sets of 40 HP motors running at full load.

Where: 20 HP. Motors have form factor

eff_M = 0.862

Power factor (cos. θ) = 0.835

And 40 HP. Motors

eff_M = 90.9

Power factor (cos. θ) = 29°

What is the total power factor resulting from these loads?

Solution.

1. Find the consumption of 20 HP motors, 10 sets.

$$KW_{Total} = \left(\frac{HP \times 0.746}{eff_M}\right) \times 10$$

$$= \left(\frac{20 \times 0.746}{0.862}\right) \times 10$$

	=	173.08		KW
θ	=	33°		
tan θ	=	0.65		
KVAR	=	KW tan θ		
	=	173.08 x 0.65	=	112.5 KVAR

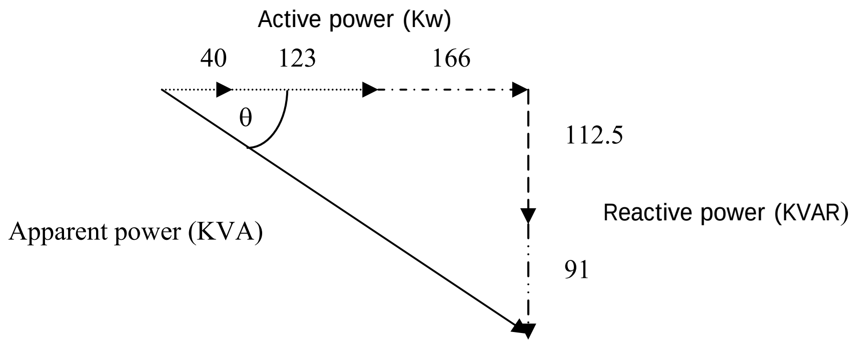
2. The consumption of 40 horsepower, 5 sets.

$$KW_{Total} = \left(\frac{HP \times 0.746}{eff_M} \right) \times 5$$

$$= \left(\frac{40 \times 0.746}{0.90} \right) \times 5$$

$$= 166 \text{ KW}$$

tan θ	=	0.55
KVAR	=	KW tan θ
	=	166 x 0.55
	=	91 KVAR.
Sum of active power(KW)	=	40+ 173 + 166 KW
	=	379 KW
Sum of reactive power	=	112.5 +91 KVAR
	=	203.5 KVAR



And the hypotenuse of power triangle as known as apparent power (KVA)

How to improve the plant power factor

1. Reducing an inefficient loading. The motors must running to full load condition its have a significantly better in power factor.

2.Provide the external capacitor in parallel with motors or at the distribution equipments.

3. Used of efficiency motors.

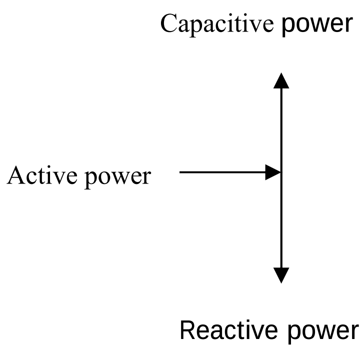
4. Using of synchronous motor instead of induction motors.

How Capacitors improve power factor and recovered electrical power.

Referent to the common role of generator it is produced an electric power with the relationship between magnetic field and length of conductor and the speed of rotation. Voltage which produce has supplied to load with comprised of different power consumption as know as active power, reactive power are the most commonly.

Recently, the electric applications are composed of active and reactive power as known as resistive and inductive loads. These loads have effected to the electric plant system cause to voltage drop. The plant has to control and kept system stable by increase or charge with the reactive power as know in the practical as increase excited current to the generator. Also speed of the prime mover has drop due to heavy load it must be increase to certain level for maintain both of voltage and frequency.

Capacitor, capacitor is one of electric loads. It is different from others compare with resistive and inductive loads. Resistive load consume only an active power, for inductive load it consume both of active and reactive power. But the capacitive load consumes a few of active power and gives better in capacitive power that is opposite with the inductive load as illustrated in the figure below.

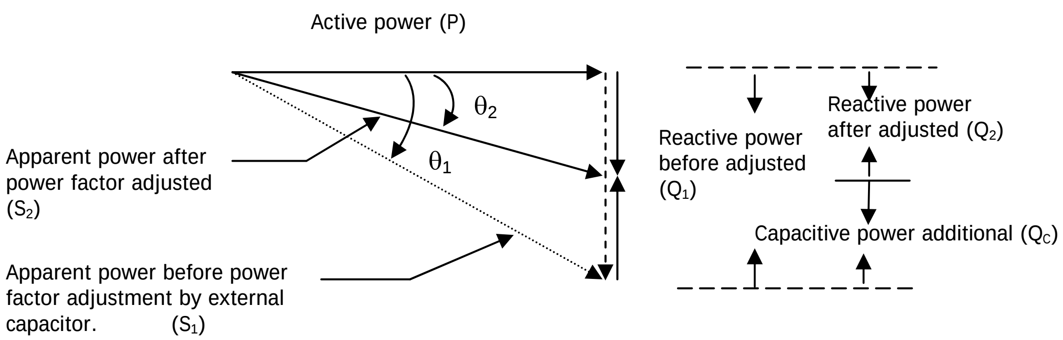


As the figure illustrated above mention, sum of portion is become to leading or lagging power factor is depnding on the value of capacitive and reactive power. In case of capacitive loads is become more bigger than reactive load. It will cause the total power factor of the system become leading. But usualy most of consumptions are reactive load that is lagging in power factor.

What is happen in case of lagging power factor. The hypotenuse of the power triangle portion as known as an apparent power (KVA) that becomes large. It is necessary to reduce the amount of load consumption by reduce the reactive power. But it is impossible to control the system with out reactive load. Then the system has to provided a compensate power as known as capacitive power to adjust or reduce the reactive consumption it will cause in better power angle. In practical it is usually maintain to coverage power factor between 0.8 to 0.85

For industry that is consumes a lot of electric power so that it is necessary to reduce the reactive power and need in better power factor control. Because the electrical authority has installed with the special kilowatt meter to record the demand of all electric consumption such as kWh, KVA, KVAR and power factor.

Sum of power portion is equivalent as show as illustrated below.



Example The 2 kilowatts load has connected to220 volts 50 Hz source operated with 0.70 power factor. The system need to corrected the power factor being to 0.90 find:

1. Reactive power before power factor adjustment.
2. Reactive power after power factor adjustment.
3. Capacitive power and capacitance to correct the power factor

Solution

$$PF_1 = \cos \theta_1$$

$$= 0.70$$

$$\cos^{-1} = 45.6^\circ$$

$$PF_2 = \cos\theta_2$$

$= 0.90$

$\cos^{-1} = 26°$

From the power triangle, the reactive power before adjust can be compute by

$(Q_1) = P \tan\theta_1$

$= 2$ Kw x tan 45.6°

$= 2040$ VAR

$= 2.04$ KVAR

Reactive power after

power factor adjust $(Q_2) = P \tan\theta_2$

$= 2$ Kw x tan 26°

$= 975$ VAR

$= 0.975$ KVAR

Capacitive power for

power factor adjustment $(Q_c) = Q_1 – Q_2$

$= 2.04 – 0.975$ KVAR

$= 1.065$ KVAR

The capacitive value is compute as the following formula

Cap. $= Q_c /(V^2 \times \omega)$

$= Q_c /(V^2 \times 2 \times 3.14 \times 50\text{Hz})$

$= 1065 / (220^2 \times 2\text{x}3.14 \times 50)$

$= 70 \times 10^{-6}$

Capacitor $= 70\ \mu\text{F}$

Apparent power $(S_1) = \text{Kw} / PF_1$

$= 2.0$ Kw / 0.7

$= 2.857$ KVA

Apparent power $(S_2) = \text{Kw} / PF_2$

$= 2.0$ Kw / 0.9

$= 2.222$ KVA

Apparent power is reduce = 2.857 – 2.222 KVA

= 0.635 KVA

Lets consider the current consumption compare with the system before and after correction of power factor by the following power relation.

$$Kw = V \times I \times PF.$$

$$I_1 = Kw / (V \times PF_1)$$

$$= 2.0 / (220 \times 0.7)$$

$$= 12.98 \text{ Amp.}$$

$$I_2 = Kw / (V \times PF_2)$$

$$= 2.0 / (220 \times 0.9)$$

$$= 10.10 \text{ Amp.}$$

Then, the system

current is reduced = 12.98 – 10.10 Amp.

= 2.88 Amp.

Conclusion

The system is able to reduced reactive power consumption from 2.04 KVAR into 0.975 KVAR. and recovered the electric power consumption 0.635 KVA by installed a compensated capacitor 1.065 KVAR 70 Micro-farad. In which no capacitor on the system, The improvement of power factor is by increasing the exciter current is used, but this method the plant system has to charged the extra reactive power as calculated about 1.065 KVAR into generator instead of capacitive power from the capacitors.

Improvement of power factor on diesel generator

The principal is to reduce engine consumption, one of others method is by load demand control. Since the demand power of electric application as illustrate by power triangle and its factors. The compensated of electrical consume is called "power factor correction" power capacitors is introduced.

Most of generators in the fishing industry like on board are installed with direct coupling with diesel engine. This system has called "diesel generators" or auxiliary engine. Diesel engine must adequate in power to drive the generator with constant in speed and reliability in mechanical power.

Fishing vessels are used diesel engine to driving the generator. When the generator capacity is determined by the total of load requirement, but the generator driving horsepower is varies according to the electric demand power at that moment. The engine horsepower requirement is determine by the simply method as following formula.

$$\text{Engine horsepower (BHP)} = \frac{\text{Generator capacity (KVA) x Power factor x gen. Eff.}}{\text{0.746 x engine eff.}}$$

$$\text{Engine horsepower loss (BHP)} = \frac{\text{Generator capacity (KVA) x gen.eff.} \ (\theta_2 - \theta_1)}{\text{0.746 x engine efficiency}}$$

Where: θ_1 = Power factor before correction

θ_2 = Power factor after correction

0.746watt = 1 Horsepower (SI unit)

Example a fishing vessel has 40 kVA diesel generator which supplies to inductive loads its cause the electrical power factor lagging 0.7 if adjust the power factor become 0.9. What is happened to the system? The generator efficiency is 100%.

Solution on generator effect

Generator capacity = 40 KVA

With 0.7 power factor before correction

Kw_1 = 40 KVA x 0.7 x 1.0

= 28 Kilowatt

With 0.9 power factor after correction

Kw_2 = 40 KVA x 0.9 x 1.0

= 36 Kilowatt

By above given formula. It is seem that after power factor correction from 0.7 into 0.9 the generator has recovered the electrical power become larger 8 kilowatts and there is capability to supplies electrical power up to 36 kilowatt

Solution for the engine capacity

Engine horsepower (HP) = 40 KVA x 0.9 x 1.0/ (0.746 x 0.8)

= 60.32 HP

In case of low efficient power factor

Power loss by reactive power = $(\theta_2 - \theta_1)$ x KVA / (0.746 x gen_{eff})

= (0.9 – 0.7) x 40 KVA / (0.746 x 0.8)

= (0.2 x 40) / (0.746 x 0.8)

∴ **The diesel engine power has losses** = 13.40 HP

7. How to reduce the fuel consumption?

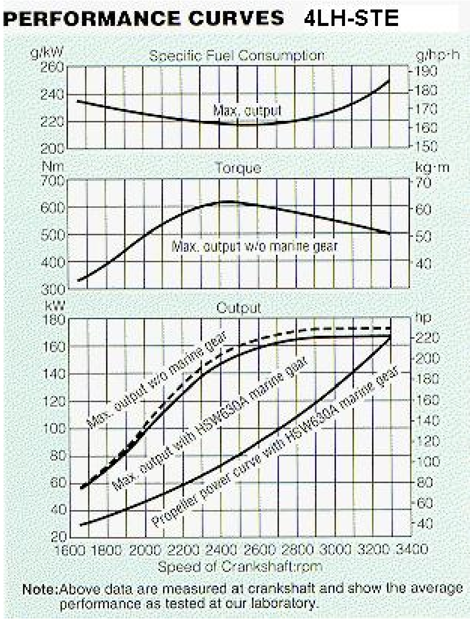
As mention above is one process of electrical utilize by power factor correction, which apply to diesel generator. The capacitors are used to supplies or compensate the capacitive power instead of increase the exciter current or increase the engine speed. This method without increase in fuel injection, it's the ways to minimize of fuel consumption and improve the system efficiency.

In case of increase the exciter current it is surly the system has better in voltage and power factor, but there is cause to losses reactive power on the system. Because exciter currents is a parts of generated voltages of the generator its self. And cause to the revolution of driven engine is reduced due to induction forces of magnetic flux density which increase. These magnetic fluxes are against the revolving of the engine.

It is automatically when the engine speed is slow down; the voltage and frequency are become decreasing. And it is necessary to increase the engine speed by automatic or man control to make the system in proper service condition by increasing the fuel injection into the engine to increase the engine power and speed. From an example as above the engine power has losses about 13.40 horsepower.

8. How to identify the engine has how much save?

In this case has to consider together with the engine performance curved on the specific fuel consumption and horsepower tested. Recently the most save fuel consumption is about 160 g/hp/hr. The amount of fuel consumption saves will be the amount of specific consumption in g/hp/hr multiply with recovered horsepower and operation hours.



From an example the recovered horsepower is 13.40 HP, in case of 24 hr operated.

Fuel consumption save = 160 g/hp/hr x 13.40 x 24

= 51.45 kg.

= 51.45 kg. / Specific weight .... Litters

= 51.45 / 0.85

= 60.52 Litters/day

9. The diesel engine horsepower on generator operation.

Since the principal of generator is need in strong enough prime movers for driving itself, which has constant in speed regulation, and power given. The prime mover must be better in speed regulation on the various loads condition such as in case of light or heavy load operation, the engine must not over speed or speed dropped operation. That is to maintain and keep stable in speed of the synchronous (N) operation

$$N = \frac{120F}{P}$$

Where: F = Frequency (Hz)

P = Magnet pole of generator

So, that the electrical automatic constant speed governor, or constant speed governor is used in this process to control the speed of the engine.

Guide line on engine power

Brake horsepower. This power is developed from the cylinder movements through crankshaft, which is reduced by friction losses of the movements as like cylinder, piston, camshaft, bearing and the power required for cooling equipment.

The net power is called brake horsepower this power is used to work. Such as driving the generator, propeller, hydraulic pump, water pump etc.,

This power is measured by brake horsepower machine called **dynamometer** by means of torque (Kg.m) along with the measure of engine speed (rpm) and calculates

$$BHP = \frac{2 \times 3.14\ TN}{75 \times 60} = \frac{TN}{716.2}$$

Shaft horsepower. This power measured at the shaft end. It is means that shaft horsepower is depend upon the transmission coefficient (η_T) In case of direct coupling like diesel generator, brake horsepower is equal to shaft horsepower. Shaft horsepower can be improved or reduced by means of clutch and transmission devices.

In which has no dynamometer available the generator is apply instead of dynamometer. By produced an output voltages currents and supply to electric loads or dummy load in order to measured the electric consumption in kilowatts and convert to shaft horsepower as giving by the following formula.

$$SHP = BHP \times \eta_T$$

In case of direct coupling, transmission efficiency (η_T) equal to 100%

$$\eta_T = 1 = 100\%$$

$$BHP = SHP$$

Torque along the shaft (T_{sh})

$$= \frac{75 \times 60 \times SHP}{2 \times 3.14 \times Eng_{eff} \times N}$$

Engine power of the generator is different from main engine on the vessels, due to constant in speed operation, which there is change in load condition. That is horsepower is the relationship between torque on the shaft and the operation speed (shaft speed). In case of generator, the demand powers of load consumption cause to produced the friction or torque to against the movements of the engine as illustrated in the following formula.

$$BHP = SHP = KVA \times PF \times 1.34$$

In practical the efficiency (η) has proportional with the output of the machine. So that, efficiency is important matter on the selection of the machine to meet the utilized of power with long life services. In practical the mechanical efficiency of diesel engine is stronger than gasoline engine its value is between 70-80% and 60-70%in order. That is the engine has capability about 70-80% or 60-70% of the maximum power on continuously operating situation.

Therefore, the engine power must bigger than loads power about 120% or 140 % according to the engine selection such as diesel or gasoline engine.

Torque along the shaft (T_{sh}) during generator operation.

$$(T_{sh}) = \frac{75 \times 60 \times SHP}{2 \times 3.14 \times N}$$

$$= \frac{75 \times 60 \times (KVA \times PF \times 1.34)}{2 \times 3.14 \times N}$$

$$\therefore \text{BHP at n revolution} = \frac{TN}{716.2}$$

$$= \frac{\dfrac{75 \times 60 \times (KVA \times PF \times 1.34) \times N}{2 \times 3.14 \times Eng_{eff} \times N}}{716.2}$$

Example

Compute the engine power to drive the generator on the capacity of 40 KVA, power factor 0.9, 1500 rpm., generator efficiency is 100% and engine efficiency is 80%.

Solution

$$T_{sh}) = \frac{75 \times 60 \times SHP}{2 \times 3.14 \times N}$$

$$= \frac{75 \times 60 \times (KVA \times PF \times 1.34)}{2 \times 3.14 \times N}$$

$$= 23.044 \quad \text{Kg.m}$$

$$BHP = \frac{\dfrac{75 \times 60 \times (KVA \times PF \times 1.34) \times N}{2 \times 3.14 \times Eng_{eff} \times N}}{716.2}$$

$$= \frac{\frac{75 \times 60 \times (40 \times 0.9 \times 1.34) \times 1500}{2 \times 3.14 \times 0.8 \times 1500}}{716.2}$$

$$= 60.33 \quad hp$$

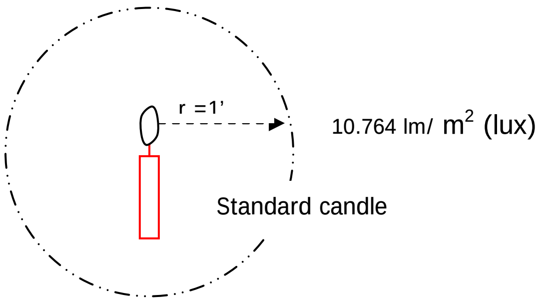
∴ Need the engine has constant speed at 1500 rpm on continuously power 60.33 Horsepower to drive the generator of 40 kilowatts with 0.9 power factor. For more effective of the utilized of the engine the maximum torque should be cover between 1450-1550 rpm. of the engine speed.

Lighting optimization

To reduced the electric lighting power of the fishing light method. By understanding the basic of lighting. There is several ways to improve the efficiency of the lighting system will become utilized.

Foot-candle

Foot-candle is measure illuminations of one standard candlepower on the luminous intensity surrounding a candle with one foot away. 1 foot-candle = 10.764 Lumen/square meter (Lux)



Luminous flux (F)

Luminous flux is the quantity of light unit as mention in lumen that is throughout surrounding the source (lamp or candle) in one second.

Since 1 foot-candle is the luminous flux quantity surrounding on the spherical area of 1-foot radius equal to 4Π lumen/second.

$$F = 4\Pi \times 1 \text{ Lumen.}$$

$$= 12.56 \text{ Lumen.}$$

Luminous intensity (I)

Luminous intensity is the candlepower (CP) throughout surround of the lamp such as 50, 100, 200,400 candlepower.

Efficiency of lamp (Eff.)

An efficiency of lamp is the proportional between luminous flux and electrical demand power in watt. That is given in lumen per watt.

Efficiency of lamp = luminous flux / watt (Lm/watt)

Example

How much the luminous flux and efficiency of 100 candlepower with 20 watts lamp?

Solution

Where: I illustrated the capacity of candlepower.

$$F = 4\Pi I$$
$$= 4 \times 3.14 \times 100$$
$$= 1256 \text{ Lumen}$$

And

$$Eff. = 1256 / 20$$
$$= 62.8 \text{ Lumen/watt.}$$

Illumination (E)

Illumination is the quantity light through to the certain area it is usually symbol by “E” and it is taken unit in lumen/square meter, lumen/ square feet and lumen/square meter. Lumen/meter^2 is usually called Lux.

The relationship of illumination of above mention is illustrated as the equation as following.

$$E = F/A$$

Where:

E = Illumination (lumen/meter^2 or lux)

F = Luminous flux (Lumen)

A = An area of the light throughout.

There are two common lighting methods are used.

1.Lumen method

2.Point by point method

The lumen method is used the principal of an equal foot-candle level throughout the task which must be maintain in the surrounding area. This method is used frequently by the lighting designer it is very simplest method. However this method waste the electrical energy

Point by point method this method has calculated the lighting requirement throughout the task and not equal in foot-candle lighting in the surrounding area. This method utilizes in electrical power consumption.

Lumen method

$$N = \frac{F_1 \times A}{L_m \times L_1 \times L_2 \times Cu}$$

OR

$$N = \frac{F_1 \times A}{L_m \times MF \times Cu}$$

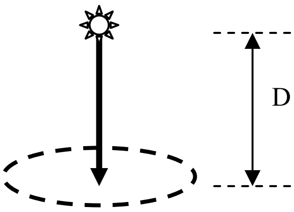
Where:

N	=	The number of lamp require.
F	=	The requirement of luminous flux level at the task. (lumen)
A	=	Area of lighting area in square meter
Lm	=	The lumen output per lamp. A lumen is a measure of lamp intensity unit. Its value usually found in the manufacturers catalogue.
M.F.	=	Maintenance factor.
	=	L_2 / L_1
Cu	=	The coefficient of utilization. It represent the ratio of the output (lumen) generated by the lamp reaching to the working plane. The coefficient of utilization makes allowance for light absorbed or reflected by walls, ceiling and the fixture itself. Its value is compute by following formula.
L_1	=	The lamp depreciation factor. It takes into account that the lamp lumen depreciation with time. Its value is found in catalogue.
L_2	=	The luminaries (fixture) dirt depreciation factor. It take into Account the effect of dirt on the luminaries and varies with type of luminaries of the atmosphere it is operated.

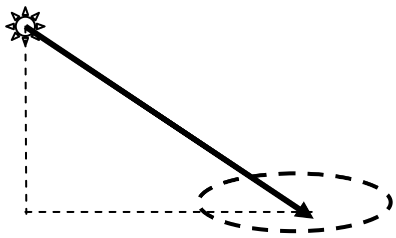
Point by point method

There are three commonly used lighting formulas associated with this method. The incandescent lamp or mercury vapor laminar is used as a point source. These equations given bellow omit inter reflections, The total measure illumination will be greater than calculated value. Inter reflection can be taken into account by referent to a lighting hand book or electrical engineering handbook.

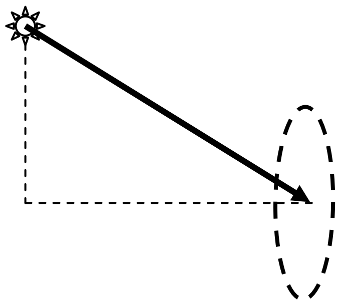
$$F_2 = \frac{0.35 \times CP}{D}$$



$$F_3 = \frac{CP \times \cos\theta}{D^2}$$



$$F_3 = \frac{CP \times \sin\theta}{D^2}$$



Where:

F_2	=	The lamination produced at the point on plane area directly under the source.
F_3	=	The illumination on horizontal plan area
F_4	=	The illumination on the vertical plan area
CP	=	The candle power or luminous flux of the source in the particular direction its value is found in the manufacturer catalogue.
D	=	The distance in feet to the point of the lamination
θ	=	The angle between D and the direct component

Beam lumen method

The objective of floodlighting is continuously the luminous instead of sun light after sunset to the abstract the outdoor and indoor objects such as complex center, garden, sport complex. Also the beam lumen method has used in the special area that need the luminous flux without glare effected as in case of navigation lamp on wheelhouse, personal lighting on the vehicles.

Beam lumen is the luminous flux floodlighting from the lamp and the relationship of beam efficiency.

Total beam lumen = luminous flux of the lamp x beam efficiency

Co-efficient of beam utilization (CBU) is the proportional between the luminous flux throughout to the object and the total beam lumen that is illustrated as equation as follow:

CBU = La / TBL

Where:

CBU = Co-efficient of beam utilization

La = Luminous flux on the specific surface

TBL = Total beam lumen

So that the luminous flux on the specific surface are able to adjust between 60-100% of the total beam lumen. Since it is depend upon the surface of the object. A large surface of the object will cause high percentage dropped of luminous flux on the object. And then beam lumen adjustment is very important, in case of over beam angle it is cause to low in co-efficient of beam utilization.

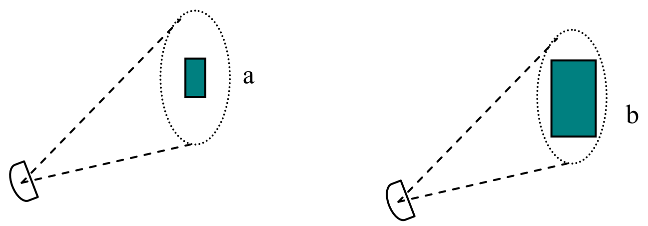


Figure as illustrates above "b" object has received a luminous flux better than an object "a" due to large in surface.

Lamp requirement of beam lumen method is compute by following formula.

N = A x F / (BL x CBU x MF)

Where:

N	=	Number of lamp require
A	=	Area of lighting surface (m^2)
F	=	Luminous flux on the task (Lumen)
BL	=	Beam lumen (Lumen)
CBU	=	Co-efficient of utilization factor
MF	=	Maintenance factor

Lighting control system

The best way to reduce lighting loads is to assure that lights are turned off when not in use or to dim light during different periods. The lighting controls are usually required for the following.

1. Turned light on at the start of office hours.
2. Turned light off at the close of office hours.
3. Turned light off base on external sunlight condition.
4. Turned light on in specified area of duty.
5. Turned light on at the burglar alarm is activated.

The above function above are accomplished by time clock switch, photo electric relays, solid state dimmer, A low voltage switch control is used control the light and recently solid state dimmer are available for high inert discharge lamp as well as incandescent lighting system.

Analysis of the lighting method for power saves.

The two method for compute the lighting requirements to meet the objective of electric power saves are concludes following.

1. Laminations (fixture) should be chose base on a high efficiency of utilization for the application.
2. Point by point method should be used at the working area with the task lighting levels.
3. Efficient lamp depreciation with high lumen per wattage consumption should be used.
4. Installation of the laminations should be based on an environmental, in the dirty environmental, lamps should prevent dust and moisture build-up.
5. A good surface reflector should be equipping with the lamp for improve depreciation efficiency.
6. To reduce the electrical power consumption beam lumen method should be added together with the others method, such as in the special point or working places that is need light intensity, beam lumen to be used.

Part 6

ALTERNATING CURRENT

MOTOR CONTROL

By

Suthipong Thanasarnsakorn

2002

Southeast Asian Fisheries development Center
Training department
Thailand

Alternating Current Motor Control

If an AC motor is started on full voltage, it will draw from two to six time of its normal running current. Because the motor is constructed to withstand the shock of starting, no harm will be causes; it is generally desirable to take some measure to reduce the starting current;

For the small motor, or where the load can stand the shock of starting and no objectionable line disturbance are created, a hand operated or an automatic starting switch can be used for control of the motor. This type of switch connects the motor directly across the line is called an across the line starter or full voltage starter.

In the case of large motor, where the starting torque must develop gradually, or where the high initial current will affect the line voltage, it is necessary to insert in the line some device which will reduce the starting current. This device may be a resistance unit or autotransformer. Controllers which use this method of starting a motor is called reduce voltage starters. Controllers are also to protect the motor from overheat and overloading, to provide speed control, to provide for reversing the motor, and to provide under voltage protection.

The following popular types of conductors will be described: push-button switch starter for small motors, magnetic across the line Star, Wye-delta starters, drum starters, part-winding starters, two speed controllers, plugging and controllers.

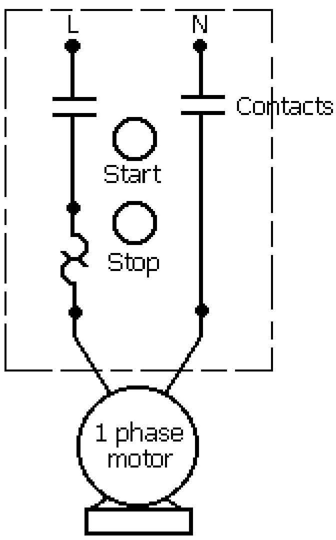


Fig. 1 Pushbutton switch starter connected to a single-phase motor.

Push-button Switch Starter for Fractional Horsepower Motors

This is a simple type of switch connects the motor directly to the line. Two push-button are located on the switch, one for starting and the other for stopping the motors. Pressing the start button case the contacts inside the switch to make and connect the motor across the line. Pressing the stop button cause the contacts to break apart and open the circuit to the motor. This type is show in Fig. 1

The usual type of push-button switch starter is equipped with a thermal overload device connect in series with the line. It opens the circuit to the motor an overload current persists for a short period of time.

Most of switch starters can be used for single, two or three-phase motors. Fig. 1 shows a diagram of a push-button starter connected to a single-phase motor and Fig. 2 shows such a starter connected to three-phase motors. In Fig. 1- 1, when the start button is pressed it close the contacts of L1 and L2 and connect the motor across the line. If an overload occurs, the thermal relay will trip the releasing mechanism and cause the contacts to open, thereby stopping the motors. To reset the tripping mechanism, it is usually to press the stop button. If the motor is running normally and it is necessary to stop it, the contacts are released by pressing the stop button. Fig. 3 is an illustration of a manual starter.

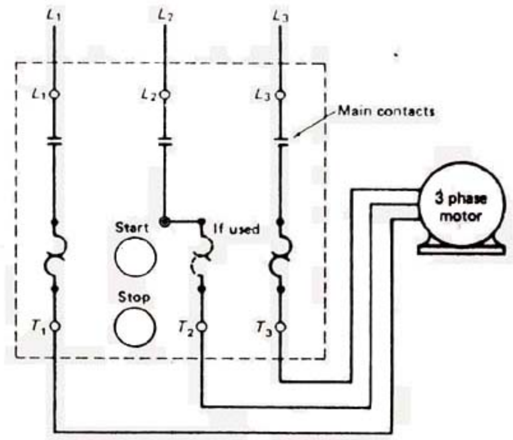


Fig. 2 Pushbutton switch starter connected to a three-phase motor.

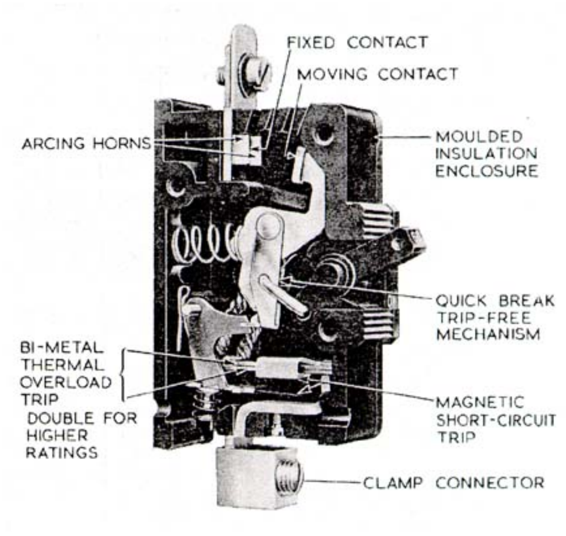


Fig.3 Type of a protection switch or manual starter

Magnetic Full-wave Starter

A starter, which connects a motor directly across the line, is called a full- wave starter. If this starter is operated magnetically, it is called a magnetic full-wave starter. A magnetic starter designed to operate a three-phase motor is shown in Fig. 4 Some of the wiring symbols in this and other diagrams are shown in Fig. 5 Fig.4 has three normally open main contacts which closed connect the motor directly to the line. It also has a magnetic holding coil, which closes the main contacts upon being energized, and also closes a normally open auxiliary and departure the contact of the normally closed auxiliary. The normally open auxiliary used to maintaining contact to the line through the holding coil. The main and auxiliary contacts are generally joined by insulating connecting bar so that all contacts will close or open when the holding coil becomes energized. It is obvious that just sending a small current through the coil can operate any size of magnetic switch. Starters are often equipping with single or dual-voltage coil for operating on either high or low voltage. Coil is made in two section in-series for high voltage, parallel for low voltage.

It should be note that two overload relays are shown in Fig.4. Most three-phase starters are made with provision for two overload elements as standard equipment, as illustrated.

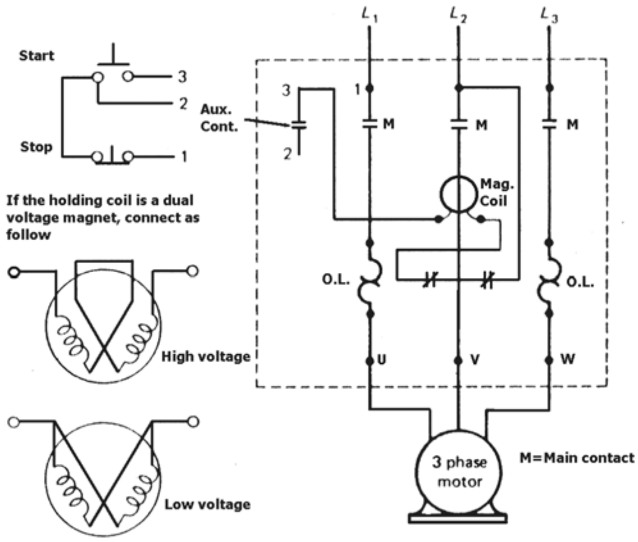


Fig.4 A magnetic across the line starter connected to a three-phase motor with two overload elements

Relay and Auxiliary Contacts	Contactor Contacts	Push Bttons	Motors and Indicating lights
Nomally Open	Nomally Open	Single Circuit Nomally Open	Indicating Light Indicate Colour By Letter Symbole
Normally Close	Normally Close	Single Circuit Normally Close	U V W 3 Phase Motor
Timed Open	Overload Relay	Double Circuits Normally Close	X Y Single Phase Non-Reversing

Fig. 5 wiring diagram symbols

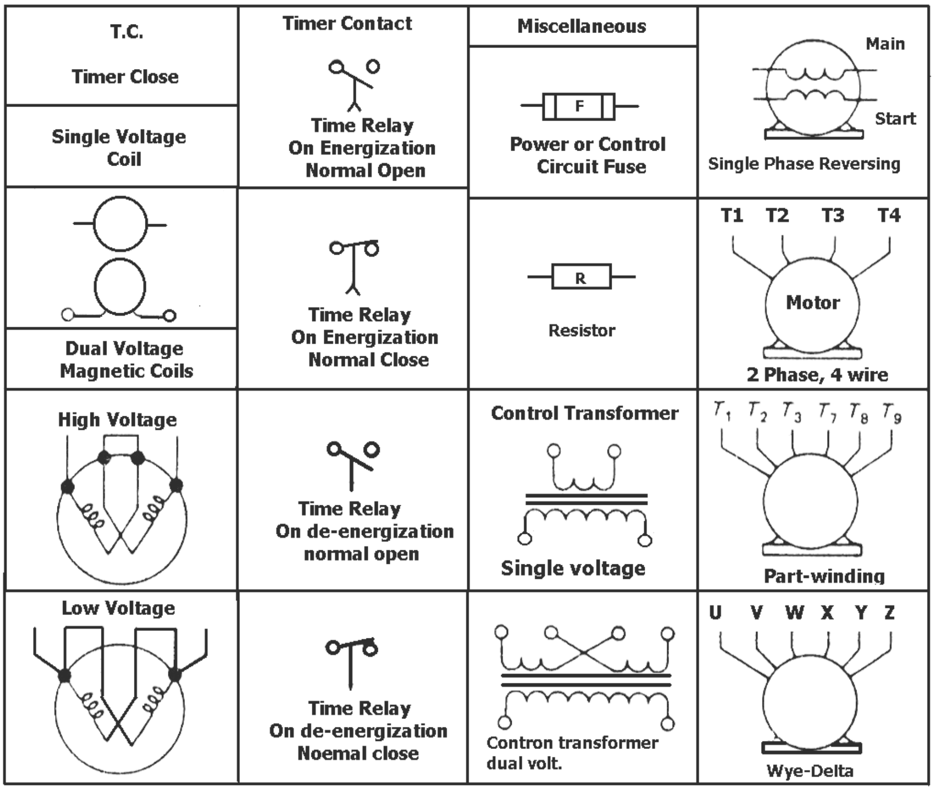


Fig. 6 wiring diagram symbols

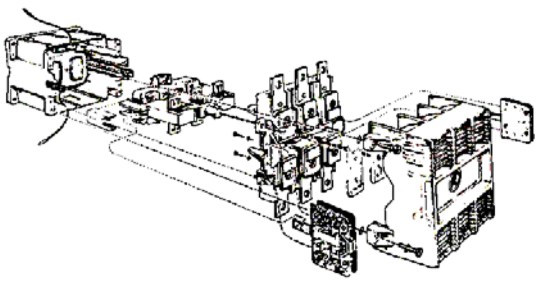
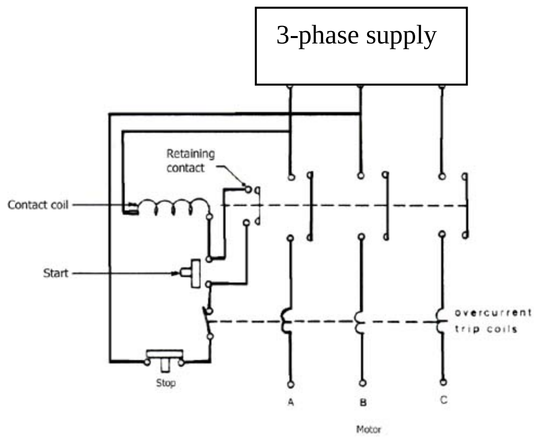


Fig. 7 A magnetic starter for a three-phase motor



An advantage of the magnetic starter over a manual starter is that merely pressing a pushbutton, which may be located some distance from both the starter and the motor, may operate it. This tends to convenience and safety in starting and stopping a motor, especially if it is high voltage or if it must be controlled from one or more remote points.

Overload Relays.

Nearly all-magnetic starters are equipped with an overload device to protect the motor from excessive current. Two types of overload relays are used on magnetic starters, and these are either magnetic or thermal in operation. The thermal overload relay may be either the bimetallic or solder-pot type.

A thermal relay is illustrated in Fig. 8 (a) and (b). This bimetallic type of relay consists of a small heater coil or strip which is connected in series with the line and which generates heat by viture of the current flowing through it; the amount of the heat generated deepens on the current flow in the line. Mounted adjacent to or directly inside, the coil is a strip formed of two metals. This is fixed at one end. The others end being free to move. The two metals have different degree of expansion, and the strip will bend when heated. The free end normally keeps the contacts of the control circuit opened. When an overload occurs, the heater heats the thermostatic so that it will bend separate the two contacts, thereby opening the holding-coil circuit and stopping the motor. The bimetallic type of overload relay is usually designed with a feature which permits automatic resetting, although it is also design for manual resetting. Some overload relays are ambient-compensated to provide maximum protection where the temperature surrounding the relay differs from the temperature surrounding the motor.

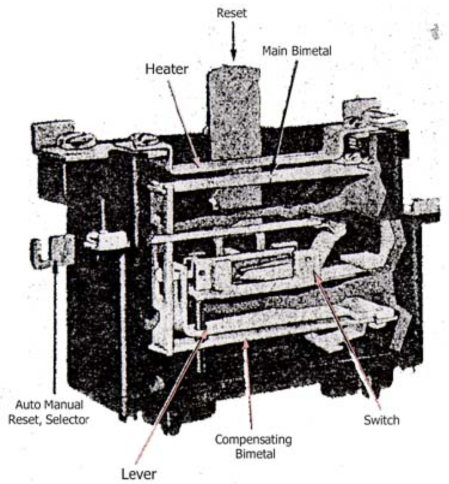


Fig. 8a bimetallic overload relay

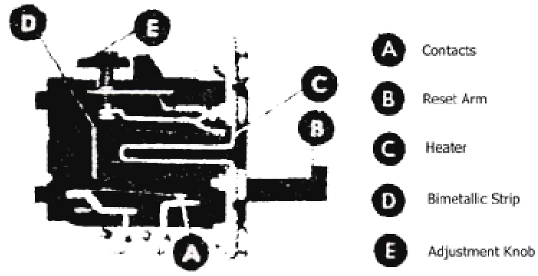


Fig. 8b. Bimetallic overload relay

Pushbutton Stations

Magnetic starters are controlled by means of pushbutton stations. The most common station has start and stop, as shown in fig. 9 when the start button is pressed, two normally open contacts are closed and when the stop button is pressed, two normally close contacts are opened. Spring action returns the button to their original position when finger pressure is removed. To operate a magnetic switch by a start-stop station, it necessary to connect the holding coil to the station contacts so that when the start button is press, the coil will become energized; and when the stop button is pressed the holding coil circuit is opened.

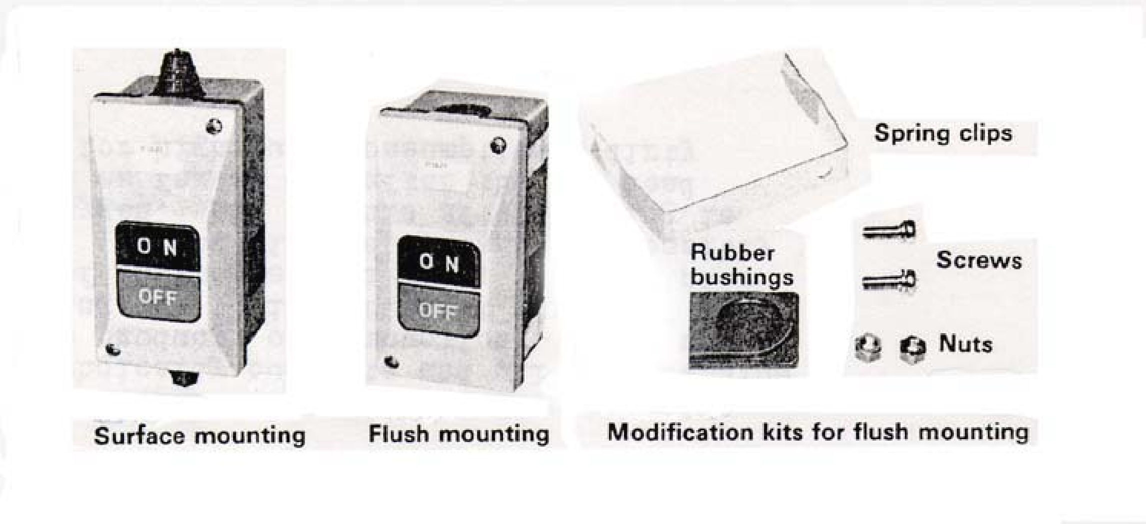


Fig. 9 Start Stop stations

A diagram of a typical full-voltage magnetic equipped with two thermal overload relays and connected to a start-stop station is shown in Fig. 10 In the diagram to follow, heavy lines indicate the motor circuits, and light lines show control circuits. The operation of this starter is as follow:

When the start button of Fig.10 is pressed it completes. The circuit from L1 to the normally closed contacts of the stop button through coil M and close contacts of the overload relays to L2. Thus the coil is energized and it closes contacts M and connects the motor across the line. A maintaining circuit is completed at point 3 to keep the holding coil energized after the finger is removed from the start button. Pressing the stop button opens the coil circuit and causes all contacts to open. If prolonged overload should occur during the operation of the motor, the motor relay contacts will open and de- energized the holding coil. If an overload condition has caused the relay to trip it will be necessary to reset the relay contact by hand before the motor can be restarted.

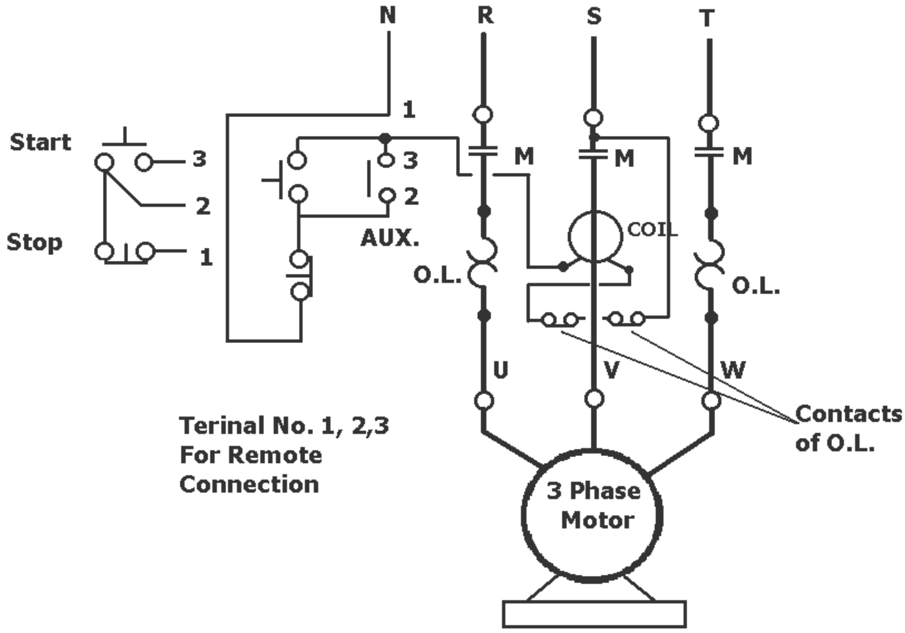


Fig. 10 A simplified diagram of magnetic across the line starter.

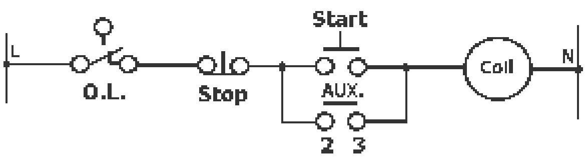


Fig. 11 showed a line diagram of the control circuit.

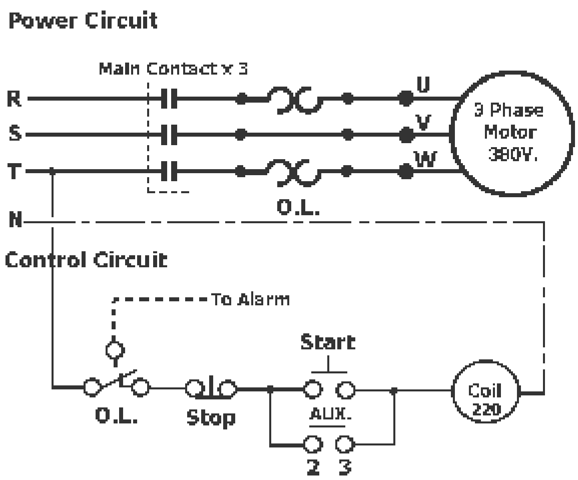


Fig. 12 line diagram of a magnetic across the line starter

The manufacturers make magnetic full-voltage starters. A typical controller is shown in Fig. 13, Fig.14, and Fig.15 shown controllers with a step-down transformer in the control circuit. This permits operating the control circuit at a lower voltage than the line voltage, and usually done for safety reasons.

If a control circuit transformer is used, the primary should be connected to the line terminals of the starter. These diagrams one end of the secondary is grounded, and also one side of control coil M is connected to the grounded.

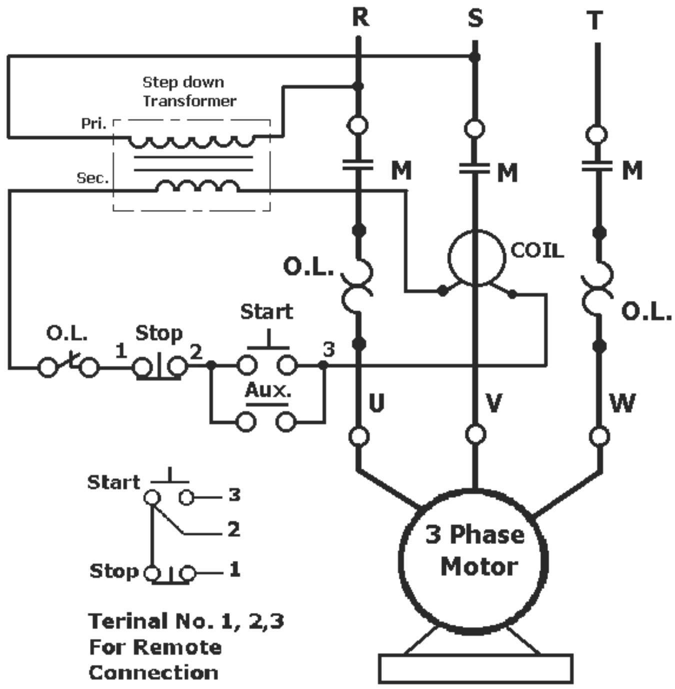


Fig.13 Three-phase starter with step down transformer in control circuit

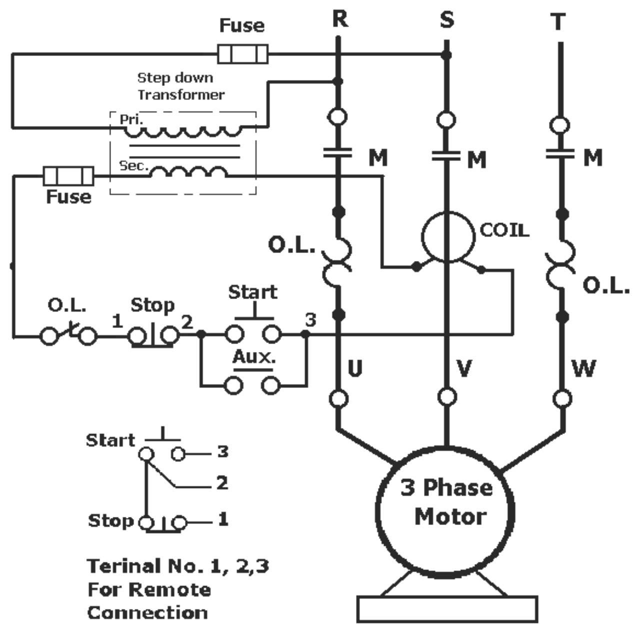


Fig.14 Three-phase starter with control circuit transformer and secondary fuse.

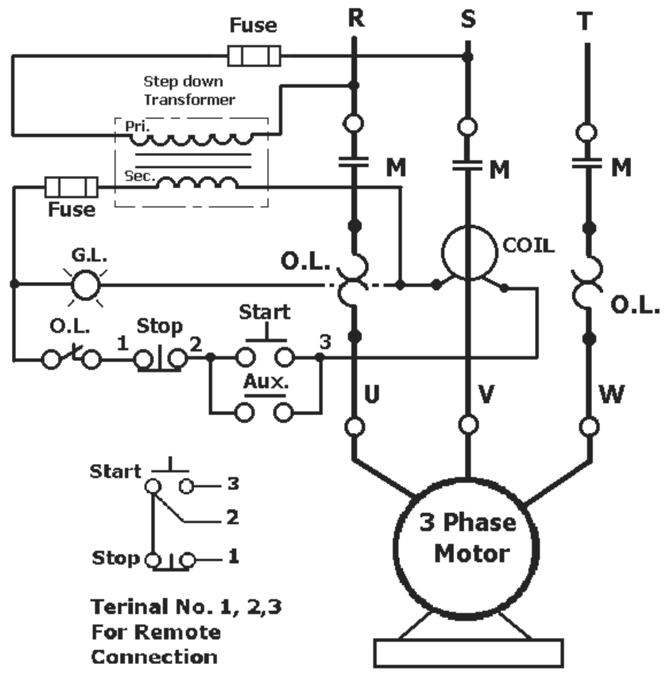


Fig.15 Three phase starter with control circuit transformer and pilot light

Combination Starters

A combination starter consists of a magnetic starter and disconnects switch mounted in the same enclosure. These starters are supplied with either a fused disconnect switch or circuit breaker. The fuse or circuit breaker provides short-circuit protection by disconnecting the line. A combination starter with circuit breaker will prevent a phasing by simultaneously opening all lines when a fault occurs in any phase. This type of starter can be quickly reset, when the fault has been cleared.

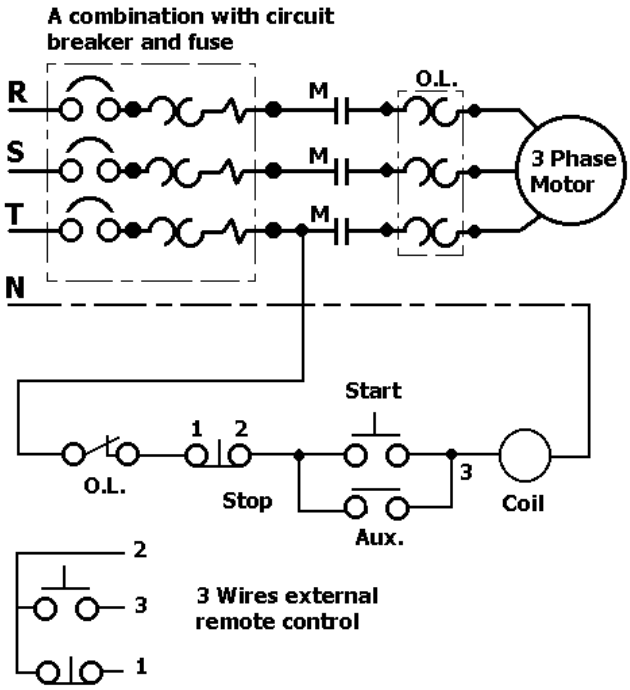


Fig.16 illustrates a circuit breaker and fused combination starter.

Pushbutton Station Connections

A number of control circuits will be illustrated involving various combinations of pushbutton stations. All of these diagrams employs one type of magnetic switch butt others can be used. Fig.17 illustrates a magnetic switch, which is operated from either of two stations. The pushbuttons are shown in two positions. Fig.18 shows a straight-line diagram of the control circuit of two start-stop stations. Fig.19 gives the control circuit of three start-stop stations. In these diagrams the start buttons are connected in parallel and the stop buttons are connected in series. This must be done, regardless of the number of stations.

The maintaining contact is always connected across the start button. All stop buttons are connected in series with the holding coil to earth, therefore the motor can be stopped any position in case of emergency.

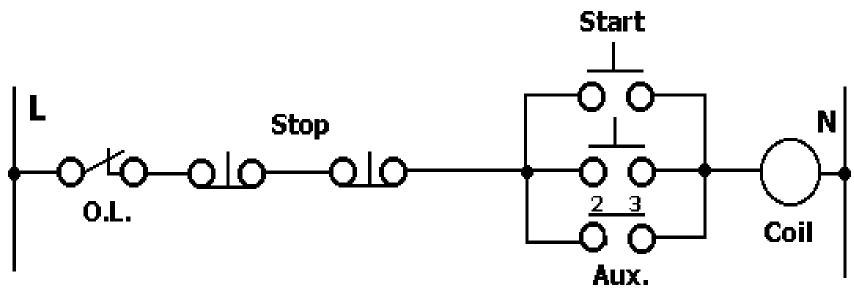


Fig.17 the magnetic switch controlled by two stop-start stations

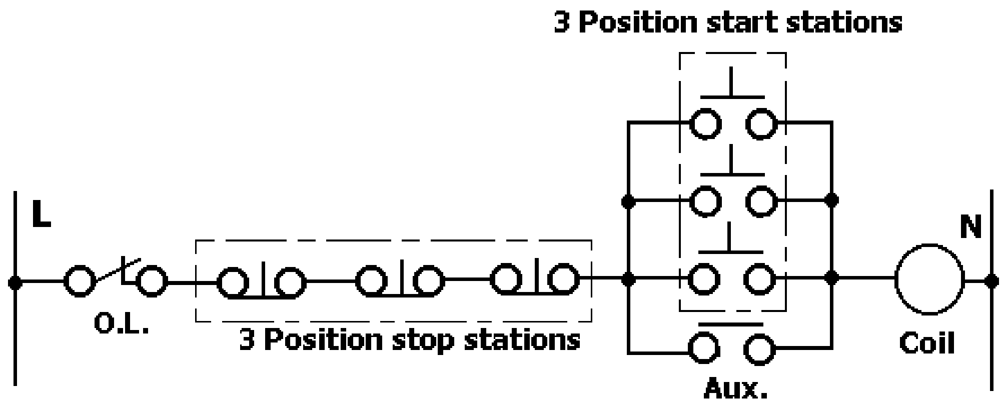


Fig.18 the control circuits for three start-stop stations

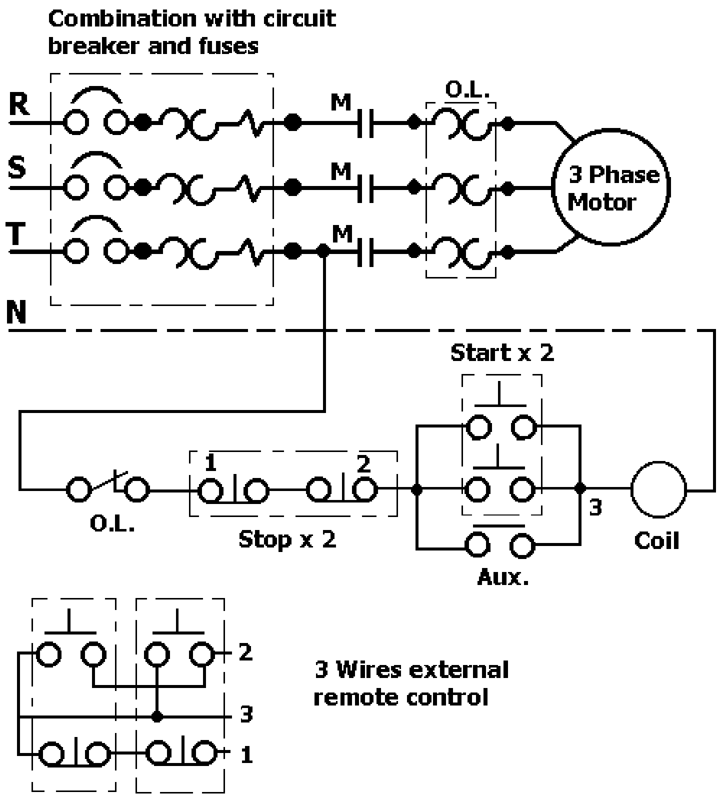


Fig.19 illustrates a circuit breaker, fuse and two start-stop push button combination starter.

Jogging

Magnetic switches can be jogged or inched by this method the motor is made to run only while the finger is pressing the jog button. As soon as pressure is removed, the motor stops.

Jogging may be accomplished by using:

1. A station with a selector pushbutton
2. A station with a selector switch.
3. A station with standard pushbutton and a jog relay.

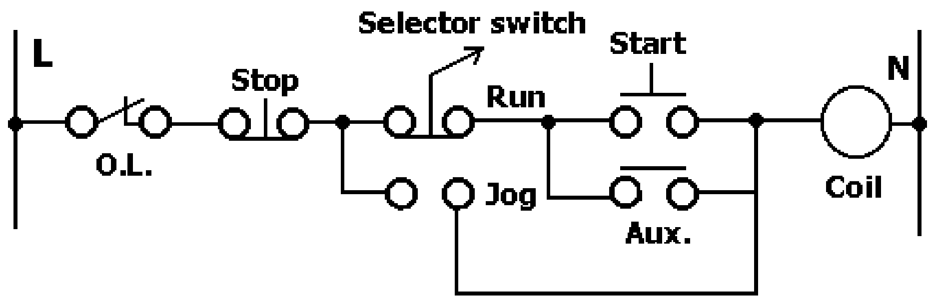


Fig.20 illustrates a start-jog-stop station by selector switch

Fig.20 shows a control circuit of full-voltage magnetic starter concerned to a start-jog-stop station having a selector pushbutton. This button is constructed with a sleeve that may be turned to either a jog or run position. With the sleeve turned to the run position, the start and stop buttons functions as in ordinary start-stop station. With the sleeve in the jog position the circuit to the holding contacts is broken and the motor will run only when the jog button is held down.

The operation of the control circuit of Fig.20 is as follow. With the selector sleeve on run, pressing the start button completed a circuit from L1 through the contact of overload relay, stop button and the close contacts of the jogging selector button, the start contacts, the holding coil to L2. This energizes the holding coil, causing contacts M to make and connect the motor across the line. The maintaining auxiliary contact keeps the holding coil in the circuit after the finger is removed from the start button. Pressing the stop button opens the coil circuit. With the selector sleeve on jog, the current cannot flow to the start button because the front contacts are in open position. Depressing the jog selector button completes a circuit through the overload relay, stop button, the jog contacts of the selector button, the holding coil, to L2. The holding coil will energize only when the button is pressed.

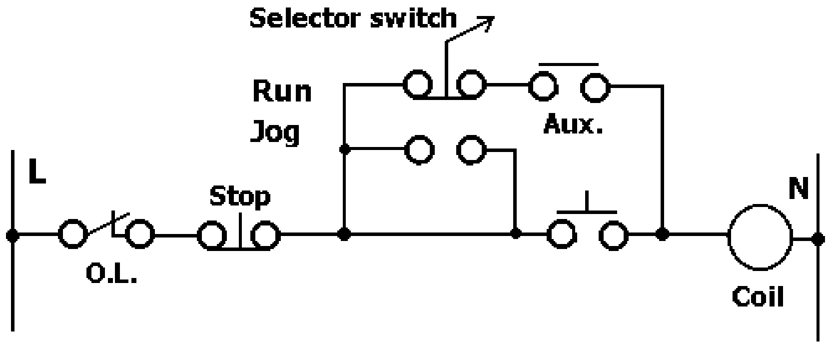


Fig 21 illustrate a jog or run is start by pushbutton

Fig.21 is show jog stations, which use a selector switch. The start button is used to jog or run the motor, depending on the position of the switch in each case with the button. In the jog position the holding auxiliary contact is broken.

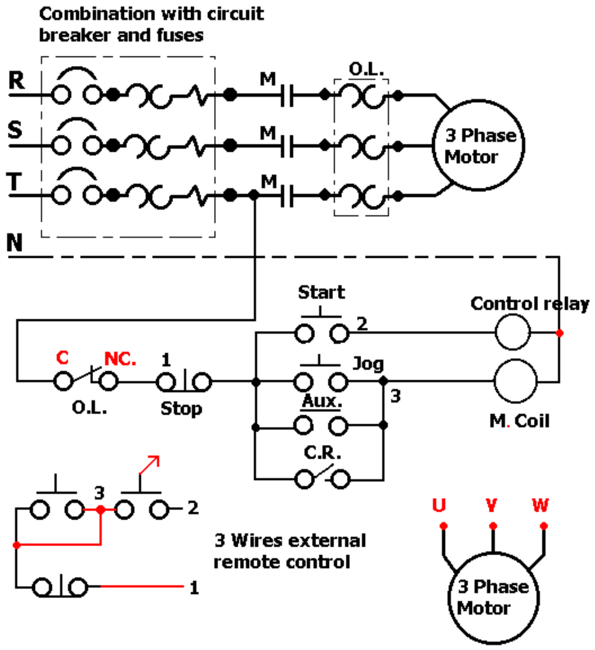


Fig. 1 - 22 Illustrate a jog or run is start by pushbutton.

When the start button is pressed, the relay coil is energized, thus the closing the relay contacts, CR; CR close the circuit for the holding coil, causing auxiliary contacts M to close. This completes the maintaining circuit for the holding coil M, when the start button is released. In the meantime all the main contacts are made, closing the circuit for the motor. If the jog button is pressed while the motor is at the stand still, a circuit is formed through the holding coils only as long as the button is pressed

Start-Stop Station with a Pilot Light

Sometimes it is advisable to have a pilot light on the pushbutton station to indicate if the motor is running. The lamp usually is mounted on the station and is connected across the holding coil. Such as connection is shown in Fig. 1- 23 and 1- 24 Fig 1-25 shows a control circuit with pilot light on when motor is stopped. Normally closed contacts are needed on this starter. With the motor running these contacts are open. Contacts are closed when the motor is stopped and pilot light goes on. A start-stop station with a pilot light is pictured in Fig.1- 23

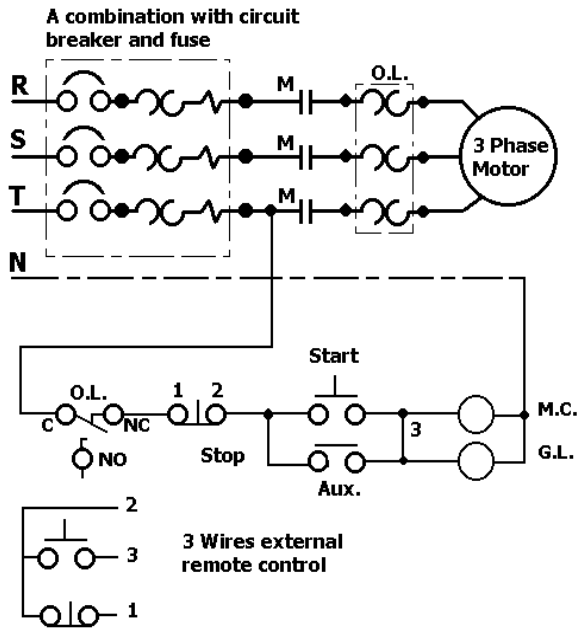


Fig. 1 - 23 Push Button Station with Pilot light connected to a 3 Phase starter.

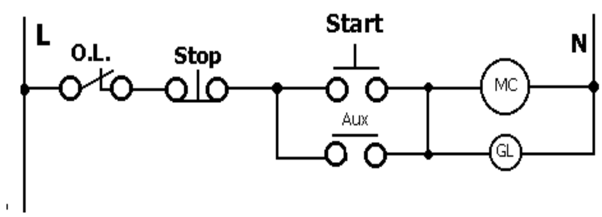


Fig. 1 - 24 A Simple control circuit of a Start-Stop Station with a Pilot light

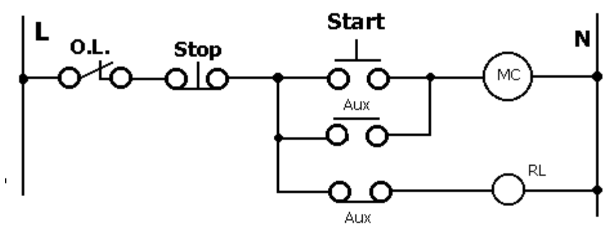


Fig. 1 - 25 Pilot light indicates when motor is not running.

Full-voltage Reversing Starter

The magnetic starters shown thus far are designed to operate the motor in one direction, either clockwise or counter clockwise. If it is necessary to reverse the motors, its connections must be changed.

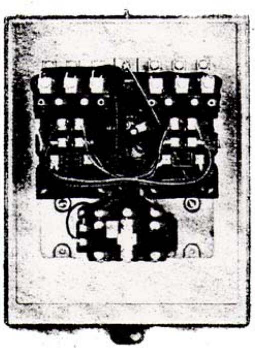
Some applications, such as conveyors, hoists, machine tools, elevators, and other require a motor starter that can reverse the motor when a button is pressed. Thus two of the line leads can be interchanged to reverse a three-phase motor by means of a magnetic reversing switch. A reversing starter of this type is shown in the Fig.1 - 26. The circuit is giving in Fig. 1 -27 and 1 - 28.

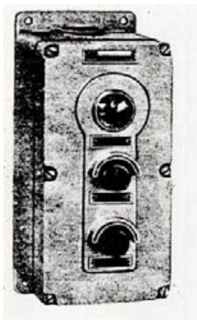
Note that it is necessary to use a Forward-Reverse-Stop station with three buttons and that two operating coils are used, one for forward rotation and the other for reverse rotation.

Two sets of main and auxiliary contacts are used. One set closes when forward operation is desired, the other set close for reverse rotation. These contacts are connects in such a manner that two line wires feeding the motor is interchanged when the reverse contacts close.

In operation pressing the forward button completes a circuit from L1 the stop button, the forward button, the forward coil, and the overload contacts to L2. This energizes the coil, which closes the contacts for forward operation of the motor. Auxiliary contacts F also close, maintaining the current through coil F when the button is released. Pressing the stop button opens the circuit through the forward coil that releases all contacts. Pressure on the reverse button energizes the reverse coil that closes the reverse contacts. Terminals T1 and T3 are now interchanged and the motor reverses.

Fig. 1 - 26 an AC. Full- Voltage magnetic reversing controller





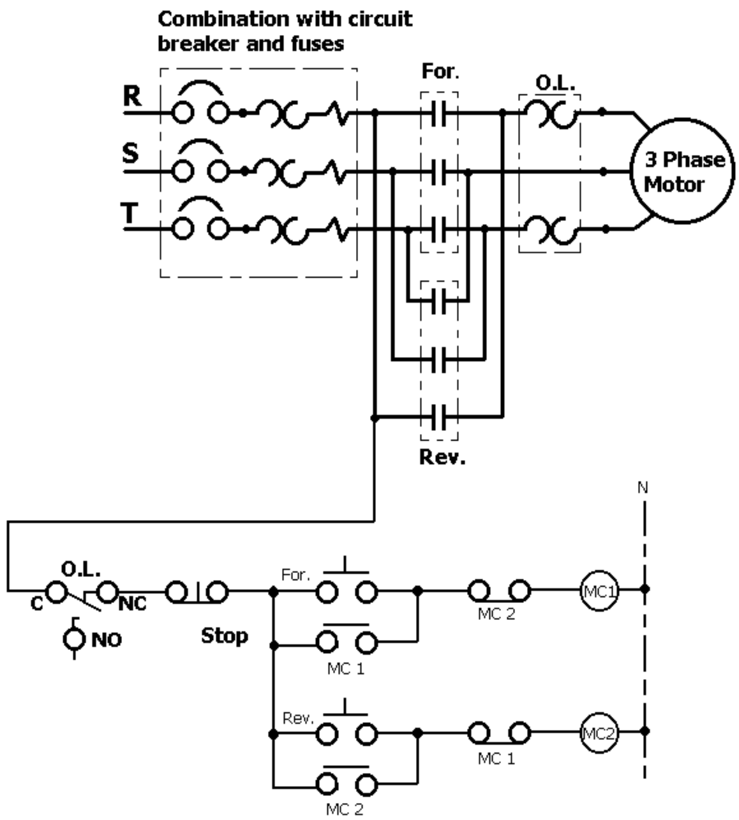


Fig. 1 - 27 A reversing magnetic starter operated by a Forward-Reverse- Stop Station

Usually, reversing starter are equipped with a mechanical interlock in the form of a bar will prevent the reverse contacts from making while the forward contacts are closed. This bar is pivoted in the center, and when the forward contractor goes in it move the bar into a position where it is impossible for the reverse contacts to make. This starter does not have electrical interlock to prevent the forward and reverse coils from being energized simultaneously. All of these starters are equipped with overload relays generally of the thermal-relay type. Remember, however that many starters use three relays for three-phase motors.

Sometime more than one forward-reverse-stop station is used to control a magnetic reversing switch. Fig. 1 - 28 shows connection diagrams of two such stations in difference positions

Besides having mechanical interlock, most reversing starter is electrically interlock. In this system, additional normally closed auxiliary contacts are used to prevent the forward and reverse contractors from being energized at the same time. The holding circuit of each main contractor coil is wired through the normally closed auxiliary contacts of the opposing contractors, thus providing the electrical interlock.

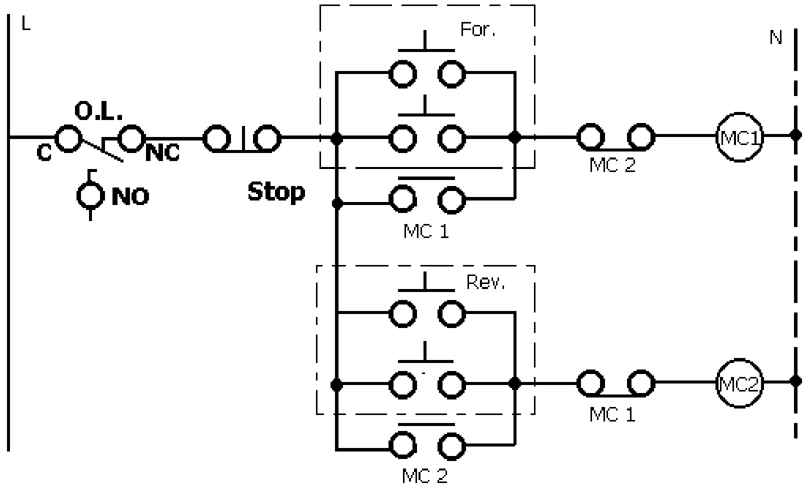


Fig.1 - 28 Connection For two Forward-Reverse and Stop stations reversing magnetic switch.

In operation, pressing the forward button closes a circuit from L1 through the stop button, the forward button, the reverse normally closed auxiliary contacts, the forward limit switch (if used), the forward coil and the overload contacts to L2. The maintaining contacts for the forward coil keep it energized when pressure is removed from the button. At the same time, the normally closed forward auxiliary contacts are opened, preventing a complete circuit through the reverse coil.