Basics of DC drives....

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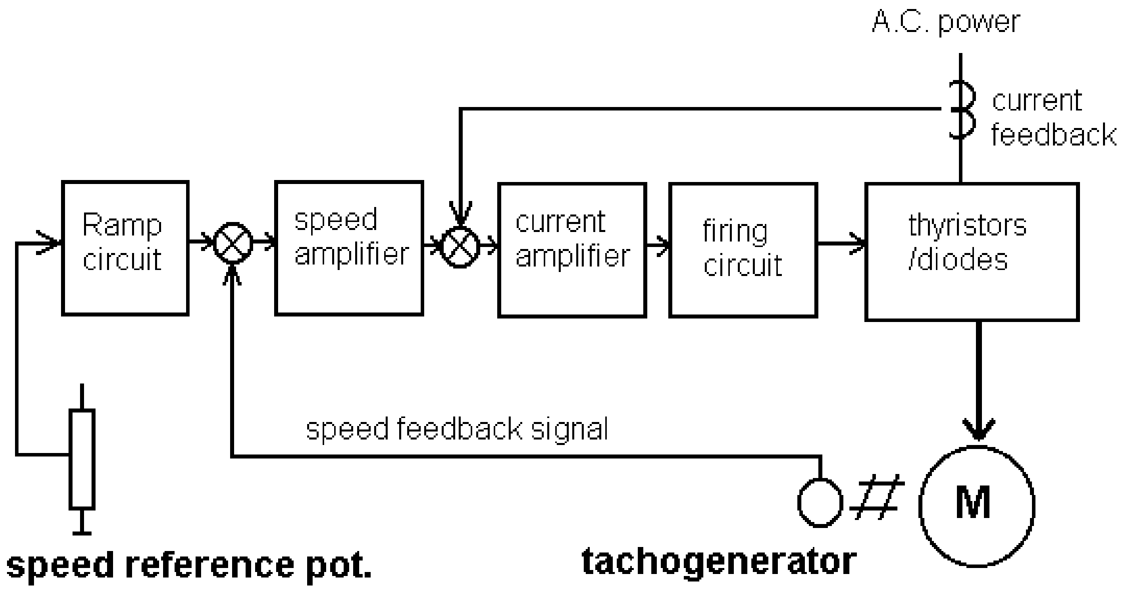
Block diagram of a DC drive :



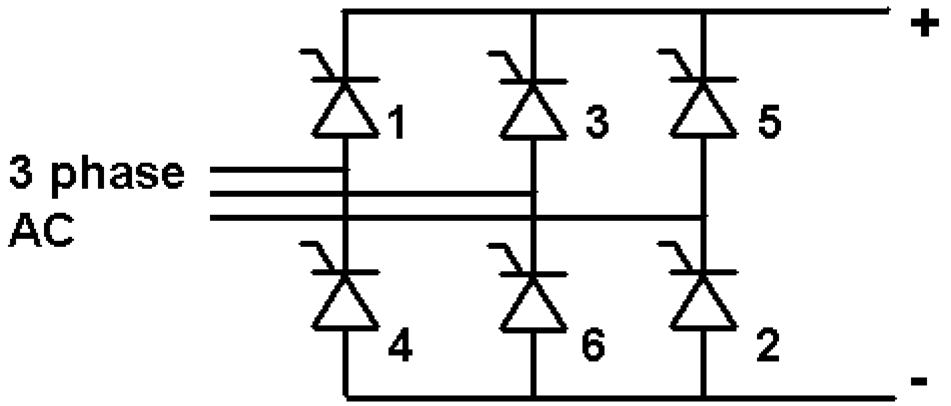
Senior Electrical Maintenance engineers above the age of forty or fifty sometimes find themselves outdated in their knowledge. With this background in mind an attempt is made here to describe certain concepts which one finds in old analog dc drives. Such drives are still in use in a large number of industries. Digital drives are different only in the manner in which these basic functions are achieved. Understanding these will help in solving many problems irrespective of the type of the drive. These details will help in better understanding of the subject which is otherwise learnt in bits and pieces by many over a period of time as they grow in industry.

Types of DC drives :

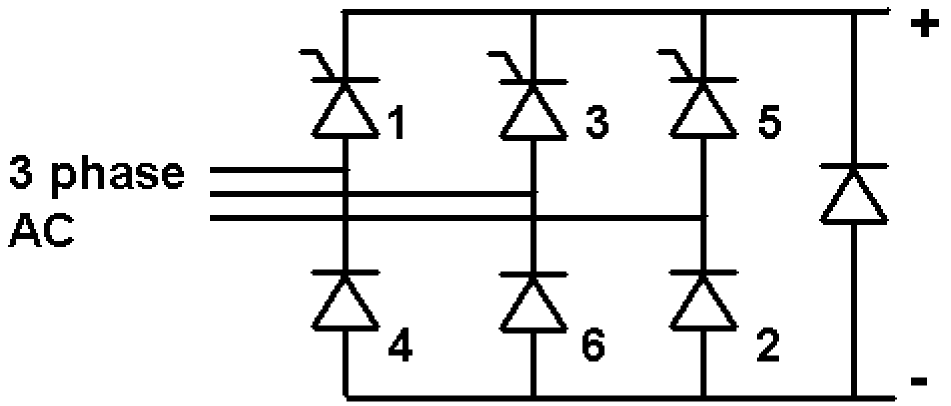
Like any other classification, there are many ways in which the DC drives can be classified. Whatever may be the way, the main purpose is to divide and learn. i.e. learn the topic by breaking it down in small areas.

Classification can be like...
-three phase or single phase
-analog or digital

-constant speed application or constant current application
-Semicontrolled or fullycontrolled etc.



three phase fully controlled configuration



three phase semicontrolled configuration

Power section of a DC drive consisting of power handling components can take any of the following shapes.

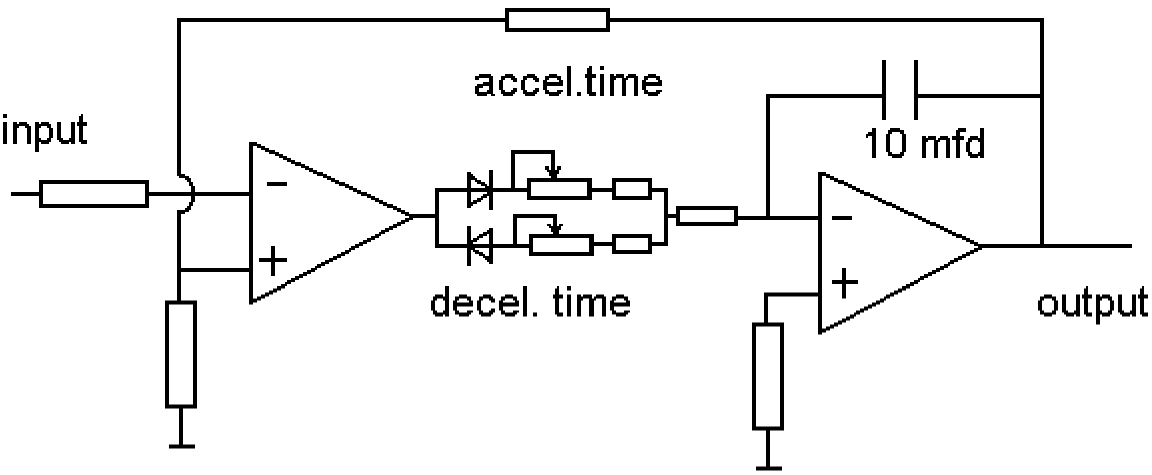
-single phase semicontrolled
-single phase fully controlled
-three phase semicontrolled
-three phase fully controlled

By semicontrol and full control we mean the type of control we have over the power controlling devices, i.e. thyristors or diodes. In semicontrolled type, in a three phase configuration, only half of the devices have control over the current flowing through them.

The sketch above shows that three out of six current carrying devices are diodes and three are thyristors. Seventh component across the +ve and -ve terminals is a diode and called FREEWHEELING diode. It is necessary to freewheel the energy in the inductance of the motor. With all six devices under control of gate pulses, the electronic circuit has total control over the motor current. This configuration is also known as 6 pulse configuration.

Ramp section :

Shown below is a typical ramp circuit found in analog dc drives.

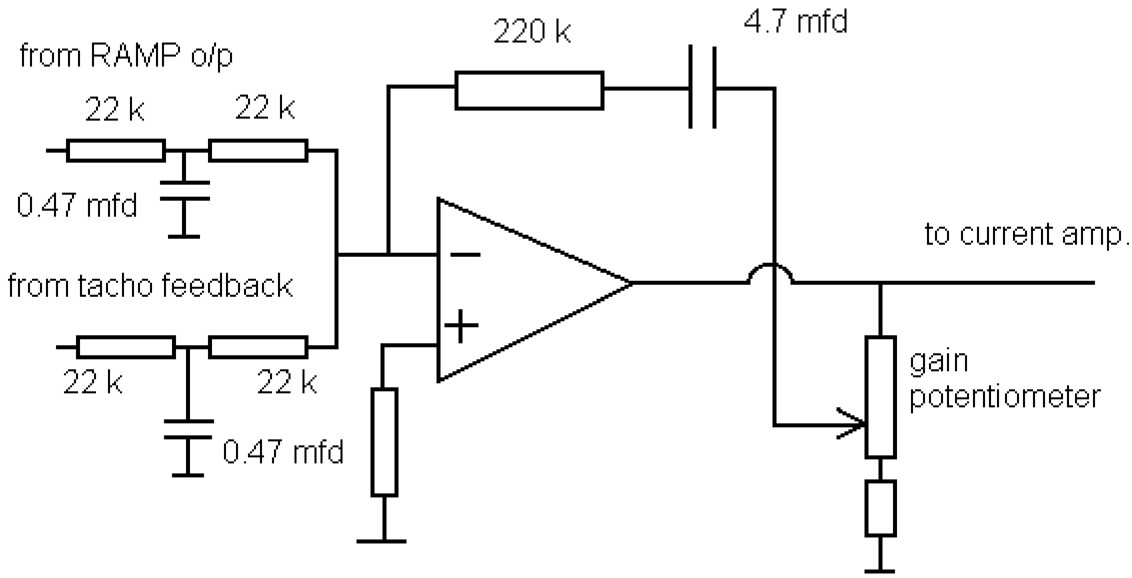


typical RAMP circuit in analog dc drives

Speed Amplifier Section:

Speed amplifier in a dc drive does ***not*** amplify speed ! It derives its name from the simple fact that the feedback signal given to this amplifier is that of ***speed*** of the dc motor. This amplifier is also called more appropriately as MAJOR LOOP. This amplifier forms a major loop (outer loop) in the overall closed loop system of a dc drive, the internal or MINOR loop being that of current with current feedback.

This amplifier, in a simple analog dc drive, is built around single operational amplifier in PI configuration. i.e. it has a resistor and capacitor in the feedback loop deciding PROPORTIONAL GAIN and INTEGRAL TIME of the amplifier. Typical values in an analog dc drives are 220 kilo ohms and 4.7 micro farad. There is also a "gain" potentiometer associated with the speed amplifier. This is set, during commissioning of the drive, to get optimally damped response of the closed loop, i.e. it is set in such a way that the dc motor reaches its set speed as fast as possible but at the same time it has no overshoots or undershoots of speed during acceleration or deceleration. Gain is normally set towards minimum of the range available, i.e. the wiper of the potentiometer is towards the output of the opamp. Output of the speed amplifier acts as the input to the current amplifier through a preset potentiometer called "CURRENT LIMIT". Read more on the current limiting and current amplifier in other links.



Majority of applications of DC drives involve holding the speed of the dc motor to a fixed set value irrespective of variation in load, supply voltage etc. For controlling the speed precisely, measurement of speed is necessary. Unless we measure we can not control. Tachogenerators do the job of measuring the speed. They give voltage proportional to the speed of the motor. Accuracy of control will therefore depend to a great extent on the quality of the tachogenerator. Typical speed holding accuracies are 0.5 % to 1 % .

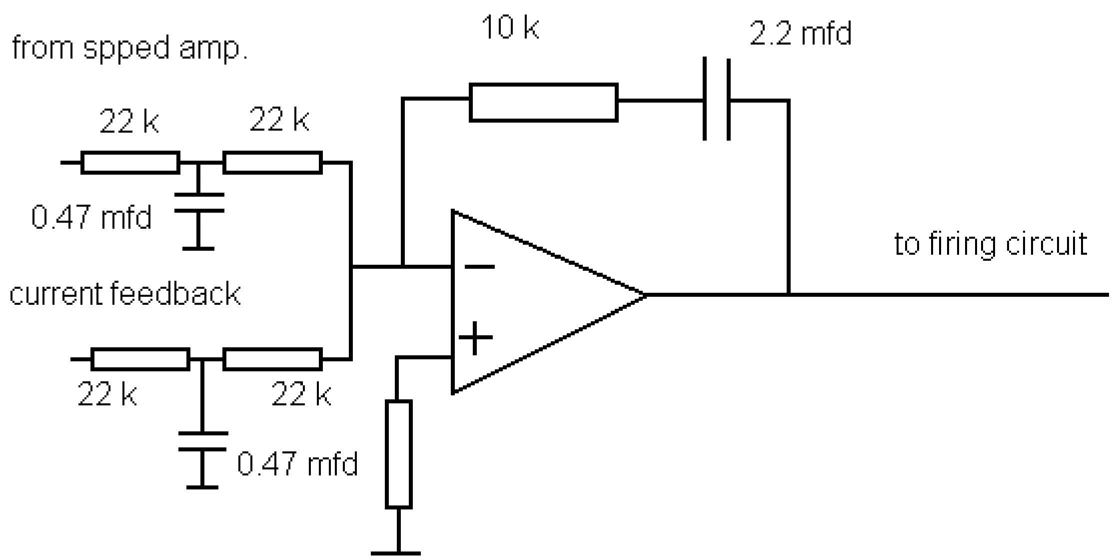
However, there are many applications which require that speed of the dc motor be varied from zero to full speed but accuracy is not necessary. In such cases, a cheaper control is possible using Armature Voltage Feedback instead of Tachogenerator feedback. The assumption here is that the speed of any dc motor is roughly proportional to the armature voltage applied, if we neglect the resistance drop taking place in the armature winding. This drop in big motors is typically up to 5 % of the rated motor voltage. That means, by using armature voltage feedback, we can get accuracy up to 5 %. . However, there is a method called “IR compensation” by which a better control is possible. It is not as good as that achieved by using a tachogenerator. A signal proportional to the Current in the Armature is already available in the drive. It is derived from Current Transformers on AC side of the thyristor bridge. This is subtracted from the feedback of Armature voltage. Thus, actual feedback equivalent to (Armature Voltage- I x R) is applied to the speed amplifier and a better control of speed is achieved.

Only precaution necessary while using the armature voltage feedback is to isolate the armature voltage galvanically before it is fed to the electronic circuit. DC to DC isolators are available for this purpose. The isolation prevents circuit components from becoming "live" if feedback is not isolated.

Current Amplifier Section :

Current amplifier in a dc drive does ***not*** amplify current ! It derives its name from the simple fact that the feedback signal given to this amplifier is that of ***current*** of the dc motor. This amplifier is also called more appropriately as MINOR LOOP. This amplifier forms a minor loop (inner loop) in the overall closed loop system of a dc drive, the external or MAJOR loop being that of speed with speed feedback.

This amplifier, in a simple analog dc drive is built around single operational amplifier in PI configuration. i.e. it has a resistor and capacitor in the feedback loop deciding PROPORTIONAL GAIN and INTEGRAL TIME of the amplifier. Typical values in an analog dc drives are 10 kilo ohms and 1 micro farad. Some designs may have Current Gain like that in speed amplifier. Output of the current amplifier acts as the input to the firing circuit. The output of this amplifier is restricted within two minimum and maximum limits set by two preset potentiometers called minimum and maximum voltage or "conversion" and "inversion" limits. This dc level decides the instance in sinewave at which the thryristors are fired. If we disconnect the output of this amplifier and connect a potentiometer to feed dc level to the firing circuit, we can test any drive in "open" loop manner. This is normally done to diagnose faults in the firing section of the drive. Since there are no safety limits left when the drive is tested is this fashion, it is advisable to take initial tests with Lamp load instead of dc motor.



Current Limiting :

Output of the speed amplifier is connected to the next stage of current amplifier through a preset potentiometer called "current limit pot". This potentiometer restricts the voltage level going to the current amplifier. If dc drive is functioning correctly, restricting this voltage level can restrict the current taken by the motor to any value from zero to full load current. To understand different uses of this feature, a brief description of the working of the two closed loops (speed and current) will be in order.

When a dc drive is started and certain speed reference voltage is given, the output voltage of the ramp circuit starts increasing slowly. This voltage is connected to the input of the speed amplifier. The output of this amplifier starts going towards the saturation level (either +supply voltage or -ve supply voltage depending upon the configuration of the opamp and reference polarity.) This voltage in turn fed to the current amplifier, pushes the current amplifier voltage also towards its saturation level slowly. The rising voltage starts firing the thyristors thereby generating gradually increasing armature voltage. The motor starts accelerating. In the process the tachogenrator mounted on the dc motor starts generating more and more voltage. At one instance, the voltage generated by tachogenerator, which reaches the input of the speed amplifier, matches the reference voltage at the input of the speed amplifier. Any tendency of tachogenerator voltage increasing the reference voltage, drops the output of the speed amplifier. The net result is that the motor starts running at a constant speed. Here, let us assume that the mechanical load is such that the current feedback generated is 1 volt. You will notice that the voltage output from the speed amplifier is also 1 volt. Now, in this condition, if the motor is mechanically loaded more, it demands more current from the thyristors. This extra current can not come from the supply without an increase in armature voltage. Increased mechanical load first drops the speed of the motor slightly. Decreased back emf of the motor allows the motor current to increase. (motor current = [applied voltage - back emf] / armature resistance). Almost in no time, the drop in speed is compensated by the speed amplifier taking a corrective action because of the closed loop feedback. If the output of the speed amplifier is monitored, it will be seen that the output has gone up and matched the current feedback level. This is tricky. It appears as if the feedback is deciding how much should be the reference ! More and more load on the motor will go on increasing the feedback signal level and a point will be reached when the output of the speed amplifier can match the current feedback level. From this point onwards, the motor current can not increase to meet the demand from the mechanical load, and as a result the speed will start falling down. This point is the point where the current has started limiting itself. Any amount of load put on the motor will only result in drop in speed. This is current limiting. So long as the motor is demanding current less than the set value, the speed closed loop will work perfectly holding the speed at the set value. Further rise in load will result in reduction in speed.

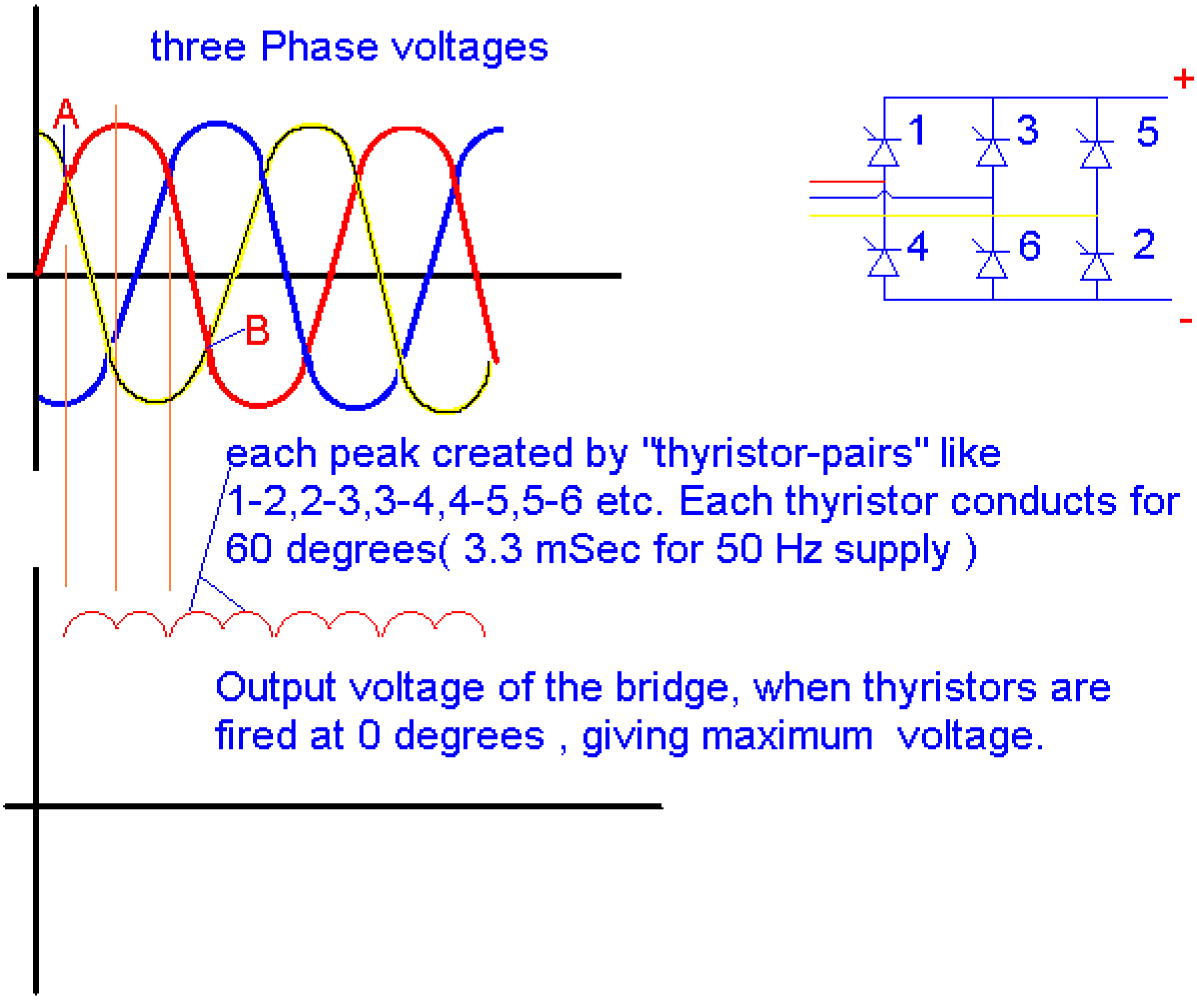
Now that the current limiting is clear, let us see the uses of this feature in a dc drive.

- To limit the current to a safe level.
- To test the tachogenerator signal by running the motor under current limit. Without drive running in current limit, it is impossible to conclude if the tachogenerator is at fault. The closed loop action makes it impossible. But by putting the drive in current limit, we are actually breaking the feedback loop thereby making it possible to diagnose.
- It helps in initial trials of the drive or motor, where excessive load can cause damage.
- It can also help in deciding the correct polarity of the tachogenerator required.
- It can be used to control tension in winder application where speed is not required to be maintained but it is the tension which is to be maintained constant.

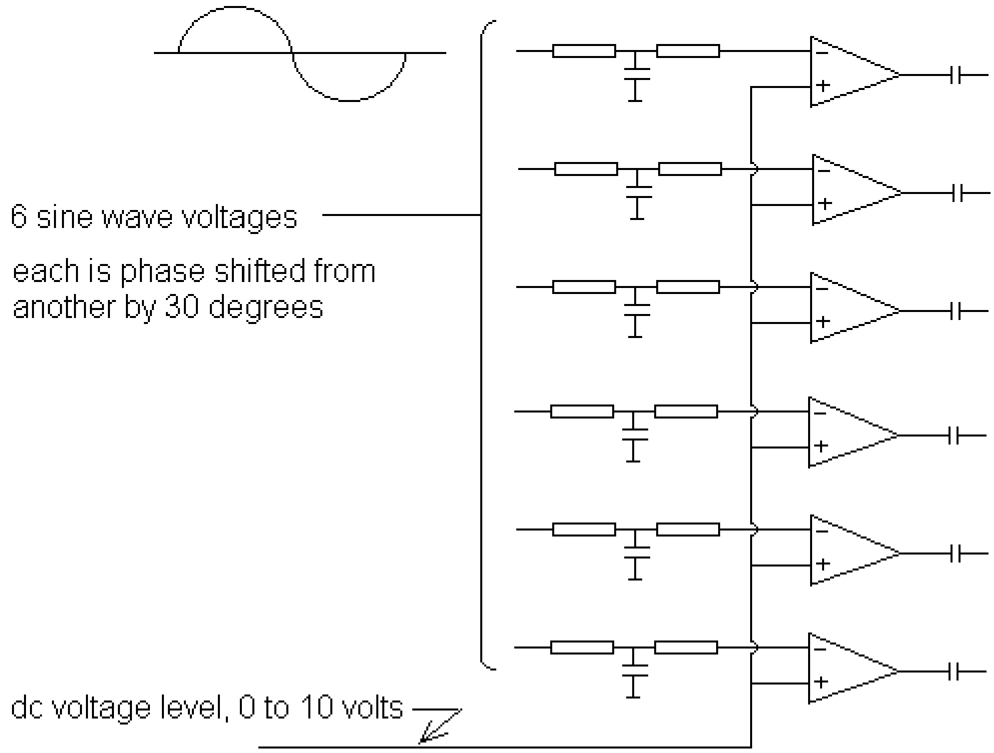
Firing Circuit Section:

In a three phase dc drives, the three line voltages applied to the thyristors. These are R-Y, Y-B, and B-R. Referring to the sketch below, thyristor 1 will conduct only when its anode is most positive compared to other two i.e. no. 3 and 5, provided, off course, the firing pulse is applied.

Looking at the three phase sinewave diagram, this possibility exists only after point "A", and continues to exist till point "B" which is 180 degrees away from "A". This means that the firing pulse generated by the electronics must be able to swing from A to B.



Pulse is generated using a dc level from current amplifier and a sinewave from the three phase supply. Both are first compared in a comparator. This comparator generates a square wave in which the rising and falling edges occur at the instant when amplitudes of sine wave and that of the dc level are equal. Therefore, one must have a sinewave signal which covers entire 180 degrees between "A" and "B" . This sine wave is normally derived by phase shifting a voltage which has 30 degrees phase shift with respect to Line voltage. Phase shifting capacitors are typically 0.1 mfd to 0.47 mfd. Resistor values are adjusted accordingly and are chosen to have low tolerance of 1 % . Output of these comparators (6 for three phase drive) is passed through capacitors, to generate pulses. These are amplified and applied to gate of the thyristor through a pulse transformer.

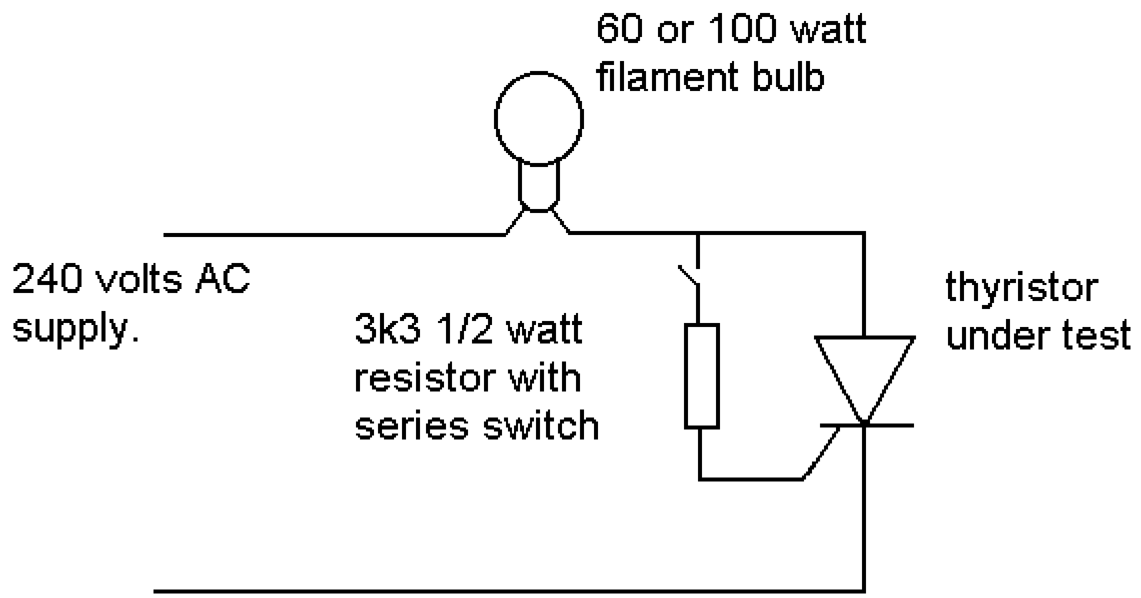


Output voltage from the Current Amplifier is a DC voltage level which varies from zero to maximum or negative to positive 10 or 15 volts depending upon the design. It is a dc level. Its voltage level decides the point along the Time axis at which the firing pulse is generated. This is achieved by comparing this voltage level with “Sine Wave” voltage applied to the inputs of comparators. The six sine wave voltages are derived from three “synchronising” transformers which generate 6 voltages. Each sine wave is phase shifted from another by 30 degrees. This phase shifting is achieved using precision resistors and capacitors with tolerances of less than one percent. Typical values for 50 Hz operation of DC drives, are 0.1 mfd to 0.47 mfd with resistance values adjusted accordingly. A total of 60 degrees of phase shift is required between the sine wave applied to the thyristor of a particular phase and the corresponding synchronising sine wave. The remaining 30 degrees of phase shift is achieved through Delta / Star configuration of primary and secondary of Synchronising Transformers. These two methods together add to filtration of noise also. Voltages at the output of 6 comparators are in the form of square wave. The rising and falling edges of the square wave give rise to pulses when these are passed through “coupling” capacitors. These are normally amplified using transistors like SL100 or ICs like 2003.

Checking a Thyristor on table :

Thyristor, when checked on digital multimeter, should show "open circuit" in both directions. Resistance between Anode and cathode is sometimes as low as 2 k but such thyristors also work okay.

Gate and cathode, when checked on "diode test" range , sometimes show voltage drop of approximately 0.5 to 0.7 volts in one direction and "open" in other direction. Some thyristors show "diode" in both directions. But "open" in both directions is not a sign for good thyristor. To check if the thyristor (rated at 60 amps or above) is triggering okay with gate pulses, the following set up on table can reveal the result. The switch should be pressed for short time, for a second or so, to avoid damage to the gate junction. If the lamp glows when the switch is closed, the thyristor can be considered to be in good condition. Very small thyristor of ratings less than typically 40 amps may require higher value of resistor to limit the gate current. High values like 47 k can be selected to begin with and reduced if the bulb does not glow. Gate resistor and a switch shown below may have to be shifted before the lamp in some cases. Do not hold the switch down for long time. Just a momentary trigger is enough.



Using an Oscilloscope on DC drives :

Electronic components in Thyristor drives have voltages of the order of 400 volts as well as dc +/- 5 volts, 12 volts etc. High voltages present around thyristors are normally derived directly from three phase supply which many a times has a neutral connection also. This means that there are dangerous voltages present around thyristors with respect to neutral. Oscilloscope operating from mains supply voltages have invariably an "Earth" connection in the mains cord. Internally, this is connected to the "zero" or "common" of electronic circuitry of oscilloscope. The BNC connectors where we connect the CRO probes, thus, have a zero volt point getting connected all the way up to the measuring tip of the probe.

Here comes the major risk. When the probe is connected to, say Gate-Cathode of a Thyristor, to check firing pulses, a dead short circuit occurs between a phase voltage and the earth, causing a big blast in the probe shield !

To avoid such a situation from arising, "earth" pin of the CRO must be REMOVED when using on DC drives. This sounds against the basics of handling electrical equipment where Earthing is a must! However in this situation it must be done with due care in handling. It is further important to keep in mind that there are dangerous voltages present on CRO metal parts which must not be allowed to come in contact with human body or other metal parts connected to ground.

Common faults :

Speed of the motor Drops :

Some times, even when the load is well within the limit of the rating of the drive and that of the motor, it is observed that speed drops when the load is increased. There can be following reasons for this.
The drive is working under Voltage Feedback Control and that IR compensation (i.e. the compensating action to compensate for the Resistive Drop of voltage in the Armature Resistance) is not adjusted properly. IR compensation is not to be applied when using Tachogenerator Feedback arrangement.
If only four thyristors are firing out of six, an increase in load can push the drive in current limit if it is set very critically without any margin left. When four thyristors fire, average current in the motor is less but the peaks are higher. These higher peaks cause the drive to go in current limit. A quick check on Oscilloscope will reveal this immediately.

More on IR compensation...

IR stands for “I into R”. i.e. Armature Current multiplied by Resistance of the Armature winding. In a dc motor the speed N is given by the formula

$$N= (V- IR) / Flux.$$

V is the applied voltage, Flux is the magnetic filed in the air gap between stator and the rotor. Considering the magnitude of IR compared to that of Voltage applied, one can ignore it. IR is not more than 5 % of full armature voltage. Speed of the motor therefore, can be simply assumed to be proportional to the applied voltage. To get somewhat closer to the real fact, one can generate a signal proportional to I x R by sensing actual armature current and use to compensate the error in N by subtracting IR from V. Thus, a feedback signal which is proportional to V-IR rather than only V is more accurate and able to control the speed more closely. Excessive compensation of IR can cause overcompensation and may tend to increase the speed as the load increases. This is not desired.

Motor going to full speed without control :

Motor can go to full speed due to faulty tachogenerator, faulty or loose coupling, wrong polarity of tachogenerator, wrong polarity of field or armature connections, defective reference signal, defective RAMP circuit, or even defective "firing" circuit. In case of faulty tachogenerator, a glance at speed indicator, which in many cases connected to the same tachogenerator, can give a clue. The indication will be zero.

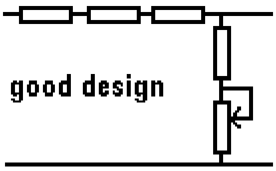
If firing circuit has no control over armature voltage, then usually the fuses will blow first before speed increases. If fuses escape from blowing, then the speed will be attained very fast with a jerk.

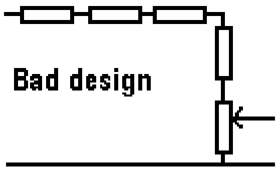
Faulty reference will usually take the motor to full speed rather smoothly if everything else is okay.

If speed indication is seen, one can check the voltage divider used for scaling down the tachogenerator voltage to low value. Normally a chain of resistors is used for this purpose.

Resistor divider in a good design will make use of many small value resistors rather than a few high value resistors. Also the variable preset potentiometer provided for adjustment of speed takes the following correct form in a good design. Note the shorting of wiper of the potentiometer with the one end. Just a small track on the PCB, but shows a real deep thinking on the designer's part. When the wiper is not shorted, as seen in the

image on the right hand side, the drive will go to uncontrolled full speed when the wiper makes poor contact after years of use. With the arrangement as shown on the left hand side, bad contact on wiper will not take the motor to full speed. It will, on the other hand, decrease slightly and therefore not damage the mechanical parts connected to the motor.

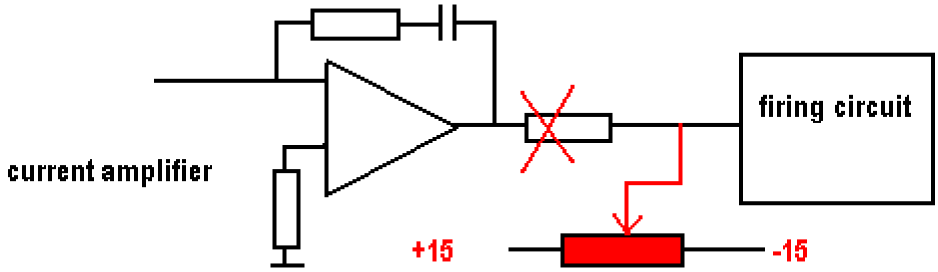




Fuses blow too often :

If main thyristor fuses blow on applying the mains power to the drive even when "enable" command has been removed or disconnected, most likely cause is "defective thyristors". Checking with multimeter, on diode range, between each AC leg and +ve (and -ve later on) one by one will indicate if the thyristor is faulty. Reading as low as 2k Ohm on resistance range are sometimes acceptable and thyristors will work in normal way. However, most of the good thyristor will show "open" or a few hundreds of kiloOhms. Some button type thyristors, require pressure to be applied before the outer metallic part gets connected to the thyristor inside. Therefore, even a dead short thyristor will escape the test if tested without pressing the probes hard. If the fuse is bowing with enable command given, the following steps will lead to some clue.

1. Disconnect the motor armature. Field can be left untouched.
2. connect two filament lamps of same wattage in series with each other, across the drive + and - terminals.
3. Firing circuit normally gets a DC voltage from "current amplifier" . The levels are either 0 to +15 volts or -15 to +15 volts or +15 to 0 volts. Looking at the circuit diagram, determine which range of voltage the drive normally works with. Accordingly, connect a 5 or 10 kiloOhm potentiometer to a suitable dc supply, preferably from the drive itself, and connect the wiper of the potentiometer to the input of the Firing Circuit. Take care to remove the normal interconnection between firing circuit and the previous stage i.e. current amplifier.

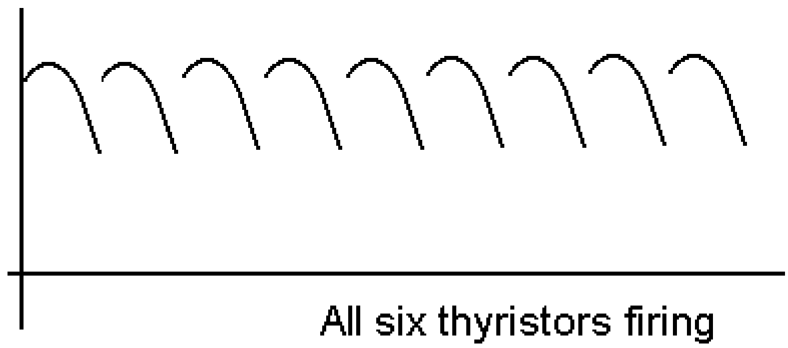


4. Apply power to the drive and give Enable command, i.e. start the drive through normal control available.

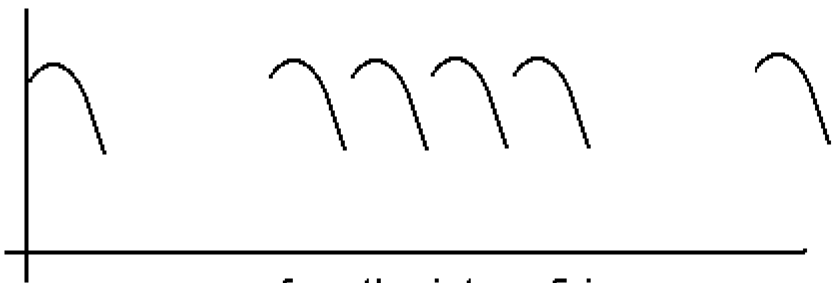
5. Vary the potentiometer from one end to the other end and you should see a very gradual and flicker free variation in the intensity of the lamp.

6. If the above is observed, then the reason for the fuse blowing is not in the firing section of the electronic cards. It could be in the motor, the load, or closed loop part of the circuit etc.

7. If the variation in the intensity of the lamp is erratic, or you see no control over intensity, then the firing circuit is defective and this could be the cause for fuses to blow. Here we assume that no one has played with the phase sequence of the supply to the drive.
8. Defects in the firing circuit could be faulty synchronizing transformers, faulty phase shift capacitors etc.
9. Phase shift capacitors, after long use for years, may become open. You will find six of them in three phase drives. Replace all.
10. If the intensity of the lamp varies smoothly from zero to full, check the maximum voltage available across drive +/- terminals. For a three phase 415 volts system, it should be as high as 560 volts dc. If not, check if the firing circuit has a potentiometer limiting the maximum firing angle. Verify that you have control over the maximum voltage available. If the voltage is not rising more than 500 volts, connect oscilloscope across one of the lamps and check the waveform. One of the thyristors not firing, can lead to this symptom of low voltage. The wave forms with all 6 thyristors firing properly and with only 4 thyristors firing, are shown below.

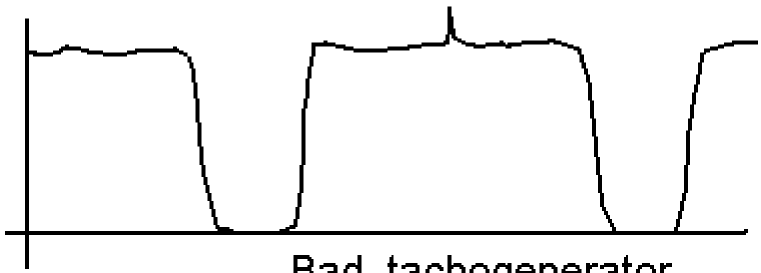


All six thyristors firing



four thyristors firing

A bad tachogenerator can also sometimes, depending on the severity of damage, cause fuses to blow. Putting the drive in current limit and then checking the signal of tachogenerator on Oscilloscope will reveal if the tachogenerator is bad or not. Putting the drive in current limit ensures that the closed loop corrective action is disabled and diagnosis is correctly made. See the signal from a bad tachogenerator which can blow the fuses occasionally. If it is not possible to put the drive in current limit, one can run the motor in "Open Loop" as mentioned above and check the tachogenerator signal.



Bad tachogenerator

Overheating of motor :

Motor can run hot for any of the following reasons :

1. cooling inadequate due to air leakages in the blower gasket
2. blower direction wrong
3. bearings faulty
4. gain adjustment of the drive incorrect
5. Four quadrant dc drives which have two sets of thyristors (Two bridges connected in back to back manner) can cause overheating of motor if the gain is not adjusted properly. Monitoring Current waveform will show that both the thyristor bridges are firing (becoming on) alternately at a fast rate. Torque is thus applied in alternate directions. However, mechanically this is not felt due to inertia. Net effect of torques in both directions is what is rotating the motor in one direction. It is like saying that we get a torque of say 3 units but it is as a result of two opposite torques of unnecessarily high values. (23-20 =3, or 56-53=3 !) Torque of +56 and –53 units cause overheating of the winding, but it is 3 units which is driving the load.
5. If motor runs normally at low speeds, reduce the diameter of the pulley on the motor shaft.
This will reduce the current drawn for the same load, thus reduce the heating.

Motor gives jerks :

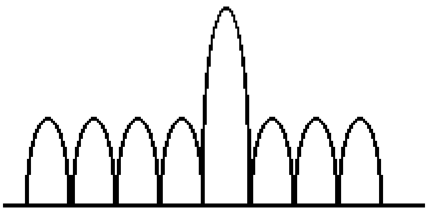
Jerks observed while running the motor are dangerous to the drive as well as to the motor and connected load. It is harmful to continue running the motor without trying to locate the source.

Jerks, many a times, appear to be arising from the mechanical parts but such conclusions are deceptive. Immediate checking of current waveform will give some clue. Note the difference in the two waveforms. Sharp rise only in one peak is normally not possible due to mechanical parts.

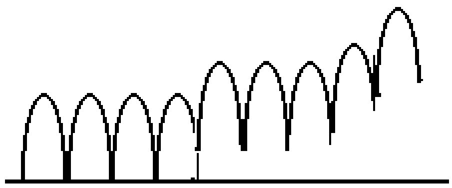
Waveform as shown in the sketch on the left hand side is also possible if a thyristor has collected a lot of dust around gate cathode area. Keeping ceramic insulator around gate clean is one solution to such cases. Thyristors misfire with such dust getting accumulated and can create a big sound from the gears connected to the motor. If one is not aware of this "electrical possibility", it misleads people to think that the gears have developed some problem.

Printed circuit boards also accumulate black dust around the tracks which causes similar symptoms.

When any contactor in the panel drops out, some times, the motor gives jerks. Dropping of a big contactor causes electrical noise to be generated which travels along and is picked up by sensitive “Gate” leads. Such jerks can be reduced by twisting the gate cathode leads with very tight twist. The twisting makes the gate cathode leads immune to picking up of noise. Shorter lengths of these wires also helps. R-C circuits across the contactor coils also help in reducing these jerks. R-C circuit eats up the noise generated right at the source.



mechanical obstruction can not cause sudden rise in one current peak alone.



this could be from firing signal or load side.

<u>Sparking on commutator :</u>

Sparks are often seen on the commutator, below the carbon brushes. There are many reasons for this. Minute observations can reveal the cause.

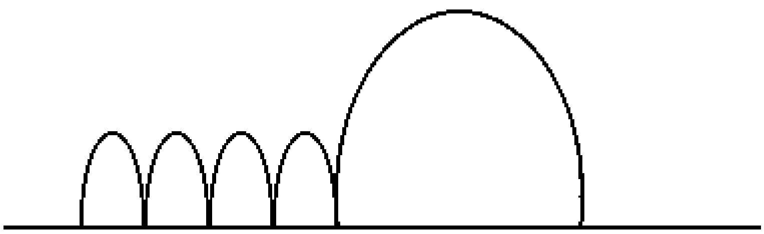
One needs to check if.....

Sparking occurs only when the load and speed are increased.
Sparks are yellowish in color and do not have blue tinge.

Sparking is intermittent and occurrence is unpredictable.

Out of many causes, the following are a few.

a) Inter turn short in the armature winding. Current waveform in such cases is seen as under.



A big current peak, in time as well as in amplitude

b) Defective interpole winding can also cause sparking. If the position of the brush holder is disturbed the following steps can be used to adjust it to normal position, assuming that the interpoles are ok.
Disconnect the motor totally.
Remove armature connections.
Apply 230 volts AC voltage to the field winding.
Measure the induced voltage in the armature on the carbon brushes. (across the terminals where DC leads from the drive were connected)
Adjust (rock the rocker slowly forward and backward) the rocker till the voltage induced is lowest.
Tighten the rocker position at this point.

c) Sparks yellow in color indicate that these are caused due to uneven surface of commutator. Particles of carbon from the brushes are flying off due to mechanical impact on the brush tips. Making the commutator smooth on a lathe machine may solve this problem.

Here is a photograph of current waveform with all 6 thyristor firing. However, all the current peaks are not of same amplitude. This means that the motor is taking high current for some time and a lower current for some time. As explained above, uneven mechanical friction can NOT cause this. Because, as you can see, each current peak lasts for hardly 3 milliseconds. Mechanical non uniformity in friction or load can not change that fast. The reason for this uneven current peaks is always from electrical side.

There are two possibilities.

First possibility is that the firing of all 6 thyristors itself is uneven or unbalanced. This can be verified by bypassing Ramp, speed amplifier, current amplifier and connecting the drive in OPEN loop mode. i.e. by giving a dc signal of firing thyristors directly from a potentiometer to the firing circuit. (See the explanation in the link "Fuses blow"). The motor must be operated very carefully in this mode as there are no protections of current limit etc. A small mistake or rough handling of the potentiometer can cause a big jerk or shock to the mechanical parts. If the current waveform does not change its shape (uneven peaks) then it can be concluded that the Phase-Shift circuit components in the Firing Circuit are not matched properly. In analog Drive, one can check values of all 6 resistors and 6 capacitors which give required phase shift for firing pulses. The resistors are usually of 1 % tolerance levels. All must be precisely same. If the current waveform becomes smooth with all 6 peaks of current of same amplitude, then it can be concluded that the cause for uneven peaks lies in the firing signal coming from the output of current amplifier

Output of the current amplifier, when seen on oscilloscope, will show wavy dc signal. Incorrect adjustment of Gain of the amplifiers(both speed and current) causes this signal to be wavy. Reduce the gain to make the DC level more like a straight line. If the gain adjustment does not solve the problem, then another source which is likely is bad tachogenerator. Missing dc voltage on some commutator segments of the tachogenerator can cause the output of the current amplifier to become wavy.

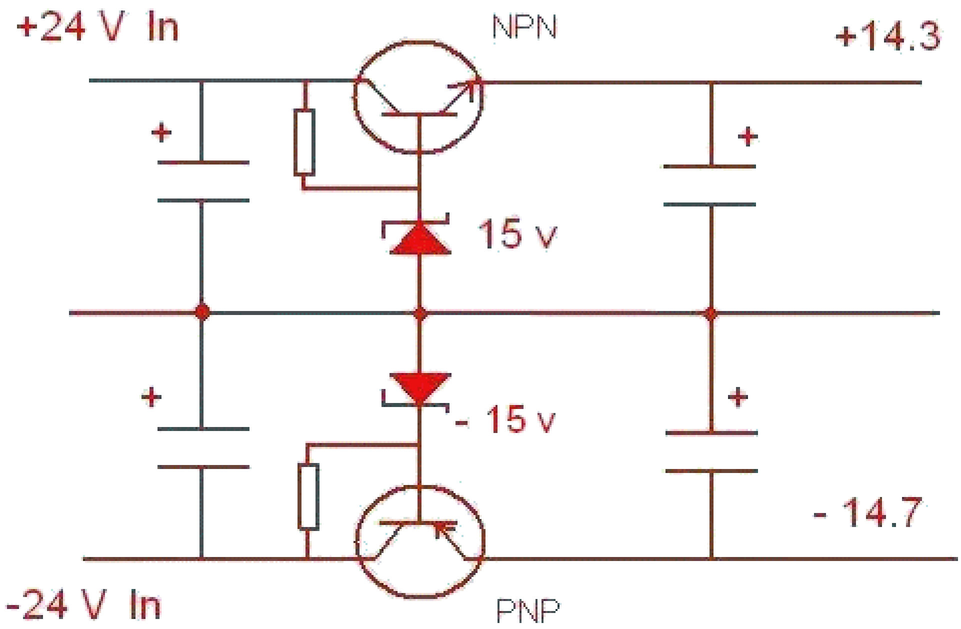
Some times, too much of gain in the Speed Amplifier makes the motor to rotate very slowly even at zero speed reference signal. The only method to prevent this from happening, if at all it is critical, is to reduce the gain without compromising on performance at higher speed levels. If the drive has a provision to apply a biasing signal of opposite polarity as that of the main speed reference signal, applying a bias may also solve this problem. This may add a small non-linearity in the overall performance.

Unstable or erratic Speed control.

Speed variation can be gradual over time or erratic and unpredictable. If the variation is gradual it could be arising from heating of some component, especially in the feedback circuit. Sudden or erratic variations can be caused by several reasons. Dry solder in reference path, leaky capacitors in Ramp circuit are just two of many reasons.

Motor starts only after reference voltage is increased substantially, but the control is okay once the motor is started...

This is a very peculiar situation. As the drive reference voltage is slowly increased, the motor does not respond for quite some voltage. The motor starts running at a much higher speed. However, once started, the reference voltage has good control and the speed can be reduced almost till zero without problem. This is caused by unequal supply voltages to the operational amplifiers in RAMP circuit. Normally the voltages are +15 and -15 volts. If these voltages are unequal, e.g. +14.3 V and – 16.5 volts, then the situation described above is arises. Given below is a typical arrangement of generating +ve and -ve voltages without using 3 pin voltage regulators. The selection of zener diode in one of the sections may require trial and error method to get exact equal voltages at the output of NPN and PNP transistors.



Hunting in speed :

This phenomenon of motor speed going up and down in a noticeable rhythm is called “hunting”.
Hunting, or speed of motor going up and down in rhythm, can be caused because of following reasons :
- Load on the motor too small and the adjustments done at normal load do not hold good for light loads.
- Current feedback absent. Check the signal on Burden Resistor of Current Transformers, with an oscilloscope.
- Gain of the speed amplifier does not match with the mechanical inertia. Normally too much gain causes this type of hunting.
- Too much of Integral time.

Irregular speed variation can be caused by loose coupling of tachogenerator, unstable output of RAMP generator, dry solder in feedback path of tachogenerator signal etc.

Motor stops all off a sudden without giving any indication:

This fault is apparently difficult to trace but a commonly found cause is “poor enable contact”. Drive is “enabled” i.e. allowed to run when everything else is okay by an electrical contact called “enable” contact of a relay or a contactor. In many drives, it is common to use a normally open contact which closes to start the drive. Therefore, a bad electrical contact often “disables” the drive for unpredictable duration depending on the period for which the contact resistance remains high. A quick measurement of contact resistance with all power put off, reveals if the bad contact is the cause. A resistance value more than 1 or 2 ohms usually an indication of bad unreliable contact. Spraying Electrical Contact Cleaner solution or CTC (Carbon Tetra Chloride) helps in restoring the contact to good usable condition. Replacing the open type contactor with a totally enclosed relay with gold plated contacts will solve the problem permanently if the surrounding of the drive is dusty.

Motor not able to drive the load.....

Some times, motor draws good amount of armature current, but not able to drive the load connected to it. Common reason for this observation is that the load is too much and is beyond the capacity of motor to produce required torque. The dc drive is said to have gone in “current limit”. This is visible on ammeter connected to the drive. One will find that the motor starts drawing more and more current and finally reaches a point where the ammeter appears to be stuck at one level. If the ammeter is of analog type, the pointer becomes rock steady. If the drive has not reached the current limit level, then the ammeter pointer normally keeps on moving up and down a bit. In such cases cause for no rotation is not from excessive load.

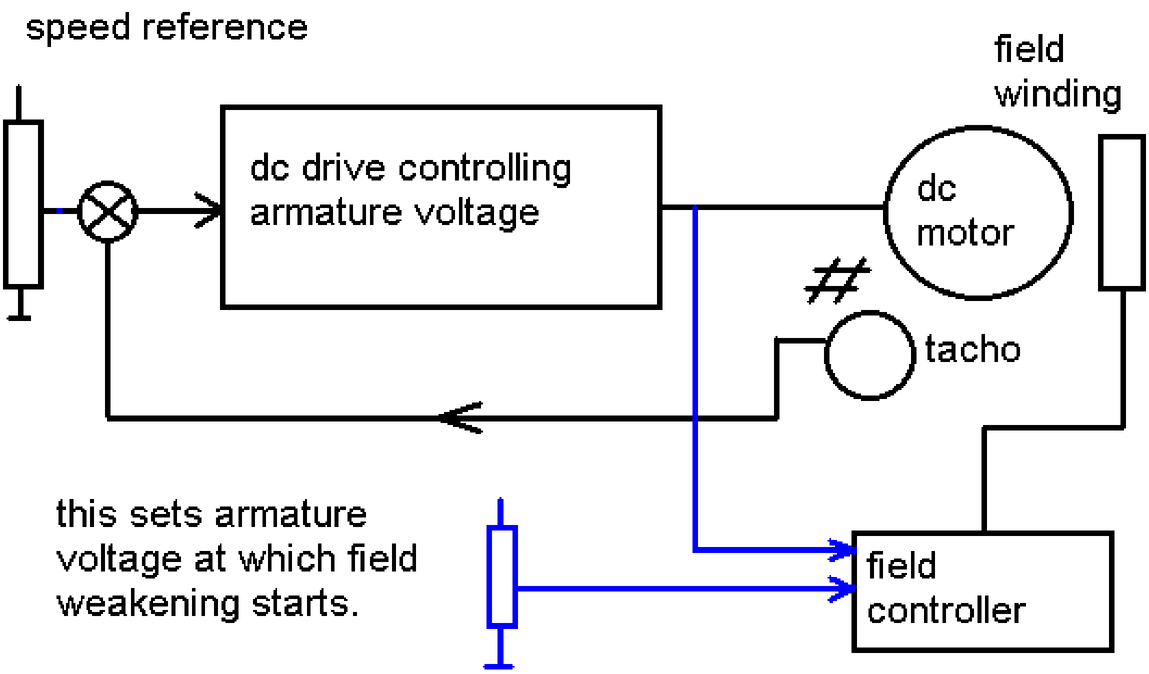
If the load is mechanically not jammed or locked, and the drive goes in current limit, there could be one more probable reason for this. It is possible that the "field voltage" is absent and the mechanism to sense "field failure" condition is bypassed! i.e. out of two magnetic fluxes produced by armature current and field winding, required for production of torque, one is absent.

If the filed voltage is also present and okay, there is another possibility, although remote, that the carbon brushes on the commutator are not making contact with commutator. In case of motors with 4 sets of brushes (located at 90 degrees) this situation is likely to occur. The armature current drawn by the motor is not at "electrical right angles" with respect to magnetic flux and therefore not able to produce any torque!

<u>Field weakening for getting speed above base speed :</u>

Speed of a DC motor is governed by two variables viz. Armature voltage and field voltage. Armature voltage and speed are directly proportional to each other. Field voltage and speed are inversely proportional to each other. i.e. if the field voltage is ***reduced*** keeping armature voltage constant, the speed of the motor goes up. On the other hand, if the field voltage is kept constant and armature voltage is ***increased***, the speed goes up.

For getting speeds up to base speed of the motor (designed speed which is achieved when armature voltage and field voltage are at their full rated values), the armature voltage is varied from zero up to full rated voltage. For getting speed above the base speed, the armature voltage is kept constant and field is gradually reduced. This is represented in the sketch below.



Electronically, using dc drives this is achieved as follows.

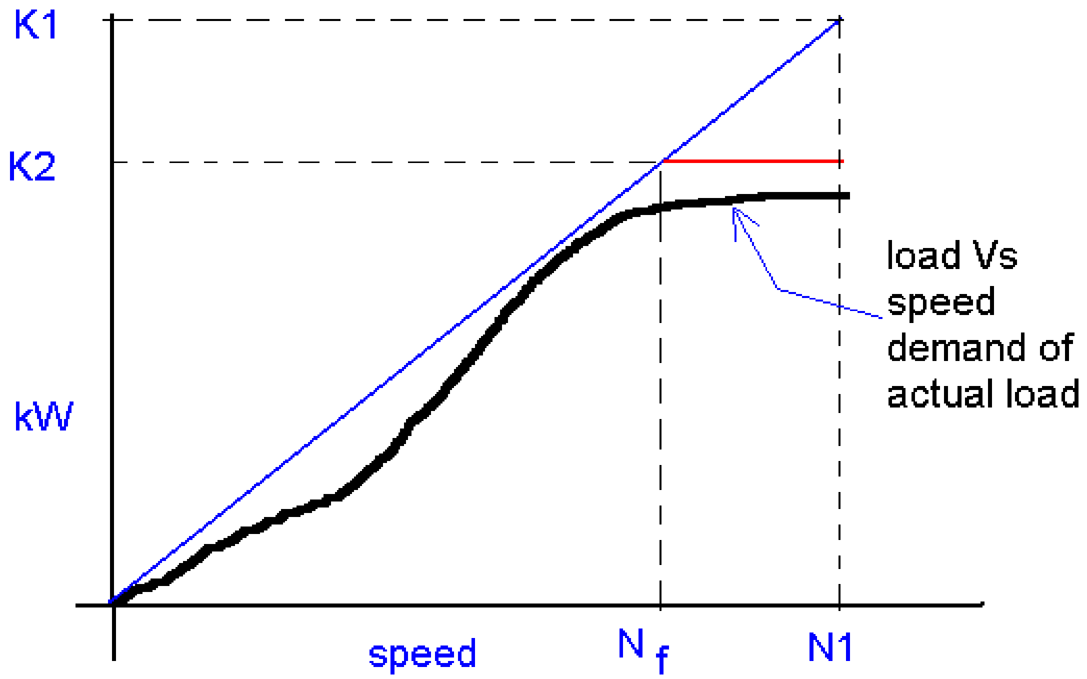
Armature of the dc motor is connected to a normal dc drive which varies the speed of the motor from zero up to its rated base speed. This is achieved, for example, with a reference voltage of zero to 5 volts. At 5 volts reference level, the motor reaches its maximum level of armature voltage allowed. As the reference is further increased from 5 to 10 volts, another thyristor unit which feeds the field current, takes over the control and starts reducing the field slowly. This changeover of controls is smooth and automatic. Referring to the block diagram below makes it clear. Such controls are useful where the load on the motor (kW) does not increase proportionately at speeds above certain speed. In this zone of speed, the higher speed of motor can be achieved through field weakening. In the zone where speed is increased by weakening of the field, the Horse Power of the motor remains constant and is therefore referred to as "Constant HP" operation. Below the point where field weakening just begins, the operation is called "Constant Torque". These two names are slightly misleading. In the Constant HP zone, the horsepower actually developed is constant. However, in the Constant Torque zone, it is not the torque developed which is constant, but it is the Maximum Torque Available is constant.

Constant HorsePower and Constant Torque :

Mechanical Load connected to the motor requires certain horsepower at certain speed. Let us say, this is as shown by the black graph in the sketch below. Point to be noted is that the horsepower requirement of the load does not go up after a certain speed , Nf in the graph. However, the selection of the motor must take care of the maximum horsepower demanded by the load. Therefore, ordinarily, we would have chosen the horsepower of the motor as that equal to K1.

But considering the fact that the load does not require more horsepower after the speed Nf, we can select a lower horsepower motor (K2) and do field weakening at speed Nf. Reducing the field voltage of the dc motor after Nf, reduces the torque which can be generated by the motor. But as the speed is more the product of speed and torque remains constant. This is CONSTANT HORSEPOWER region of the operation of the motor.

The zone between zero speed and speed Nf, the horsepower generated by the motor goes on increasing. However, the "maximum torque available" is constant. This zone of operation is called CONSTANT TORQUE region. It is to be noted that the torque generated by the motor is not constant but the maximum torque available from the motor is constant.



Power Factor:

In alternating current circuits, alternating voltage and alternating current are not always necessarily in phase with each other. i.e. to say, the current flowing in any circuit component, which a result of applied voltage, follows the voltage wave form with a time gap. This time gap could be either ahead of the voltage applied or it could be behind the voltage applied. In circuit with a lot of inductance present, the current is behind the voltage applied. In such cases the current is said to be “lagging” the voltage, as if it is a bit reluctant to flow. The amount of “lag” depends on the amount of inductance present. In circuits with a lot of capacitance present, the voltage follows the current. In such cases the current is said to be “leading” the voltage.

In case of DC drives with fully controlled configuration, low speed operation of dc motors is achieved by firing the thyristors nearer to 180 degrees for getting lower voltage. Thus, for every sinusoidal cycle of supply, the current starts flowing late as compared to the voltage. DC drives, therefore, when operated at low speeds, cause a very low or “poor” power factor. There is no way by which this situation could be improved. It is an effect created as a “by product” of the method used for speed control.

Trying to improve the power factor by putting capacitors near the dc drive is known to have created problems of blowing of thyristors or fuses for no apparent reasons.

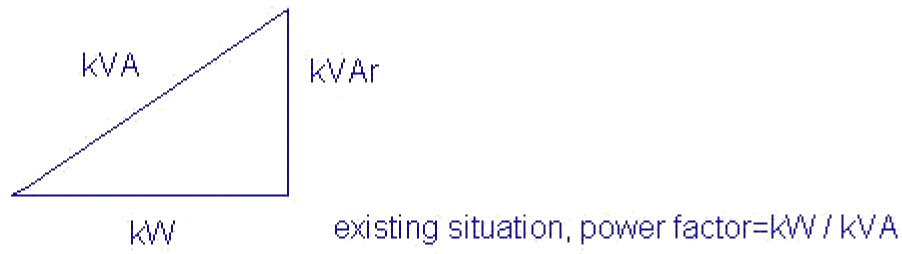
In situations where the added kVAr by capacitors exactly cancel the inductive kVAr, unity power factor is achieved. This is actually a resonance condition. Theoretically the voltage can rise to any level damaging sensitive electronic parts. Practically the voltage does not rise to very high level because the “Q factor” of the overall plant is low. i.e. the plant load has got a lot of resistive consumption also. (In absence of resistive element, the voltage could go to very high levels as in case of resonant tank circuits in High Frequency circuits like radio frequency amplifiers.)

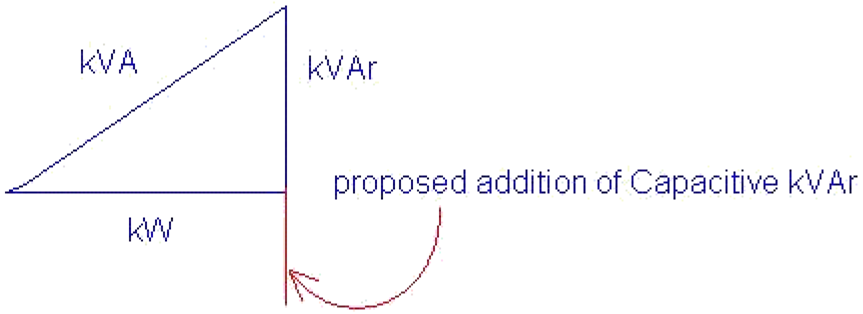
When load in the plant reduces, the added capacitors tend to over compensate and make the power factor as “leading power factor”. The Electricity Supply Companies normally ignore this as it is advantageous for them. Loss on account of other surrounding plants which do not maintain good power factor is compensated by this leading power factor in some plants.

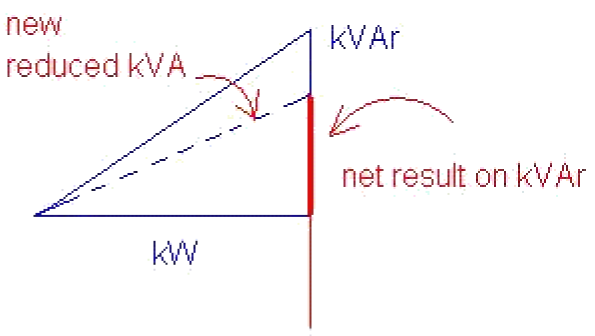
If large amount of inductive load is compensated by equally large amount of capacitive correction to get good power factor, there is a dangerous situation waiting when the load reduces to very low level. For example, on holidays, when the load is almost zero, the capacitors keep drawing reactive power and the excessive capacitive current can fail cables, or cable terminations or trip the circuit breakers. Apparently, this looks funny and one keeps wondering as to why the cables burnt when load was zero on holidays. Manually connected capacitors must be disconnected when likely reduction in load is anticipated.

Power Factor Improvement :

By adding capacitors in parallel to the inductive load suitably, power factor can be improved and brought to the desired level. Ideally, bringing it to 1 is desirable. However, there are some problems involved which are associated with over compensation and resonance arising at unity power factor. Having seen the **basics of power factor**, now let us see how we can estimate the value of capacitors required for improving the power factor to a desired level. For this purpose, we need to know the existing load in kW, existing power factor and the power factor desired after improvement. The situation is described in the sketch below. The solution involves some trigonometric calculations. The value of capacitors required is normally not expressed in microfarads. Instead, it is expressed in kVAr, when used for the purpose of power factor improvement.





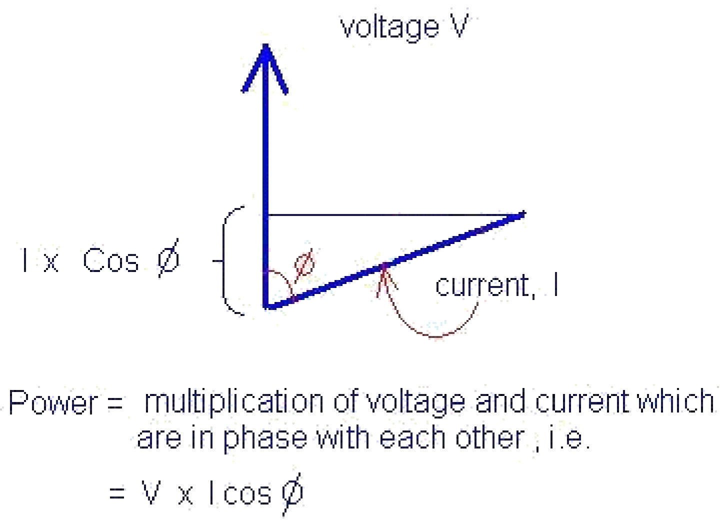


Imagine a simple circuit with a resistor connected to a dc voltage through a switch. The moment the switch is closed, the dc voltage of the source appears across the resistor. The resistor immediately starts carrying a current which is equal to Voltage / Resistance. (V/R). The current stops flowing immediately when the switch is opened. The situation is somewhat different when the resistor is replaced by an inductor. At the time of switching on the switch, there is a sudden change in the level of voltage which is seen by the inductor, from zero volts to V volts. As we know, the inductor always opposes any change in the state of current which is carrying. It tries to hold on to the existing state of current in it. If the voltage and current waveforms are sinusoidal, then cosine of the angle between the voltage and current waveforms is called Power Factor.

Why cosine? Why not sine or tan?

Power is Multiplication of Voltage and Current. But if the voltage and current are not in phase with each other, simple multiplication does not result into power. Power is therefore, multiplication of voltage and only *that* component of current which is in phase with voltage. i.e. P= V x I x cos Ø. This explains why cosine and not sine or tangent of the angle!

Imagine that you want to go to a bank and deposit your money. When you reach the bank you find that bank is closed. So you come back with the cash without delivering. By the time you reach home, bank is again opened. You start again from home, reach the bank but find that bank is again closed. That is to say your money does not get transferred to the bank because opening of the bank and you reaching the bank does not synchronize. In other words, the two actions are not in phase with each other. Similarly, if the current is not phase with the voltage it does not create any transfer of power from source to the load. The current simply travels without any result. This is called wattless power. It does not result into "watts" or power.



In case of DC, the voltage and the current are always in synchronism with each other and therefore, there is no question of power factor.

In a ceiling fan the power factor is typically around 0.7 . This means that only 70 % of the current drawn from the supply lines is utilized in generating mechanical power by way of rotating the blades. It is inefficient use of current provided by the Electric Supply Company. The energy meter fitted in the incoming line, however, records actual energy consumed, taking into account the low power factor of 0.7. Therefore, one does not pay more for making poor use of current. However, the electricity company advises consumers to improve power factor and make better use of the current supplied by them, so that they need not lay thick copper cables for everyone.

In industrial environment, the situation is commercially different. Poor power factor by industries is penalized by noting the power factor separately. Industrial consumers of power therefore take measures to improve the power factor by putting capacitors to compensate the inductance of motors in the factory.

* * * end of Part-2 * * *