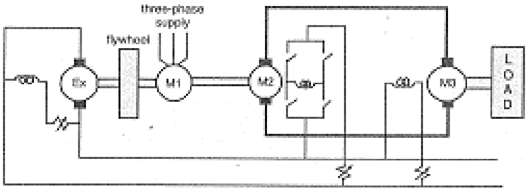


Figure 8.22 Ward-Leonard system.

Decreasing speed by increasing excitation, on the other hand, has a rather limited range because excitation is usually kept close to its rated value to fully utilize the iron. Speed control by changing excitation is economical because the power losses in the field rheostat are small and the rheostat required is compact and inexpensive.

8.11.3 Speed Control by Varying Applied Voltage

As evident from Eq. 8.37, the operating speed can also be varied by adjusting V_a. An adjustable dc supply of V_a can be obtained from another dc machine or from a static converter. Figure 8.22 shows a Ward-Leonard system, where the main dc motor, M3, is fed with an adjustable dc supply generated by another dc machine, M2, that is driven by an ac motor, M1. In low-power applications, M1 can be a squirrel-cage induction motor, but for higher power applications, a wound-rotor induction motor, synchronous motor, or a diesel engine would be needed. The exciter, Ex, provides a constant excitation voltage. Speed reversal of the dc motor, M3, is obtained by reversing the polarity of the excitation to the dc generator, M2.

Some of the advantages of such a system are:

1. Wide range of speed control, typically 25:1, often limited by the useful range of M2's output voltage of about 10:1 because of residual magnetic flux and the steepness of the speed-torque characteristic of motor M1.
2. Fast acceleration of high inertia loads possible with I_a set at the maximum allowable.
3. Regenerative load braking can be effected simply by lowering generator M2's voltage.
4. Dispensation of lossy and bulky resistance and switches in the armature circuit for starting and braking.

The disadvantages are in the number of full-size machines in the chain, which raises the cost and lowers the overall efficiency.

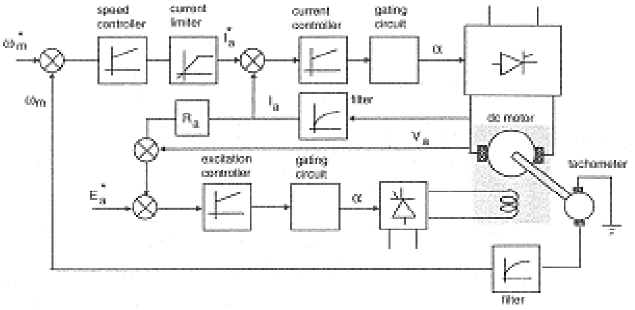


Figure 8.23 Current and speed control loops of a dc machine drive.

Electronic control. Figure 8.23 shows an electronic speed control dc machine drive with outer speed and excitation regulation loops operating through a faster current regulation inner loop. The current control via α is discrete (six times per cycle for six pulse units). The speed response of the drive is mainly governed by the mechanical time constant. The inner current loop response is determined mainly by the armature circuit time constant, which is usually much smaller than the mechanical time constant. The feedback current value can be obtained from a Hall effect sensor, a non-inductive resistive shunt and isolation amplifier, or by measuring the ac-side current using a combination of current transformers (C.T.s), rectifier, and filter.

Speed sensing based on the back emf by measuring $(V_a - I_a R_a)$ may not be as accurate as that from a tachogenerator with a good linear voltage to speed characteristic. Speed and position sensing can also be accomplished with a digital encoder.

Full utilization of both machine and converter ratings over a wide speed range can be achieved by a combination of voltage and flux control. For this discussion, base speed is the operating speed at which rated open-circuit voltage is obtained with rated field current excitation. For a converter that is appropriately sized to handle the dc machine's voltage and current ratings, maximum torque at speeds below base speed can be obtained when armature and field currents are regulated at their respective maximum values. Lower values of developed torque can be obtained by regulating the armature current accordingly, and by keeping field excitation at the maximum. Since E_a will increase with speed if flux remains constant, beyond base speed, field excitation must be lowered to keep the terminal voltage within the allowable operating voltage of the converter. Thus, operation beyond base speed is also referred to as the field weakening mode, in which the output power will be constant if E_a and I_a are held at their respective limits. The profile of I_a, I_f, E_a, output power, and torque over the speed range are shown in Fig. 8.24.

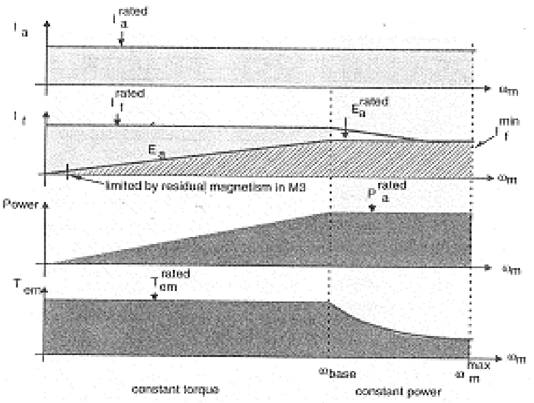
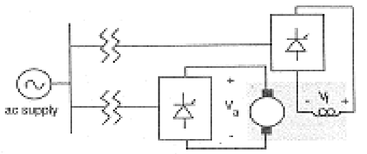


Figure 8.24 Speed range with torque and power control.

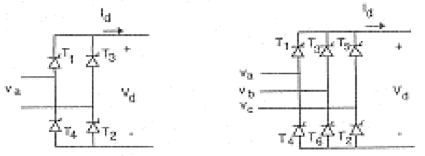
2 FOUR-QUADRANT OPERATION

Most of the newer dc drives are of the electronic type - supplied by controlled rectifiers. Figure 8.25a shows a dc drive with an electronic bridge converter supply to both the armature and field circuit. The converters can be single-phase or three-phase controlled bridges. With a fully-controlled bridge, the terminal voltage, V_a, can be varied by controlling the firing angle of the switching devices in the bridge. For example, if the ac source inductance is neglected, the average values of the dc output voltage of a two- and six- pulse rectifier fed from an ac supply of voltage magnitude V_m with the firing angle, α, are $(2V_m/\pi)\cos\alpha$ and $(3\sqrt{3}V_m/\pi)\cos\alpha$, respectively. Theoretically, V_a can be adjusted to any desired value between the full-positive and full-negative limits by changing the firing angle, α. In practice, some margin angle in the inversion mode would be needed to allow for the finite turn-off of real switches.

A motor usually has a large thermal constant that will allow it to withstand transient overcurrent for a short while with no serious consequence. Unlike motors, the semiconductor switches in a converter are less forgiving insofar as their capability to safely withstand overcurrent or overvoltage. Better controlled performance may be achieved with the converter's current rating higher than that of the motor, if the current control of the converter can be properly coordinated to protect the motor against sustained overloading.

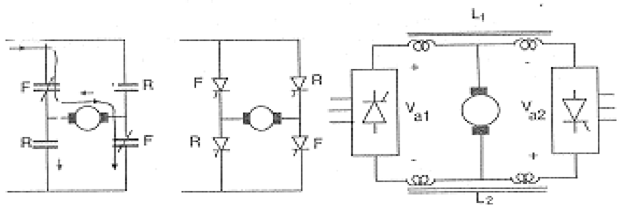


(a) dc drive with electronically-controlled armature and field voltages



(b) single-phase, 2-pulse bridge (c) three-phase, 6-pulse bridge

Figure 8.25 Electronic control of armature and field voltage.



(a) reversing contactors (b) reversing switches (c) Dual converters

Figure 8.26 Connections for bi-directional current operation of dc machine.

The usual bridge circuit of semiconductor switches will conduct current in one direction. Thus, a dc machine with only a single bridge supply will only be capable of operation in the first and second quadrants of the torque-speed plot shown in Fig. 8.18. For the dc machine to operate in all four quadrants, its armature current must be reversible. This can be accomplished using reversing switches or contactors, or two converters connected back-to-back, such as those shown in Fig. 8.26.

With reversing switches or contactors, the changeover needed to handle a reverse flow of I_a of the dc machine should be performed at a current zero, as chopping the current