Lecture - 21

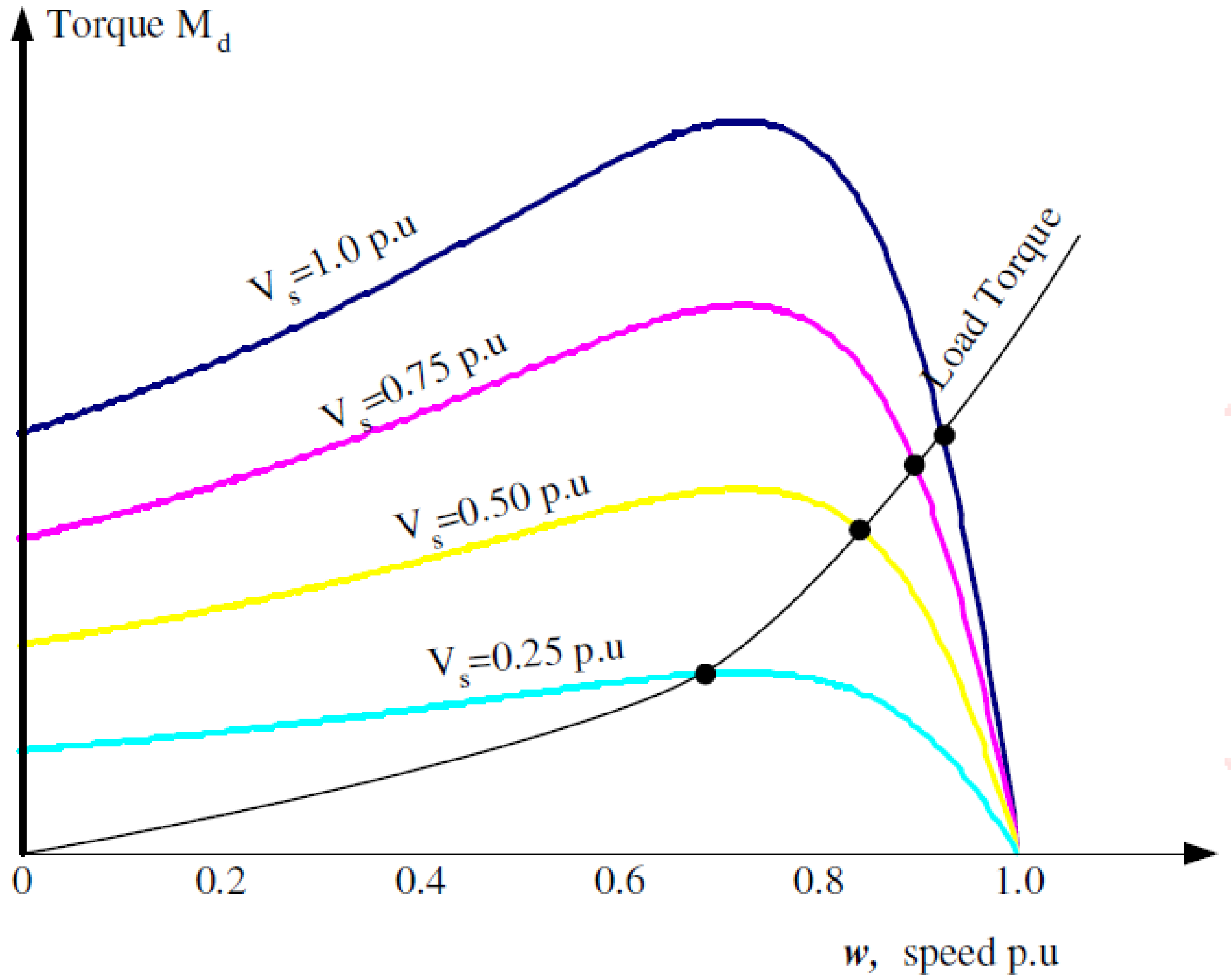
Simple Drive Schemes for Inverter Fed Induction Motors

Stator Voltage Control

- The torque developed in an induction motor is proportional to the
  - square of the flux and
  - proportional to the rotor(or slip) frequency ω_r.
- In order to obtain the full torque capability of the motor at any speed, the flux must be maintained at the rated value.
- If speed control is attempted by varying the stator voltage, keeping the frequency constant, flux and consequently torque capability of machine get drastically reduced.

Stator Voltage Control

- The torque speed characteristics under this method of control are shown in Figure below.

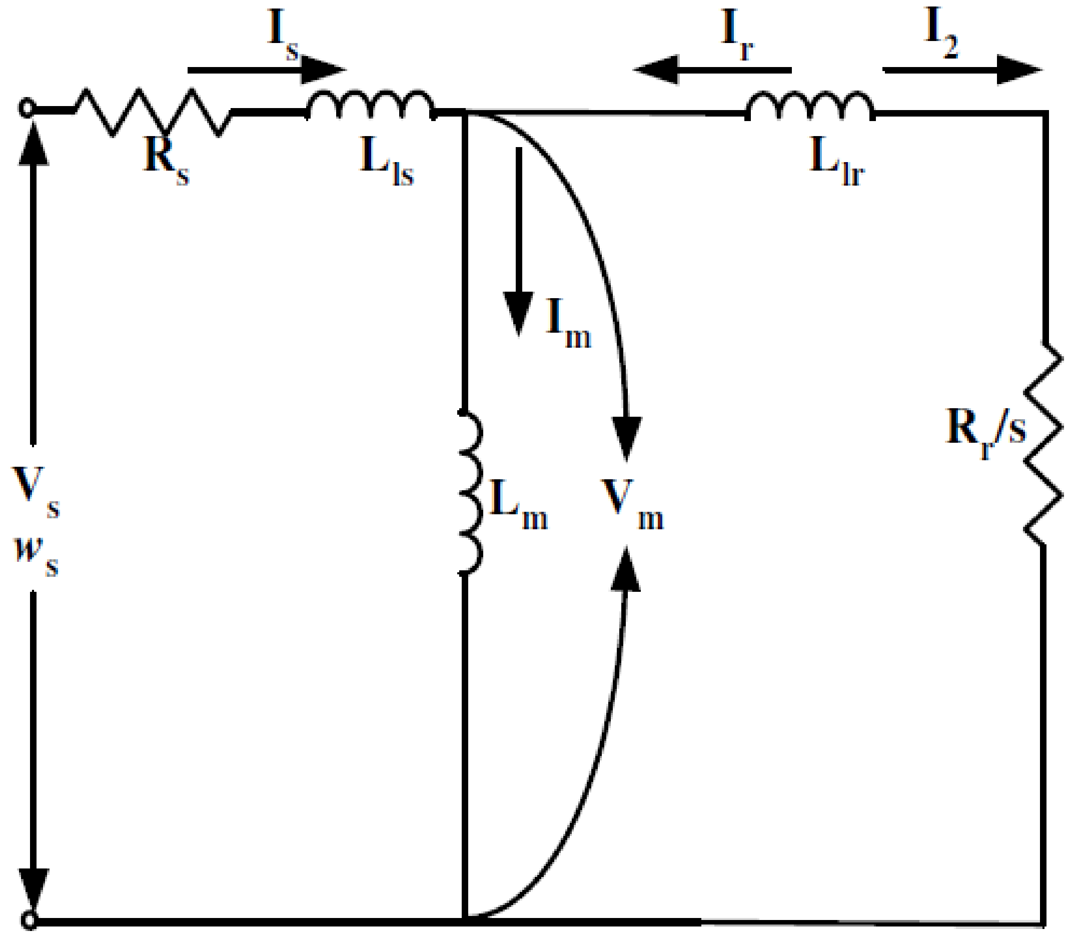


Stator Voltage Control

- Since the stator frequency is constant, the synchronous speed remains the same in all cases.
- As the voltage is reduced, the peak torque ability of the motor gets reduced.
- Although speed is controlled, the motor operates at high values of slip and high currents.
- This type of control is thus not very efficient and is only used sometimes with the fan type load, whose torque demand comes down with speed.
- In order to preserve the torque capability of the motor at all speeds over the control range, the preferred method is variable frequency control.

Variable Frequency Control

- Consider the equivalent circuit of the induction motor, reproduced in Figure below



Variable Frequency Control

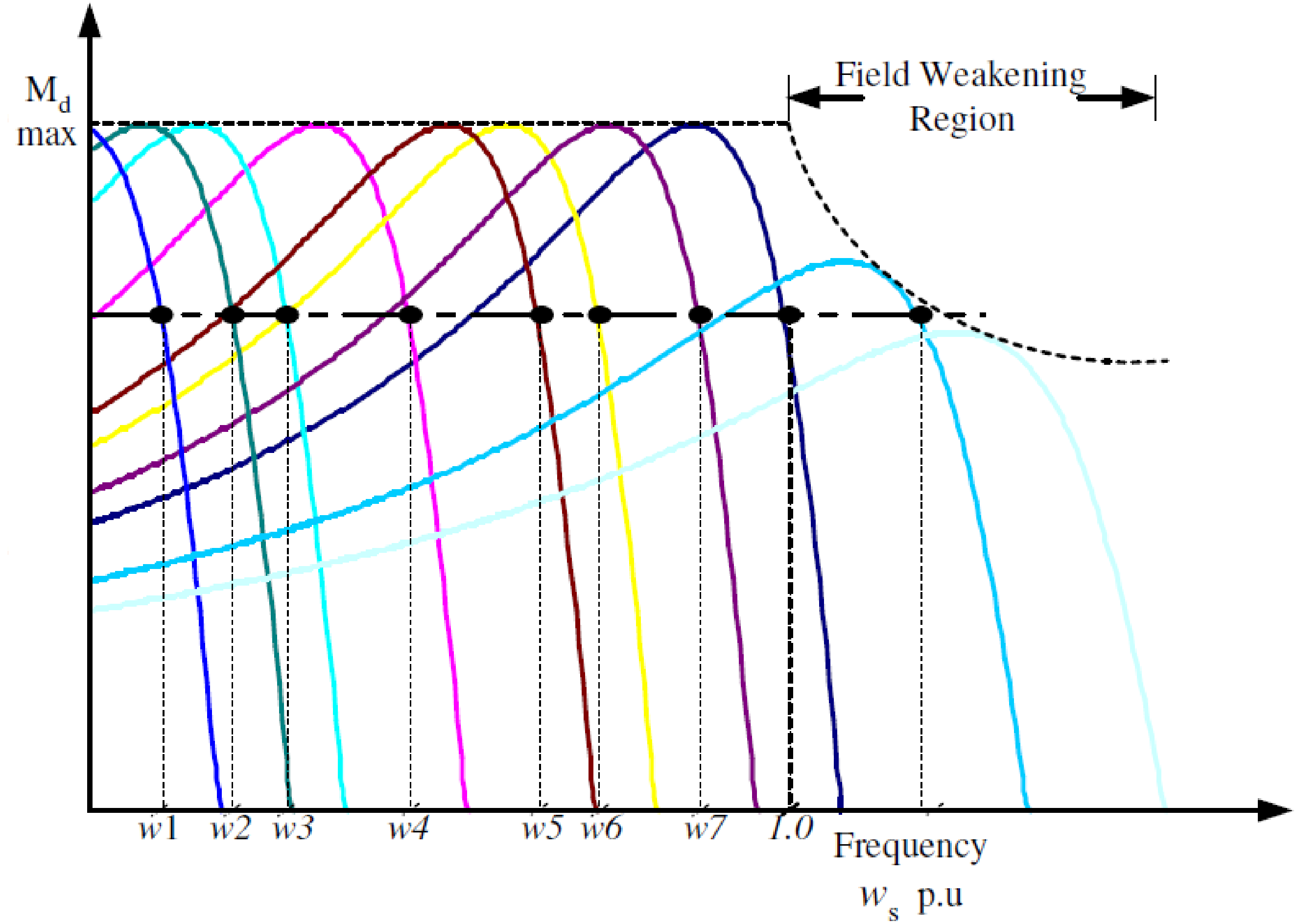
- The rotor current I_r is given by
- $$I_r = \frac{V_m}{\frac{R_r}{s} + j\omega_s L_{lr}}$$
- The air-gap power
- $$P_{ag} = 3|I_r|^2 \frac{R_r}{s}$$
- $$= 3 \frac{V_m^2}{\left(\frac{R_r}{s}\right)^2 + (\omega_s L_{lr})^2} \frac{R_r}{s}$$
- $$= 3 \frac{V_m^2 s}{R_r^2 + (\omega_r L_{lr})^2} R_r$$

Variable Frequency Control

- The output torque
- $$M_d = \frac{P_{ag}}{\text{synchronous speed in Mech rad/sec}}$$
- $$= 3\,\frac{P}{2}\,\frac{1}{\omega_s}\,\frac{V_m^2 s}{R_r^2 + (\omega_r L_{lr})^2}\,R_r$$
- $$= 3\,\frac{P}{2}\left(\frac{V_m}{\omega_s}\right)^2 \frac{\omega_r}{R_r^2 + (\omega_r L_{lr})^2}\,R_r$$
- The above equation implies that the developed torque of the machine will depend only on ω_r, irrespective of the stator frequency ω_s, provided the ratio V_m/ω_s is kept constant.
- This ratio is nothing but the amplitude of the air-gap flux.

Variable Frequency Control

- Thus by keeping the air-gap flux constant, and varying the stator frequency ω_s, a family of torque speed curves can be obtained for the motor as shown in Figure



Variable Frequency Control

- This method of speed control is referred to as constant flux control.
- Note that constant flux control is only possible up to rated voltage and frequency.
- For further increase in the frequency beyond rated frequency, if the voltage be increased proportionally this would exceed the rating of the machine.
- Therefore, beyond the rated frequency, the peak torque ability of the motor decreases as the ratio V_m/ω_s is less than the rated value.
- This region of operation is referred to as the field weakening region.

Variable Frequency Control

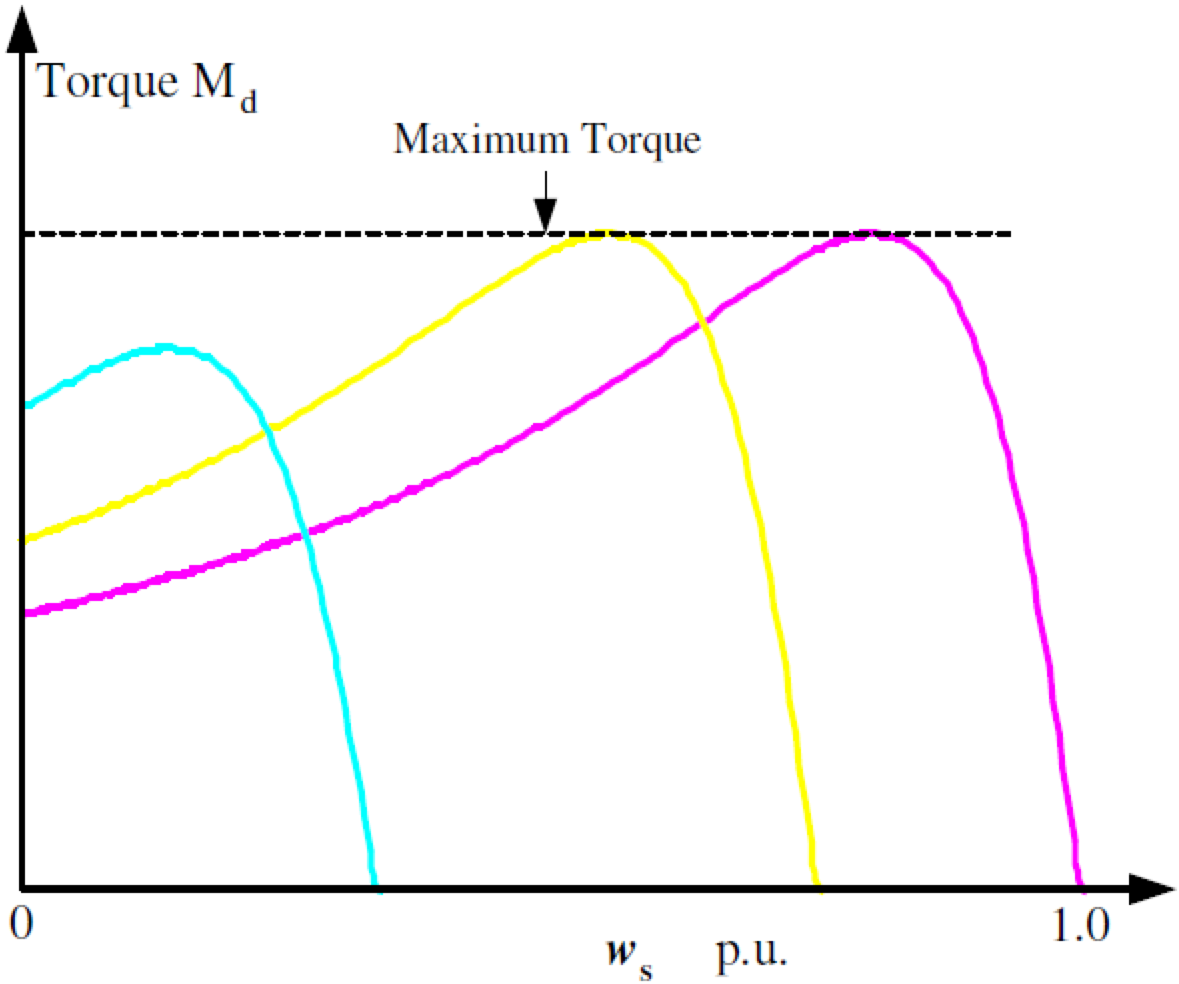
- The above method is difficult to implement as the air-gap voltage V_m cannot be measured directly.
- It can be calculated by measuring the motor terminal voltages and currents, but this results in considerable complexity of the control circuits.
- Alternately the air-gap flux can be measured directly by incorporating flux sensing coils or hall sensors in the motor and integrating their output voltages.
- This requires modification of the motor.
- However, it is difficult to carry out integration at low frequencies.
- Therefore, in practice, the above technique is implemented in an approximate manner, by keeping the ratio of the terminal voltage V_s to ω_s constant.

Variable Frequency Control

- The terminal voltage and the air-gap voltage are reasonably close in magnitude at speeds above 10% of rated speed.
- At very low speeds (and hence stator frequencies) the drop in the stator resistance and leakage reactance becomes appreciable in magnitude compared to the air-gap voltage.
- Therefore, at low speeds, keeping V_s/ω_s constant is not equivalent to keeping the flux constant.
- The torque capability of the machine therefore comes down.

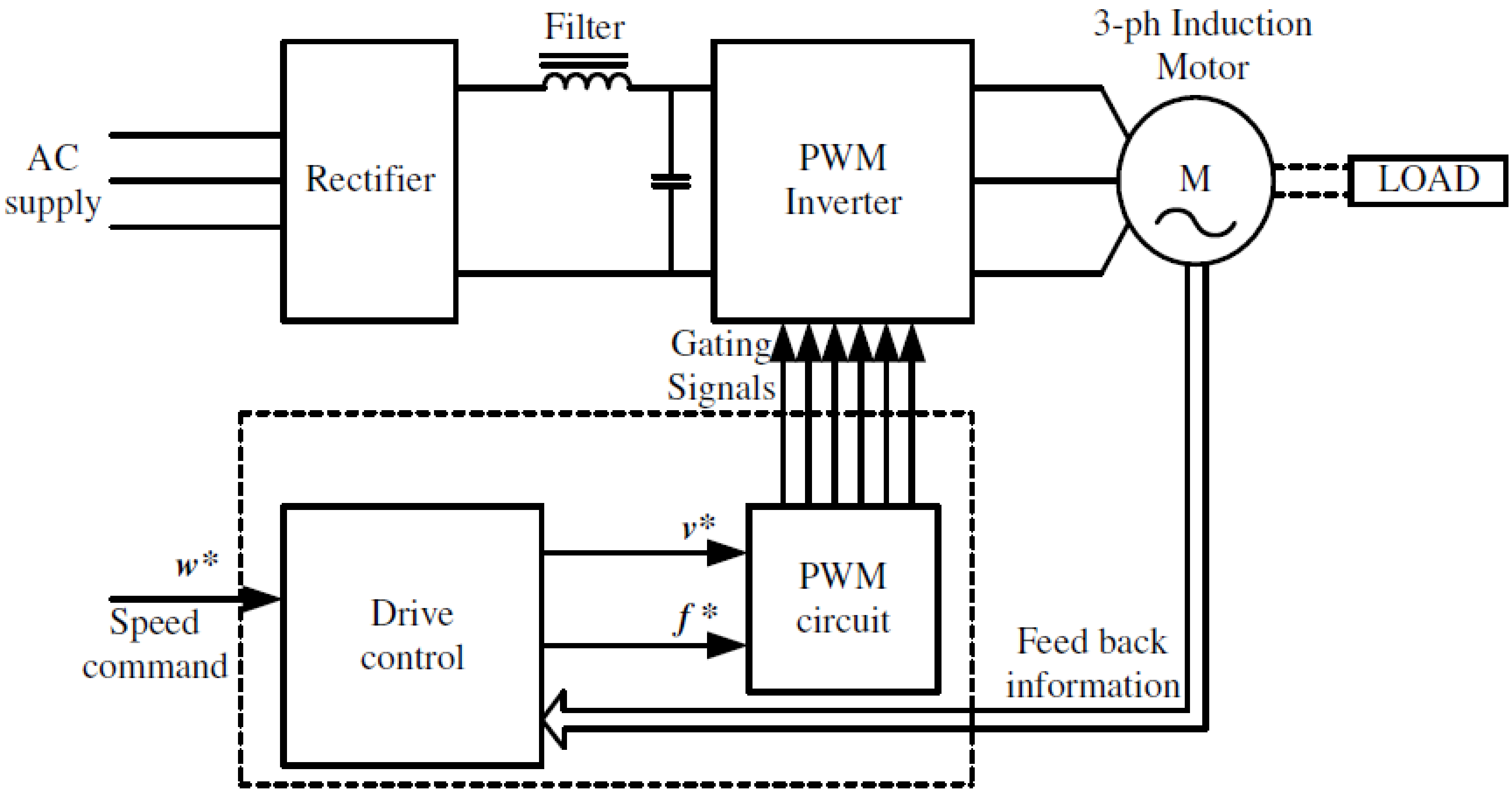
Variable Frequency Control

- The family of torque speed curves for constant V_s/ω_s control (or constant V/f control as it is referred to) is shown in Figure



Block diagram of inverter fed drive

- The block diagram of an adjustable speed drive incorporating a PWM inverter and an induction motor is shown in Figure



Block diagram of inverter fed drive

- Power is normally available as AC. Therefore a front-end rectifier and filter are needed to create the DC voltage for the inverter.
- The simplest type of rectifier is the uncontrolled diode rectifier, as shown in block diagram.
- Any fluctuations in the mains voltage will therefore cause fluctuations in the DC bus voltage also.
- A controlled rectifier can be used to regulate the DC bus voltage.
- Note that in either case, power flow cannot be reversed, i.e., regeneration is not possible.

Block diagram of inverter fed drive

- In the majority of industrial drives, regeneration is not required and so this is not a limitation.
- The drive control system accepts as inputs the speed command and any feedback signals available from the motor.
- It generates the stator frequency command f* and voltage command v*.
- The PWM circuit then generates the gating signals required to impress the commanded voltage and frequency on the motor.

Open loop drives with V/f control

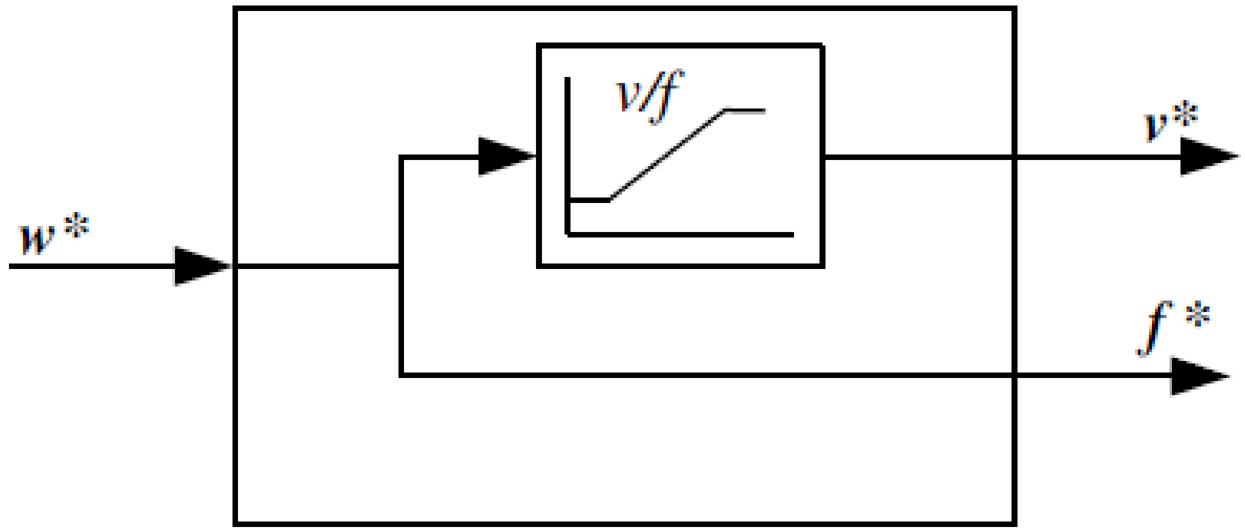
- In a speed control system, evidently the actual speed of the motor should be measured through a tacho generator in order to accurately control the speed.
- In many industrial drives, it is desirable to avoid the installation of a tacho, from the point of view of cost, installation problems, reliability, etc.
- Such drives are referred to as open loop drives.
- No feedback information is available from the motor and the drive control has only the speed command to act upon.
- As has been pointed out earlier, the voltage and the frequency have to be related to each other through the V/f program.

Open loop drives with V/f control

- This program generates the voltage command using the frequency command as the input.
- Therefore, the task of the drive control reduces to that of generating the frequency command using the speed command as input.
- Since the rated or full load slip of an induction motor is usually small, the simplest approach to generating the frequency command is to directly use the speed command as the frequency command.

Open loop drives with V/f control

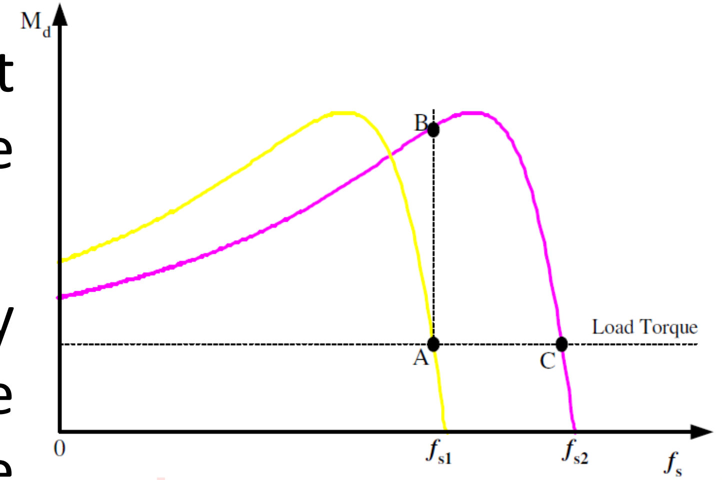
- The resulting drive control block diagram is shown in Figure.



- With such an arrangement the motor will always run at a speed which is less than the commanded speed by the slip speed corresponding to the prevailing load torque.
- If this speed error is accepted, then the system will run satisfactorily in the steady state.

Open loop drives with V/f control

- However, the above simple arrangement may result in the motor pulling out when the speed command is suddenly changed. This may be explained as follows.
- Referring to Figure below
- Let the machine operate initially at frequency f_{s1}, at the point A on the torque speed characteristic.
- If the speed command is suddenly changed resulting in a sudden change of frequency to f_{s2}, the new torque speed curve prevails.



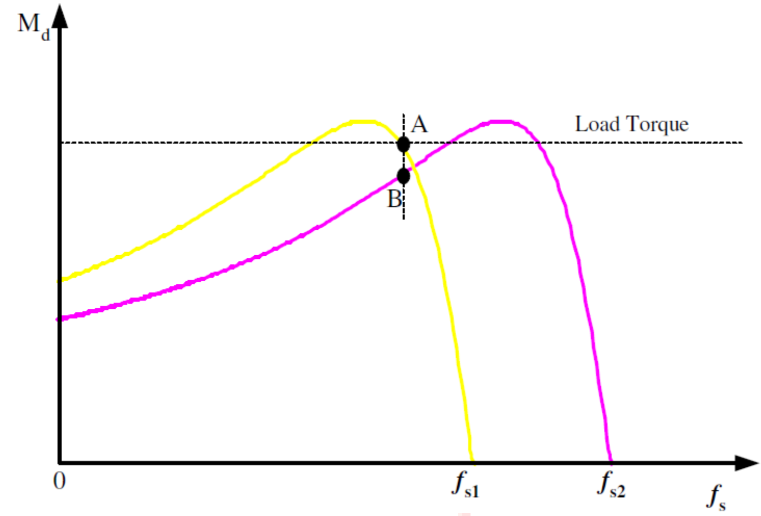
- Because of the inertia of the mechanical system, machine speed cannot change suddenly.
- Therefore, the operating point jumps to B on the new curve.

Open loop drives with V/f control

- The slip at B is large and will result in large stator current.
- The developed torque is, however, larger than the load torque and the motor will accelerate.
- The operating point will move along the characteristic and settle at C.
- The above transient may be acceptable provided the resulting transient over-currents can be handled by the inverter.

Open loop drives with V/f control

- Consider the situation depicted in Figure.
- In this case, when the operating point jumps from B to A the resulting developed torque is less than the load torque.



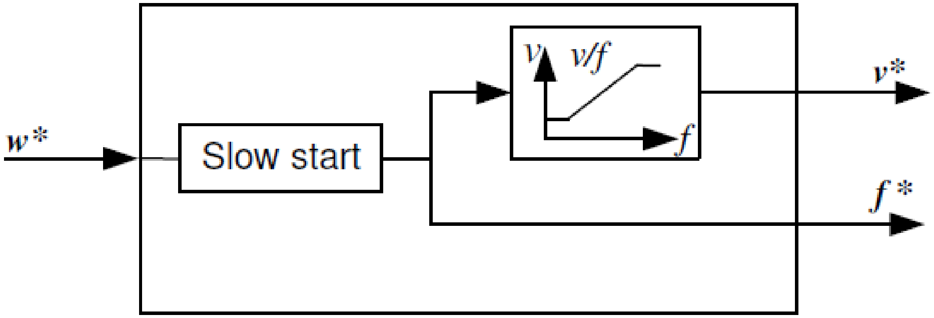
- The motor decelerates, resulting in further reduction of developed torque and further deceleration.
- The motor will eventually pull out and come to a stop.
- In the process, large currents may be drawn from the inverter.
- Similar arguments can be advanced for sudden reduction of frequency also.

Open loop drives with V/f control

- Therefore, the simple drive control scheme of slide 18 has to be modified to prevent the sudden changes in the frequency command f*.
- This can be achieved by making the frequency command f* track the speed command ω* at a finite speed, through what is referred to as a `slow start' circuit.
- In the simplest case, this consists of a RC circuit.
- The rate of change of f* must be limited to such an extent that the motor speed variation is able to track of changes in f*.

Open loop drives with V/f control

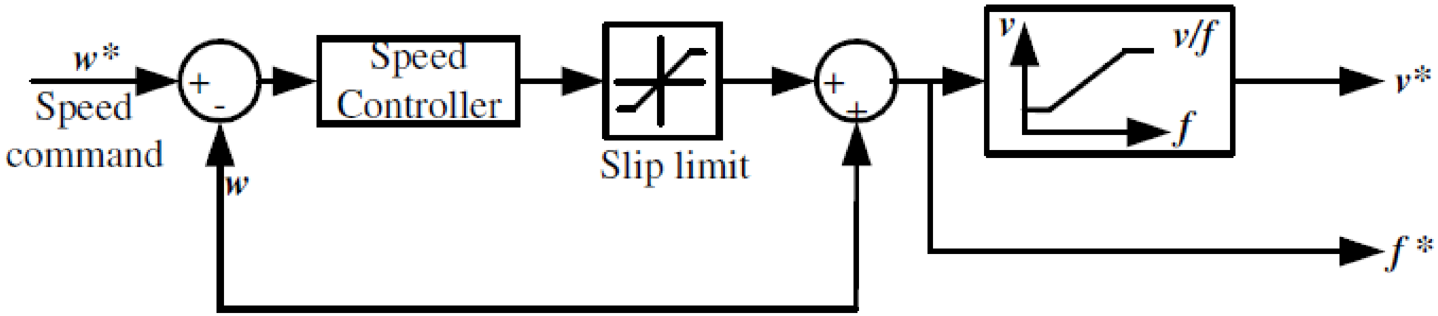
- The resulting block diagram is shown in Figure below.



- Note that in the steady state f* will be equal to ω*.
- However, the speed of the response of the drive to changes in the speed command is now very much limited.
- This is not a drawback in many drives, as speed changes are commanded only once in a while.

Drive with Speed Feedback

- If a tacho-generator can be provided to measure speed, then the motor speed can be directly controlled.
- The block diagram of the drive can then be as shown in Figure below.



- The output of the speed controller is directly used as the slip frequency by adding it to the speed feedback signal to generate the stator frequency command.
- Therefore, by limiting the controller output as shown, the maximum slip frequency can be limited and pullout of the machine can be avoided.

Drive with Speed Feedback

- Simple drive schemes for inverter fed induction motors have been outlined.
- The control schemes are based on steady state relationships in the machine and are not suitable for applications requiring fast dynamic response.
- For such applications, more sophisticated algorithms based on the dynamic model of the induction motor become necessary and will be discussed subsequently.