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Unit: III- Control Strategies

Class-07:
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Presented by
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Subject Name
EE: Modelling and Control of Electric Drives

Discussed in the Previous Class

In the previous class discussed the following topics:

- ❖ Power Electronics Converters
- ❖ Introduction of Electric Vehicles
- ❖ Types of Converters used in Electric Drives
- ❖ Battery Management Systems for Electric Vehicles

Lecture Outcomes

- Open-loop and closed-loop control techniques for electric drives
- Speed control, torque control, and position control methodologies
- Control of DC drives fed through single-phase and three-phase semi-converter
- Lecture remarks: Key points of today's class

Introduction of Control Systems

- Motor control is a crucial aspect of various industries, enabling precise control over the movement and operation of electric motors.
- Two primary methods used for motor control are **open-loop** and **closed-loop control**.
- In this lecture, we will explore the differences between these control techniques, their advantages and disadvantages, applications, and factors to consider when choosing between them.

V, I → Electrical

N, T → mechanical

Open Loop Control Systems

- Open loop motor control is a method where the motor operates without any feedback to adjust its performance.
- The control system sends a command or setpoint to the motor, but there is no mechanism to monitor the actual output or make corrections based on feedback.

speed $\propto$ voltage

Advantages of Open Loop Control Systems

Open loop motor control offers several advantages, including:

Simplicity: Open loop systems are relatively simple to implement as they do not require feedback sensors or additional circuitry.

- **Cost-effective**: Since open loop systems are less complex, they are often more cost-effective than closed loop systems.

- **High-speed operation**: Open loop control can be ideal for applications where precise speed control is not critical, and high-speed operation is desired.

Disadvantages of Open Loop Control Systems

However, open loop motor control also has some drawbacks:

Lack of accuracy: Without feedback, open loop systems may not achieve the desired accuracy, especially in dynamic or unpredictable environments.

- **Susceptible to external factors**: Open loop control is more vulnerable to disturbances and variations in load conditions, leading to potential performance issues.
- **Limited adaptability**: Open loop systems cannot automatically adjust to changing conditions or compensate for wear and tear, requiring manual tuning.

Examples of Open Loop Control Systems

- **Industrial Conveyor Systems:** Open loop motor control is commonly used in conveyor systems where precise positioning is not critical. For instance, in manufacturing plants, open loop control is employed to drive conveyor belts for transporting goods between production stages.

- **HVAC Systems:** Heating, ventilation, and air conditioning (HVAC) systems often utilize open loop motor control for fan operation. In such applications, the speed of the fans can be controlled without the need for feedback, allowing for efficient air circulation in buildings.

- **High-Speed Spindle Drives:** Open loop control is widely used in high-speed spindle drives for machining operations. These drives rotate at extremely high speeds and require less emphasis on position accuracy, making open loop control a suitable choice.

Closed Loop Control Systems

- Closed loop motor control, also known as feedback control, incorporates a feedback mechanism to continuously monitor and adjust the motor's output.
- It uses sensors or encoders to measure the actual performance of the motor and compares it to the desired output.
- Based on this feedback, the motor controller adjusts the input signals to achieve the desired control.

Advantages of Closed Loop Control Systems

Closed loop motor control offers several advantages, including:

- **Improved accuracy**: Closed loop systems continuously monitor and adjust the motor’s performance, resulting in higher accuracy and precision.

- **Robustness**: Closed loop control is more resilient to external factors, ensuring consistent performance in varying load conditions.

- **Adaptability**: Closed loop systems can automatically compensate for changes in operating conditions, ensuring stable and reliable motor control.

Disadvantages of Closed Loop Control Systems

However, closed loop motor control also has some drawbacks:

1. **Complexity**: Closed loop systems require additional components such as sensors, feedback circuits, and control algorithms, making them more complex to implement.

2. **Higher cost**: Due to the additional components and complexity, closed loop systems are generally more expensive than open loop systems.

3. **Response time**: Closed loop systems may have a slight delay in response due to the feedback loop, which can be a critical factor in time-sensitive applications.

Examples of Closed Loop Control Systems

- **Robotics and Automation:** Closed loop motor control is extensively employed in robotic systems to achieve precise and accurate movements. Whether it's an industrial robot arm or a collaborative robot (cobot), closed loop control enables precise control of motor positions for various tasks, such as assembly, pick-and-place, or welding.

- **Electric Vehicles (EVs):** Closed loop motor control is essential in electric vehicle propulsion systems. The control algorithms continuously monitor and adjust motor performance based on various parameters such as speed, torque, and battery condition, ensuring optimal efficiency and smooth acceleration.

- **Medical Equipment:** Closed loop motor control finds applications in medical devices such as surgical robots, prosthetic limbs, or medical imaging systems. These applications require precise motor control for delicate procedures, accurate limb movement, or precise positioning of imaging equipment.

Speed Control and Drive Classification

- Speed Control and Drive Classification are the Drivers where the driving motor runs at a nearly fixed speed are known as **Constant Speed** or **Single Speed Drives**. (1)

- Multi-speed drives are those which operate at discrete speed settings. Drives needing stepless change in speed and multispeed drives are called **Variable Speed Drives**. (2)

- When several motors are fed from a common converter, or when a load is driven by more than one motor, the drive is termed as multi-motor drive.

(1) constant speed drive

(2) variable speed drive. (Multi-speed drive).

Speed Control and Drive Classification

- A variable speed drive is called constant torque drive if the drive's maximum torque capability does not change with a change in speed setting.

$speed \propto V$

$\tau \propto I$

- The corresponding mode (or region) of operation is called **Constant Torque Mode**.

- It must be noted that the term **'Constant Torque'** refers to maximum torque capability of the drive and not to the actual output torque, which may vary from no load to full load torque.

- The **Constant Power Drive** and **Constant Power Mode** (or region) are defined in the same way.

Speed Control and Drive Classification

- Ideally it is desired that for a given speed setting, the motor speed should remain constant as load torque is changed from no load to full load.

- In practice, speed drops with an increase in the load torque.

- Quality of a speed control system is measured in terms of speed regulation which is defined as

$$Speed\ Regulation = \frac{No\ load\ speed - Full\ load\ speed}{Full\ load\ speed}\ x\ 100\% \qquad (1)$$

- If open-loop control fails to provide the desired speed regulation, drive is operated as a closed-loop speed control system.

Current Limit Control of Drives

- Current Limit Control of Drives scheme of Fig. 1 is employed to limit the converter and motor current below a safe limit during transient operations.
- It has a current feedback loop with a threshold logic circuit.
- As long as the current is within a set maximum value, the feedback loop does not affect the operation of the drive.

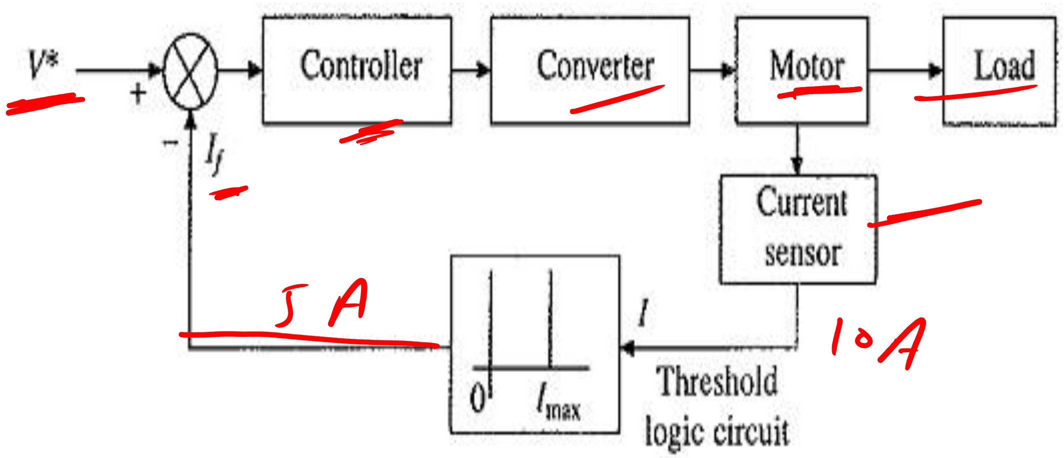
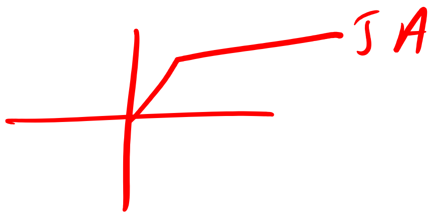


Fig. 1. Current limit control.



Current Limit Control of Drives

- During a transient operation in Current Limit Control of Drives, if the current exceeds the set maximum value, the feedback loop becomes active and current is forced below the set maximum value, which causes the feedback loop to become inactive again.

- If the current exceeds the set maximum value again, it is again brought below it by the action of the feedback loop.

- Thus the current fluctuates around a set maximum limit during the transient operation until the drive condition is such that the current does not have a tendency to cross the set maximum value, e.g. during starting, current will fluctuate around the set maximum value.

- When close to the steady-state operation point, current will not have tendency to cross the maximum value, consequently, feedback loop will have no effect on the drive operation.

Speed Sensing

- Sensing of speed is required for the implementation of closed-loop speed control schemes.
- Speed is usually sensed using tachometers coupled to the motor shaft. A tachometer is an ac or dc generator with a high order of linearity between its speed and output voltage.
- A dc tachometer is built with a permanent magnetic field and sometimes with silver brushes to reduce contact drop between the brush and commutator.
- Typical voltage outputs are 10 V per 1000 rpm.

Types of sensors

Closed Loop Torque Control of Drives

- Closed Loop Torque Control of Drives scheme of Fig. 2 finds application in battery-operated vehicles, rail cars and electric trains.
- Driver presses the accelerator to set torque reference T*. Through Closed Loop Torque Control of Drives, the actual motor torque T follows torque reference T*.
- Speed feedback loop is present through the driver. By putting appropriate pressure on the accelerator, driver adjusts the speed depending on traffic, road condition, his liking, car condition and speed limit.

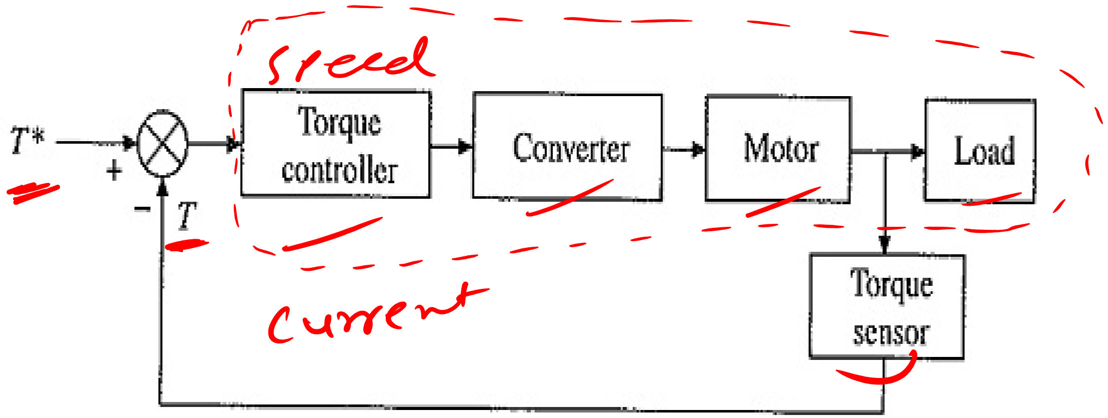


Fig. 2. Closed loop torque control of drives.

Closed Loop Speed Control of Drives

- Figure 3 shows a closed loop speed control scheme which is widely used in electrical drives.

- It employs an inner current control loop within an outer speed-loop. Inner current control loop is provided to limit the converter and motor current or motor torque below a safe limit.

- In some schemes the current is controlled directly. In others it may be controlled indirectly. For example, in a variable frequency induction motor drives the current is controlled by controlling the slip.

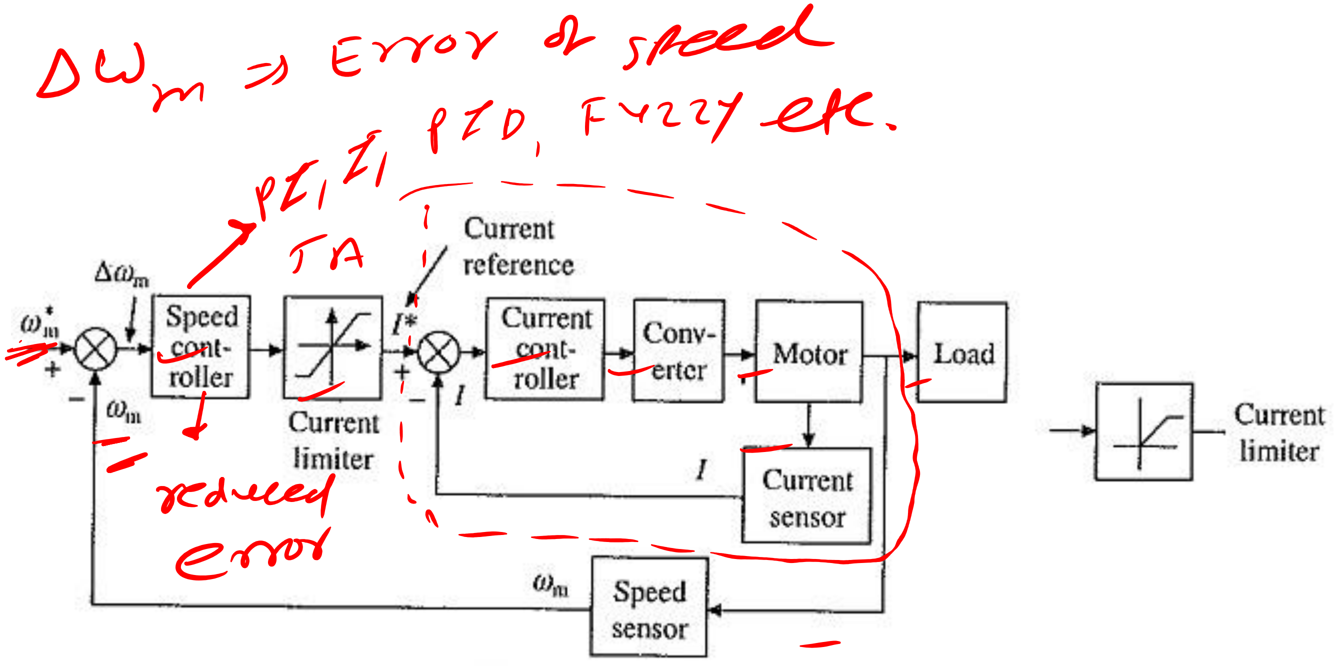


Fig. 3. Closed loop speed control of drives.

speed ⇒ outer loop
current ⇒ inner loop

Closed Loop Speed Control of Drives

Current and speed controllers shown in Figs. 2 and 3 may consists of proportional and integral (PI), proportional and derivative (PD) or proportional, integral and derivative (PID) controller, depending on steady-state accuracy and transient response requirements.

PID,
Fuzzy
AI,
NN
Controllers

Closed Loop Speed Control of Multi-Motor Drives

- When mechanical part of the load is of large physical dimension it becomes desirable to share the load between several motors.

- For example, a rotary printing press usually has several printing stations which are mechanically coupled by a long drive shaft.

- Each section (printing station) is driven by its own motor, which carries most of its load. As load requirements may be different, the motor ratings may also be different for each section, although all of them must run at the same speed.

Closed Loop Speed Control of Multi-Motor Drives

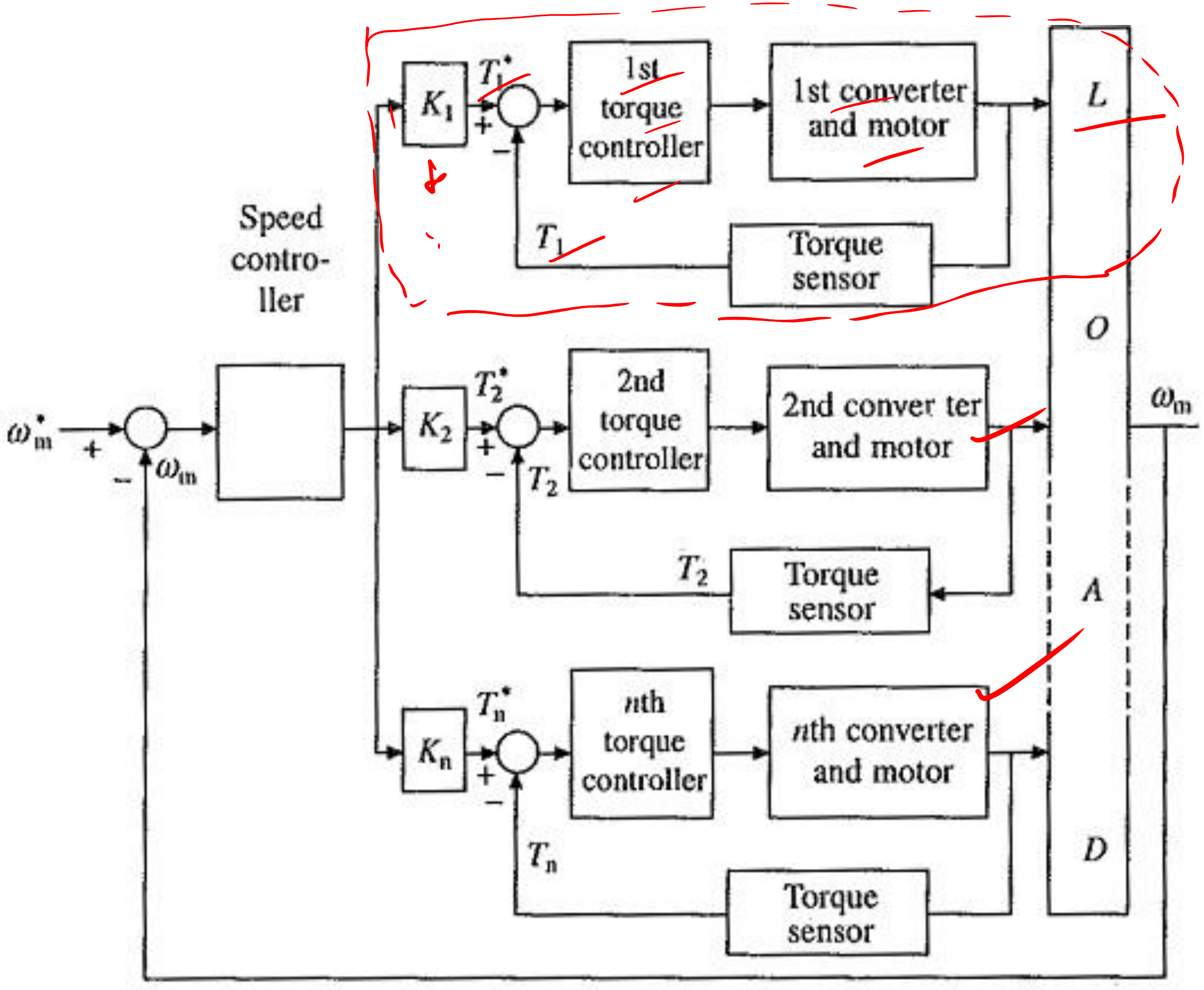


Fig. 4. Multi-motor drive with mechanically coupled loads

1
2
n- number

Issues with synchronization

Closed Loop Speed Control of Multi-Motor Drives

- Such multi-motor drives are also employed in electric and diesel electric locomotives, rapid transit vehicles and some paper machines.

- In a locomotive because of different amount of wear and tear, all wheels do not have the same diameter.

- Therefore, for a given speed of train they would revolve at different speeds. Consequently, the driving motor speeds will also be different.

- In spite of different speeds torques must be shared equally between different motors; otherwise when one motor is fully loaded others will be underloaded, and thus, the rated locomotive torque will be less than the sum of individual motor torque ratings.

Phase Locked Loop Control (PLL)

- A PI controller ideally should provide perfect speed regulation.
- However, due to imperfections in sensing and control circuits, the closed-loop schemes described earlier can at best achieve a speed regulation of 0.2%.
- The Phase Locked Loop Control (PLL) can achieve a speed regulation as low as 0.002% which can be useful in conveyers for material handling, paper and textile mills, and computer peripherals.

Phase Locked Loop Control (PLL)

- The Phase Locked Loop Control are available as inexpensive integrated circuits. Their circuit is shown in Fig. 4.

- Two pulse trains reference pulse train of frequency f* and the feedback pulse train of frequency f are compared in a phase detector.

- Output of the phase detector produces a pulse-width modulated output V_c. Pulse-width of V_c depends on the phase difference between the two input pulse trains and polarity depends on the sign of phase difference (i.e. lag or load) between them.

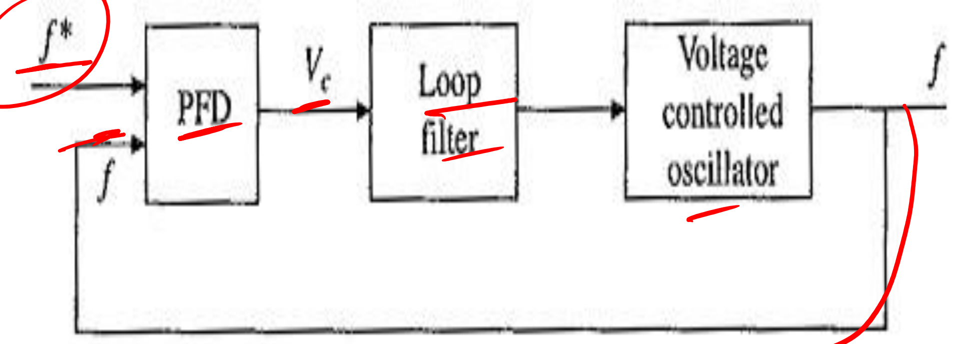


Fig. 4. Phase-locked-loop.

Phase Locked Loop Control (PLL)

- The output of the phase detector is filtered by the loop filter to obtain a DC signal and applied as a control voltage to a voltage-controlled oscillator (VCO); the output of which is the feedback signal f.

- Because of the closed-loop, VCO output frequency changes in a direction that reduces the phase difference.

- When steady state is reached, f becomes exactly equal to f* and the loop is said to have locked.

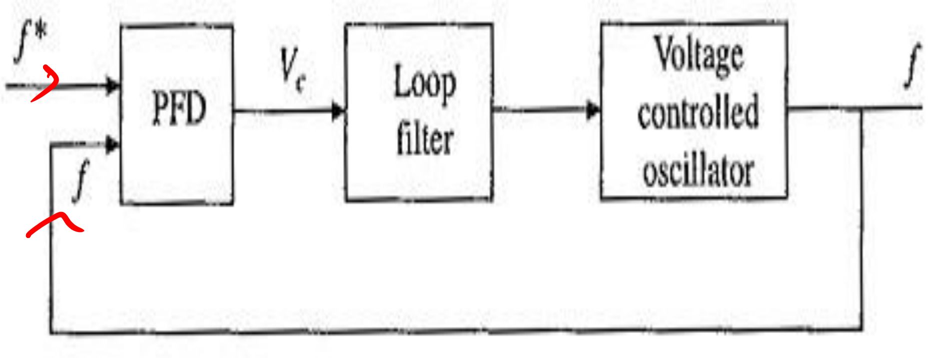


Fig. 4. Phase-locked-loop.

Closed Loop Speed Control using PLL

- An electrical drive employing Phase Locked Loop Control is shown in Fig. 5. The VCO is replaced by converter, motor and speed encoder.

- Output of the loop filter forms the control signal for the converter.

- It alters the converter operation such that the motor speed adjusts to make the frequency of speed encoder output signal f equal to the frequency of reference signal f*. By changing f* the motor speed can be changed.

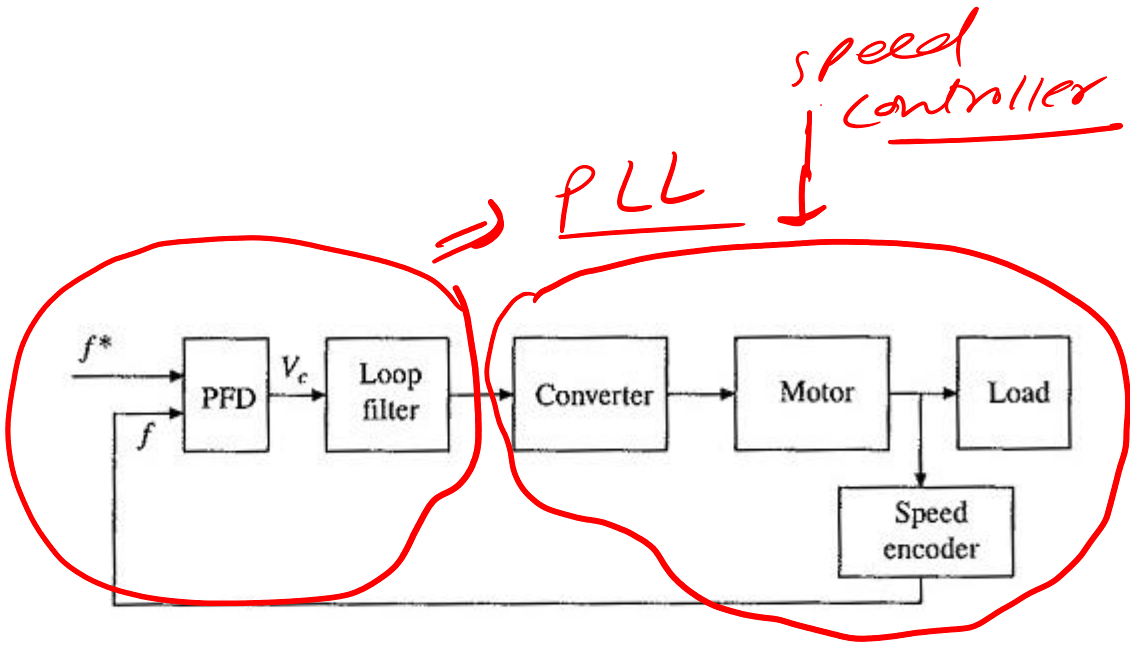


Fig. 5. Closed loop speed control using PLL.

Closed Loop Speed Control using PLL

- Excellent speed regulation is the main feature of this drive.
- However, it has two important disadvantages: transient response is slow and it has a low speed limit below which it becomes unstable.

Closed Loop Speed Position Control

- A Closed Loop Position Control scheme is shown in Fig. 6.

- It consists of a closed-loop speed control system with an inner current control loop inside an outermost position loop.

- Current and speed-loop restrict the current and speed within safe limits, enhance the speed of response, reduce the effects of nonlinearities in the converter, motor and load (such as nonlinear transfer characteristic of converter, coulomb friction, variation of parameters due to temperature and friction) on the transient and steady state performance of the position control system.

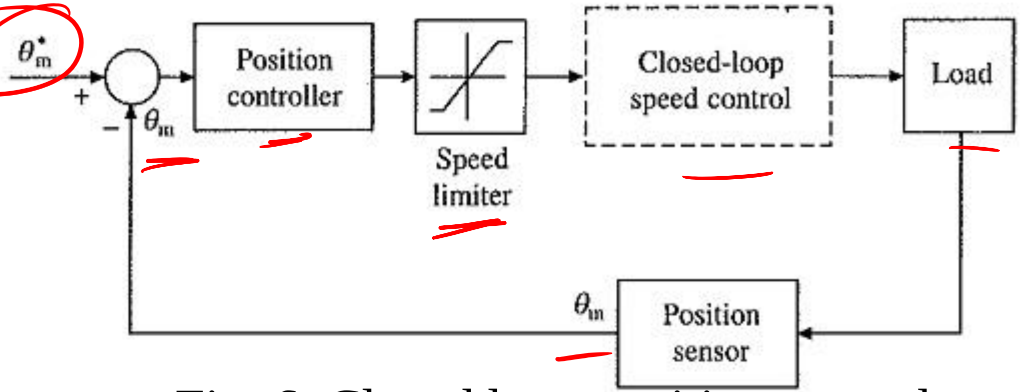


Fig. 6. Closed loop position control.

Key Points from Today's Class

- Open-loop and closed-loop control techniques for electric drives
- Speed control, torque control, and position control methodologies
- Control of DC drives fed through single-phase and three-phase semi-converter

Key Points from Next Class

In the next class, we will be discussing on the

- ❖ Open-loop and closed-loop control techniques for electric drives
- ❖ Speed control, torque control, and position control methodologies
- ❖ Control of DC drives fed through single-phase and three-phase semi-converter

Thank you so much for your attentions

Q & A