Tribhuvan University
Institute of Engineering
Pulchowk Campus
Accredited by University Grants Commission (UGC) Nepal 2020

Unit: III- Control Strategies

Class-14:
1st March 2024

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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:

- ❖ Three-phase Induction Motor

- ❖ Analysis and Performance of 3-phase Induction Motor

Lecture Outcomes

- ❖ Variable Frequency Control of Induction Motor Drive →

- ❖ Lecture remarks: Key points of today's class

Speed ∝ voltage

Torque ∝ current

$$N_s = \frac{120f}{P}$$

Variable Frequency Control of Induction Motor Drive

- A **Variable Frequency Drive** (VFD) is a device that controls the speed and torque of an AC motor by adjusting the frequency and voltage of the power supply.

- A VFD can also regulate the acceleration and deceleration of the motor during start-up and stop, respectively.

- A VFD consists of three main components: a rectifier, an inverter, and a control system.

Variable Frequency Control of Induction Motor Drive

A VFD is used for various purposes, such as:

1. Saving energy and improving system efficiency
2. Improving the working environment by lowering noise and vibration
3. Reducing mechanical stress on the motor and extending its lifetime
4. Saving peak consumption and reducing the motor size required
5. Matching the speed or power of the motor to the process requirements

Variable Frequency Control of Induction Motor Drive

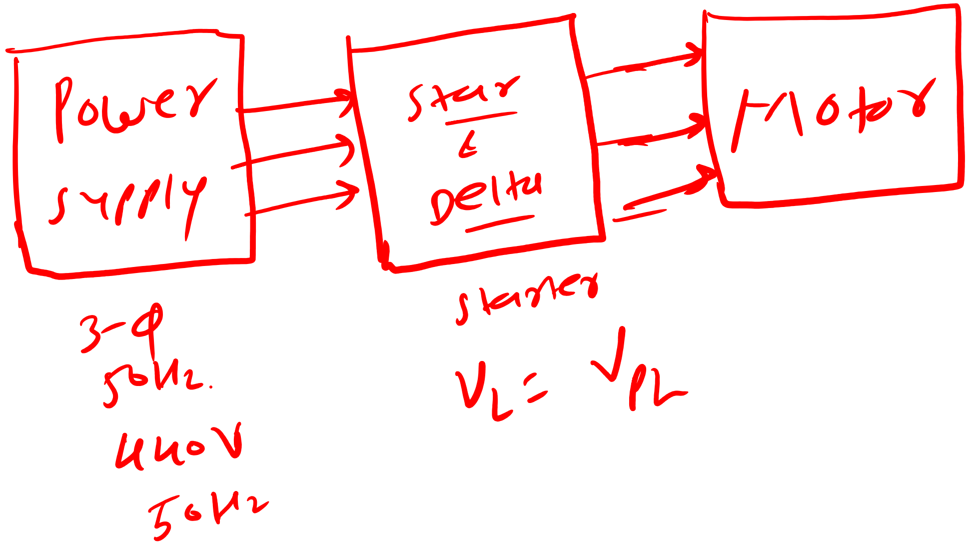
- A VFD is commonly used in applications that involve fans, pumps, compressors, conveyors, crushers, mills, lifts, escalators, etc.

- A VFD can provide significant benefits over other types of motor controllers, such as soft starters or across-the-line contactors.

$$N_s = \frac{120f}{p}$$

Star: $V_L = \sqrt{3} V_{ph}$, $I_L = I_{ph}$

Delta: $V_L = V_p$, $I_L = \sqrt{3} I_{ph}$



Variable Frequency Control of Induction Motor Drive

- A variable frequency drive is defined as a type of AC motor drive that controls the speed and torque of an electric motor by varying the frequency and voltage of its power supply.

$N_s = \frac{120f}{P}$

- The frequency of the power supply determines the rotational speed of the motor, while the voltage determines the torque.

- A VFD can be classified into different types based on its topologies, such as voltage source inverter (VSI), current source inverter (CSI), or load-commutated inverter (LCI).

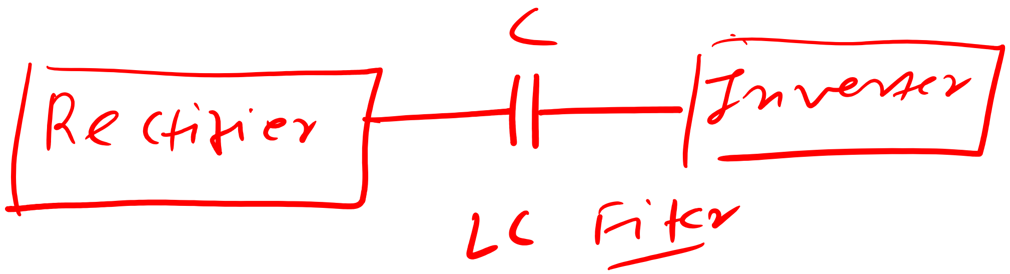
- A VFD can also be categorized by its load characteristics, such as variable torque, constant torque, or constant power.

VSI,
CSI

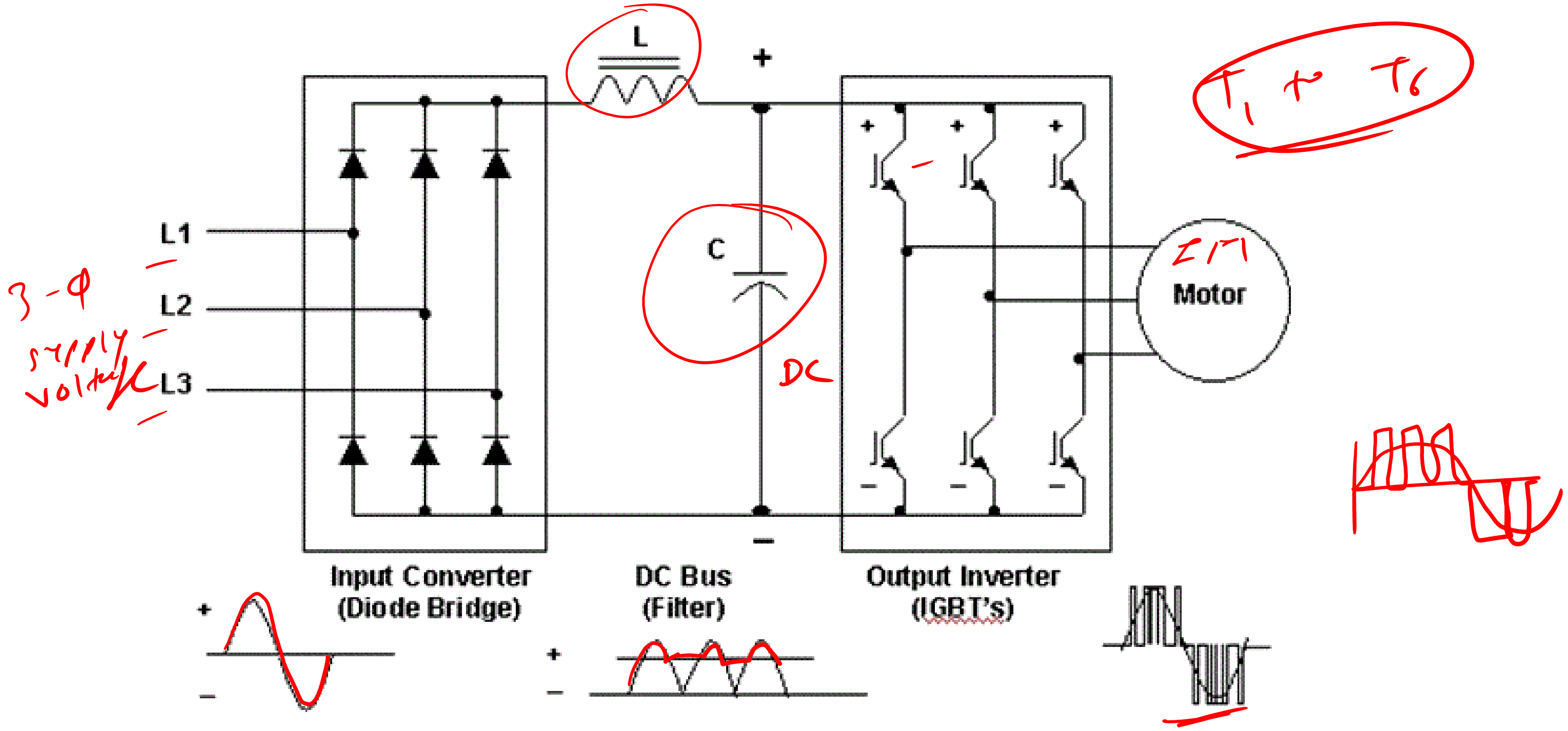
Variable Frequency Control of Induction Motor Drive

- The most common type of VFD is the VSI drive, which converts a fixed-frequency, fixed-voltage AC input to a variable-frequency, variable-voltage AC output using a rectifier, a DC link, and an inverter.

- The rectifier converts the AC input to DC, the DC link smooths out the DC output using a capacitor, and the inverter switches the DC output to produce a quasi-sinusoidal AC output using power electronic devices such as IGBTs or GTOs.



Variable Frequency Control of Induction Motor Drive



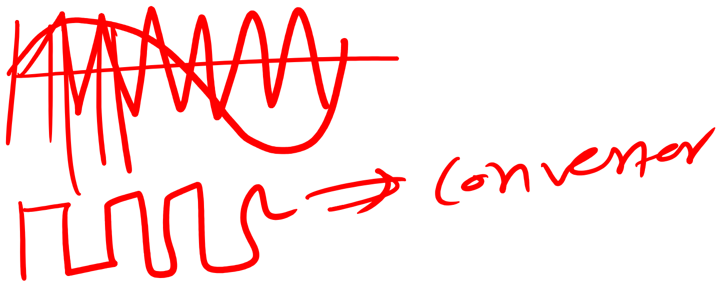
Variable Frequency Control of Induction Motor Drive

- The inverter uses different modulation techniques to control the output voltage and frequency, such as pulse width modulation (PWM), sine wave PWM (SPWM), or space vector PWM (SVPWM).

- The PWM technique produces a series of pulses of constant amplitude and variable width that approximate a sine wave.

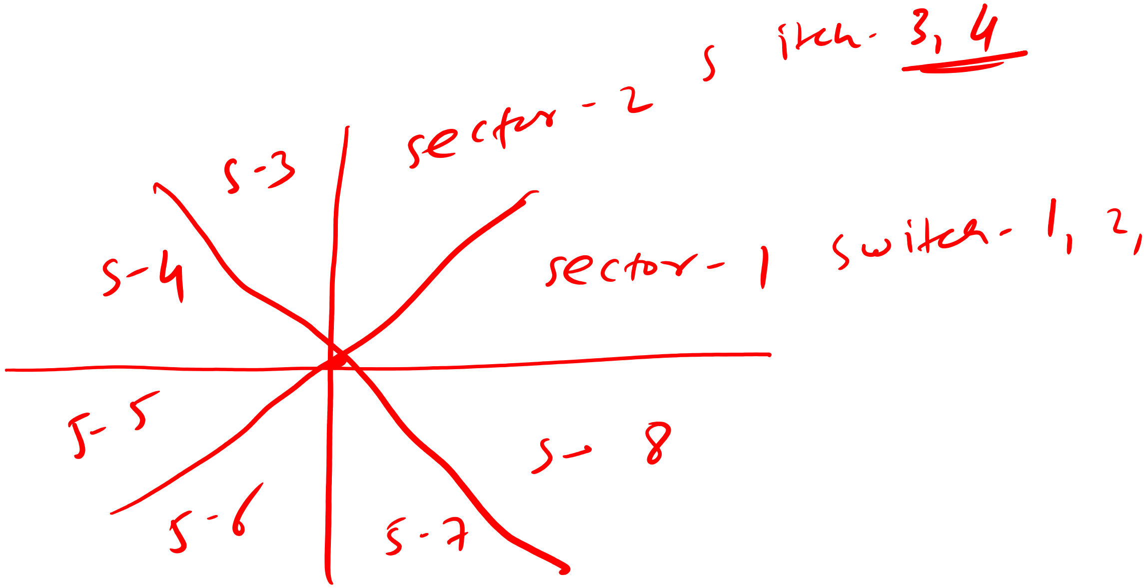
- The SPWM technique compares a reference sine wave with a triangular carrier wave to generate pulses.

- The SVPWM technique uses a vector representation of the output voltage to optimize the switching sequence.



Variable Frequency Control of Induction Motor Drive

- The control system monitors and adjusts the output voltage and frequency according to the feedback signals from the motor and the desired set points.
- The control system maintains a constant ratio of voltage to frequency (V/f) to ensure optimal operation of the motor.



Variable Frequency Control of Induction Motor Drive

How Does a Variable Frequency Drive Work?

- A variable frequency drive works by changing the frequency and voltage of the power supply to an AC motor according to its load and speed requirements.
- The AC input is fed to a rectifier that converts it to DC.
- The DC output is filtered by a capacitor that forms a DC link. The DC link supplies power to an inverter that switches it on and off at high frequency to produce an AC output with variable frequency and voltage.
- The AC output is connected to an AC motor that rotates at a speed proportional to the frequency.

Variable Frequency Control of Induction Motor Drive

The speed of an AC motor is given by:

$$N_s = \frac{120f}{P}$$

where Ns is the synchronous speed in rpm, f is the frequency in Hz, and P is the number of poles.

By changing f, we can change Ns and hence control the speed of the motor.

The torque of an AC motor is given by:

$$T \propto \phi I$$

Variable Frequency Control of Induction Motor Drive

What are the Advantages of Using a Variable Frequency Drive?

Energy Saving

P^3, P^2 $V \propto$ speed $P_{consumption} \propto$ speed of motor

- A VFD can reduce energy consumption by adjusting the speed and flow of the motor according to the load and process requirements.

- This reduces the waste of energy and improves the system's efficiency. For example, in fan and pump applications, which have a variable torque load, reducing the speed by 20% can achieve energy savings of 50%, according to the cube law relationship between speed and power.

- A VFD can also improve the power factor of the system by reducing the reactive power drawn by the motor.

Variable Frequency Control of Induction Motor Drive

Increased Reliability

- A VFD can increase the reliability of the motor and the system by providing smooth and precise control of speed and torque. A VFD can eliminate the mechanical stresses and shocks caused by direct-on-line starting or stopping of the motor, which can damage the windings, bearings, belts, gears, and other components.

- A VFD can also protect the motor from electrical faults such as overvoltage, undervoltage, overcurrent, phase imbalance, short circuit, etc. by monitoring and adjusting the output voltage and current.

- A VFD can also reduce the noise and vibration levels of the motor and the system, which can improve the working environment and extend the equipment's lifetime.

Variable Frequency Control of Induction Motor Drive

Speed Variations

- A VFD can provide a wide range of speed variations for different applications that require variable speed control. A VFD can adjust the speed of the motor from zero to above its rated speed, depending on the load and process requirements.

- A VFD can also provide a “crawl” speed for maintenance purposes, eliminating the need for additional drives or devices.

- A VFD can also enable soft starting and stopping of the motor, which can reduce inrush current, voltage drop, mechanical stress, and wear and tear.

Variable Frequency Control of Induction Motor Drive

Soft Starting

- A VFD can provide a soft starting of the motor by gradually increasing the frequency and voltage of the power supply from zero to the desired value.
- This reduces the starting current of the motor, which is normally six to ten times its rated current when started directly online.
- A high starting current can cause a voltage drop on the supply network, affecting other equipment connected to it. It can also cause winding stress, winding overheating, and insulation damage in the motor.
- A VFD can prevent these problems by limiting the starting current to a safe level.

Variable Frequency Control of Induction Motor Drive

Extended Machine Life and Less Maintenance

- A VFD can extend the machine's life and reduce maintenance costs by using a VFD. A VFD can prevent dust, moisture, and corrosion from affecting the motor and the system by keeping them clean and dry.

- A VFD can also prevent loose connections, faulty cables, and damaged components from causing electrical faults or performance issues by checking and replacing them regularly.

- A VFD can also reduce the wear and tear of the motor and the system by providing smooth and precise control of speed and torque. A VFD can also monitor and diagnose the condition of the motor and the system by using networking and diagnostic capabilities.

Variable Frequency Control of Induction Motor Drive

A VFD can improve the power factor of the system by reducing the reactive power drawn by the motor in two ways:

1. By Adjusting the voltage and frequency of the power supply to match the load and speed requirements of the motor, reduces the magnetization current and hence the reactive power.

2. By including capacitors in the DC link of the VFD, which provide reactive power compensation and maintain a high power factor on the line side of the VFD. This eliminates the need for additional expensive capacitor banks.

starting current → 10A → 5 wb/m²

Key Points from Today's Class

- ❖ Variable Frequency Control of Induction Motor Drive

Key Points from Next Class

In the next class, we will be discussing on the

- ❖ Space Vector PWM
- ❖ Dynamic Modelling of Electric Machines

Thank you so much for your attentions

Q & A