Tribhuvan University
Institute of Engineering
Pulchowk Campus
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Unit: IV- Dynamic Modelling and Simulation

Class-15:
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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:

- VFD of Three-phase Induction Motor
- Analysis and Performance of 3-phase Induction Motor

Lecture Outcomes

- ❖ Space Vector PWM Method
- ❖ Difference Between VSI and CSI
- ❖ Cube Law Between Speed and Power
- ❖ Development of Dynamic Models for Electric Drives
- ❖ Simulation Tools to Check the Performance of Electric Drive
- ❖ Types of Duty Cycles
- ❖ Lecture remarks: Key points of today's class

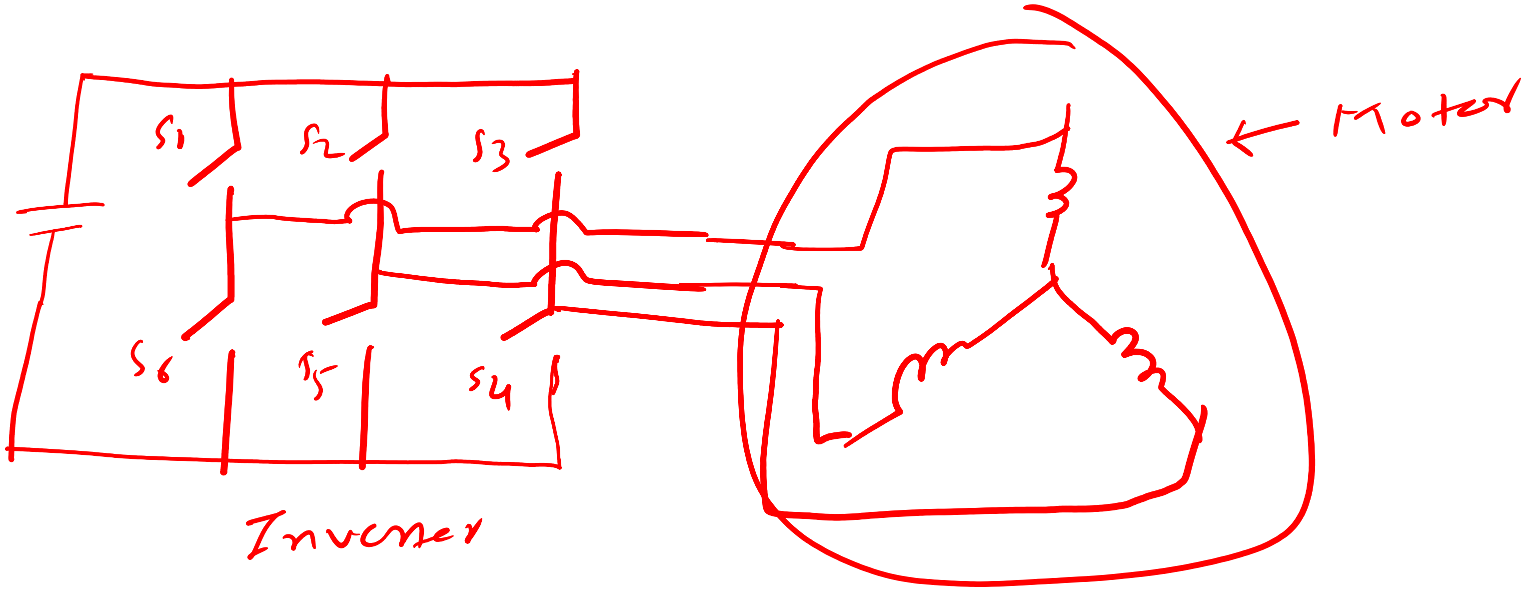
3rd Unit

4th Unit

Introduction: Space Vector PWM

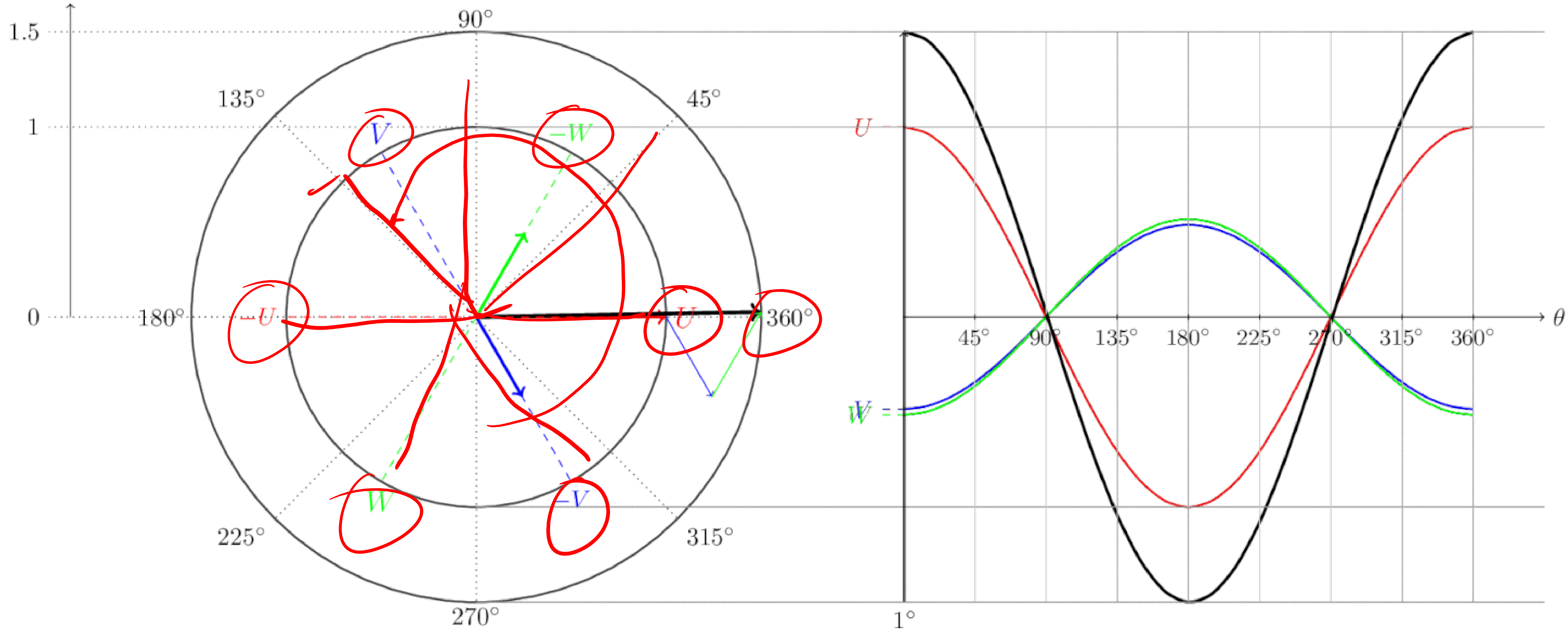
- Space Vector Pulse Width Modulation (SV-PWM) is a *modulation scheme* used to apply a given *voltage vector* to a three-phased electric motors

- The goal is to use a steady state DC-voltage and by means of six switches (e.g. transistors) emulate a three-phased sinusoidal waveform where the frequency and amplitude is adjustable.



Introduction: Space Vector PWM

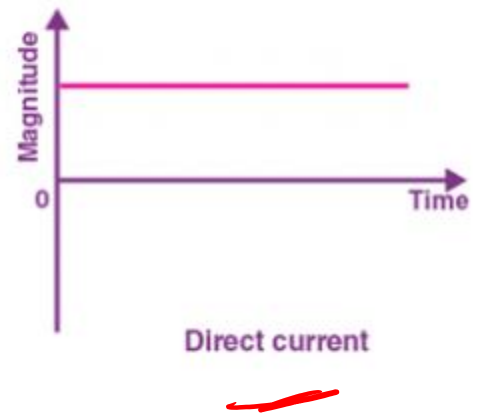
Three-phased sinusoidal system and its rotating equivalent space vector

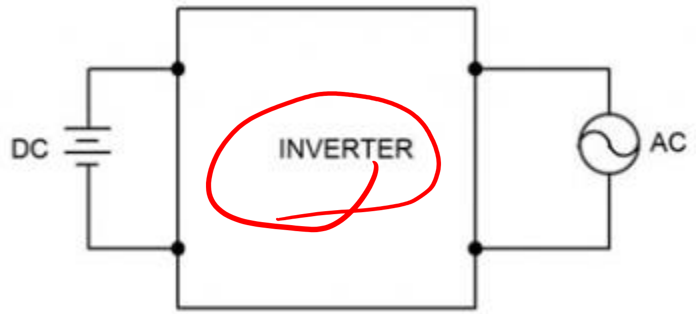


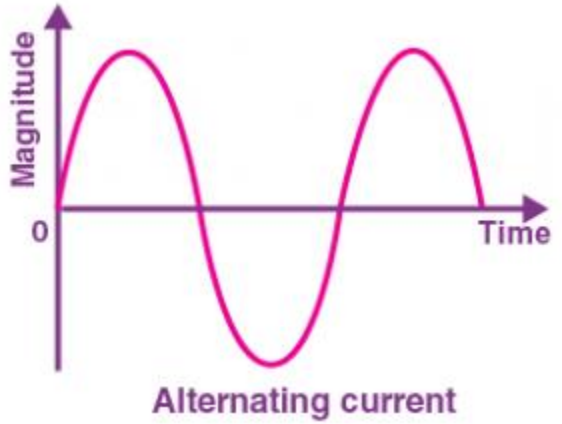
Difference Between VSI and CSI

Difference Between VSI and CSI

An **inverter** is a power electronics device which is used to convert fixed DC (Direct Current) into controlled AC (Alternating Current)". Here, Controlled AC means we controlled two parameters of AC signal Frequency and Amplitude.







Classification of Inverter

Inverters are mainly classified into two types:

1. VSI (Voltage Source Inverter)
2. CSI (Current Source Inverter)

$V = L\frac{di}{dt}$

$i = C\frac{dV}{dt}$

$I_L = \frac{V_{th}}{R_{th} + R_L}$

$Z = \frac{1}{R}$

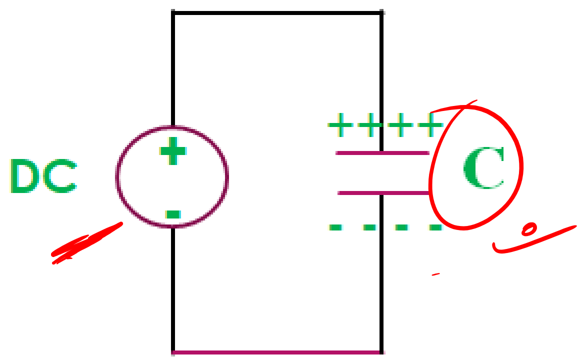


Fig. 1. VSI.

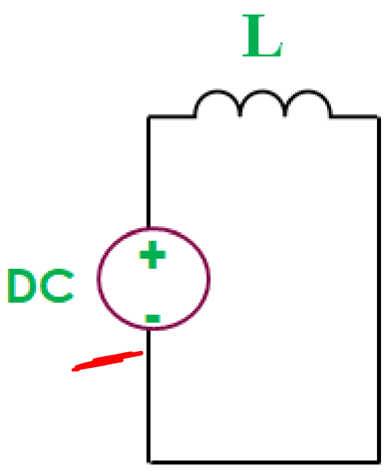


Fig. 2. CSI.

Voltage Source Inverter

- In a voltage source inverter (VSI) input voltage is kept constant. VSI is fed from a DC voltage source having negligible or zero impedance.
- So, to make a VSI we connect a DC source in parallel with a large capacitor that maintains Input voltage constant.
- In the case of VSI an output voltage is independent of load. Here, the waveform of the load current as well as its magnitude depends upon the nature of load impedance.

Voltage Source Inverter

- A voltage source inverter is fed by a stiff DC voltage or constant DC voltage is called Voltage Source Inverter (VSI) or Voltage Fed Inverter (VFI).

- In Voltage Source Inverter (VSI) we use power semiconductor switching devices in the circuit like Power BJT, Power MOSFET, IGBT having self-commutation properties.

- VSI drives are more efficient than CSI designs. This is because in VSI drives we use IGBT switching devices that is more efficient than the GTO or SGCT devices used in CSI versions.

Important Points of Voltage Source Inverter

1. **Input Configuration:** VSIs typically have a DC input source, such as a battery or a rectifier, supplying a constant voltage.
2. **Output Current:** The output current is controlled by varying the inverter's switching pattern or modulation techniques like Pulse Width Modulation (PWM). The inverter regulates the output voltage by adjusting the duty cycle of the switching signals.
3. **Output Voltage Control:** VSIs can provide variable output voltage with a fixed frequency. By adjusting the pulse width, the RMS value of the output voltage can be controlled.
4. **Load Type:** VSIs are generally suitable for supplying voltage-controlled loads like motors, induction heaters, or certain types of AC drives.
5. **High Input Impedance:** The input impedance of a VSI is typically high, which means it draws less current from the input source.
6. **Short Circuit Protection:** VSIs may require additional protection circuitry to prevent damage due to short circuits at the output.

Current Source Inverter

- In current source inverter (CSI) input current is kept constant. CSI is fed with adjustable current source from a DC voltage source of high impedance.
- VSI can be converted into CSI, by connecting large series inductance that maintained input current constant.
- In CSI output current is independent of load.
- Here, the magnitude of output voltage and its waveform depends upon the nature of the load impedance.

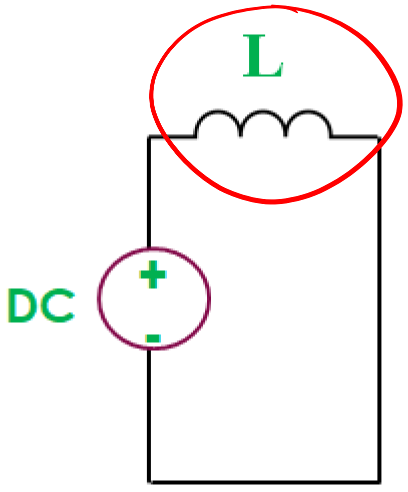


Fig. 2. CSI.

Current Source Inverter

- A Current Source Inverter is fed by a stiff current source or constant current source also called Current Source Inverter (CSI) or Current Fed Inverter (CFI).

- In the Current Source Inverter (CSI) we use Thyristor as a semiconductor switching device.

Important Points of Current Source Inverter

1. **Input Configuration:** CSIs typically have a DC input source, such as a current-regulated rectifier or a current-controlled DC source.
2. **Output Current Control:** The output current is controlled by varying the inverter's switching pattern or modulation techniques. The inverter regulates the output voltage by adjusting the load impedance to maintain a constant current.
3. **Output Voltage:** The output voltage of a CSI is determined by the load impedance and the output current. As the load impedance changes, the output voltage varies accordingly.
4. **Load Type:** CSIs are generally suitable for supplying current-controlled loads, such as electric arc furnaces, some types of motor drives, or applications where a constant current is desired.
5. **Low Input Impedance:** The input impedance of a CSI is typically low, which means it draws more current from the input source.
6. **Self-Short Circuit Protection:** CSIs have inherent short circuit protection since they are currently regulated. In case of a short circuit, the output current is automatically limited.

Difference Between VSI and CSI

Three terminals switches

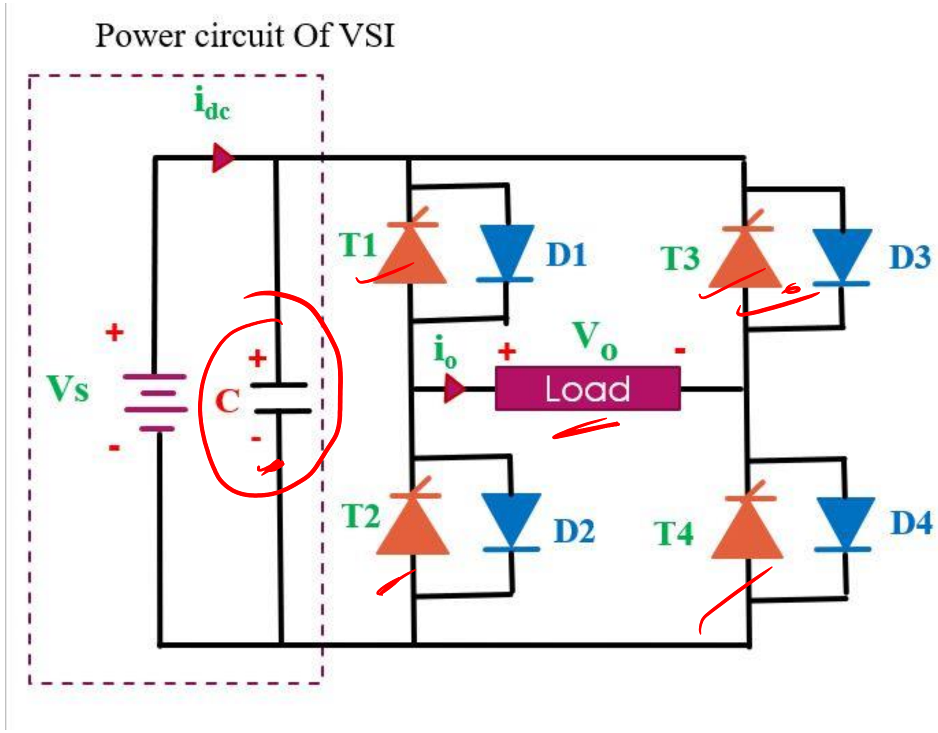


Fig. 3. Configuration of VSI.

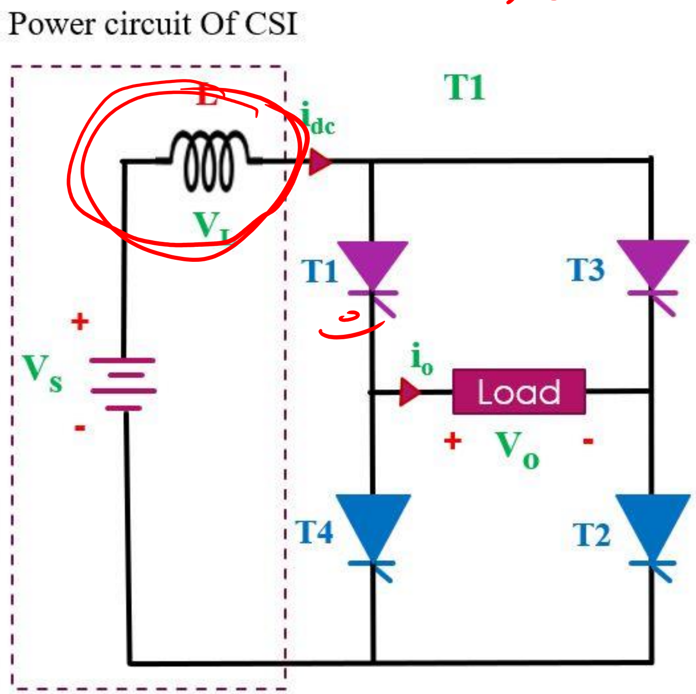


Fig. 4. Configuration of CSI.

Difference Between VSI and CSI

Sr. No.	VSI	CSI
1	In voltage source inverter input voltage is kept constant.	In current source inverter input current is kept constant.
2	VSI is fed from a DC voltage source having small or negligible impedance.	CSI is fed with adjustable current source from a DC voltage source of high impedance.
3	DC source in parallel with large capacitor.	VSI can be converted into CSI, By connecting large series inductance.
4	Input voltage is maintained constant.	The input current is constant but adjustable.
5	An output voltage is independent of load.	An output current is independent of load

Difference Between VSI and CSI

Sr. No.	VSI	CSI
6	The waveform of the load current as well as its magnitude depends upon the nature of load impedance.	The magnitude of output voltage and its waveform depends upon the nature of the load impedance.
7	VSI has slow response than CSI.	CSI has fast response than VSI.
8	VSI requires feedback diodes	The CSI does not require any feedback diodes.
9	The commutation circuit is complicated. It uses current commutation.	Commutation circuit is simple as it contains only capacitors. It uses voltage commutation.
10	Power BJT, Power MOSFET, IGBT with self commutation can be used in the circuit.	Thyristors are Used.

Cube Law Between Speed and Power

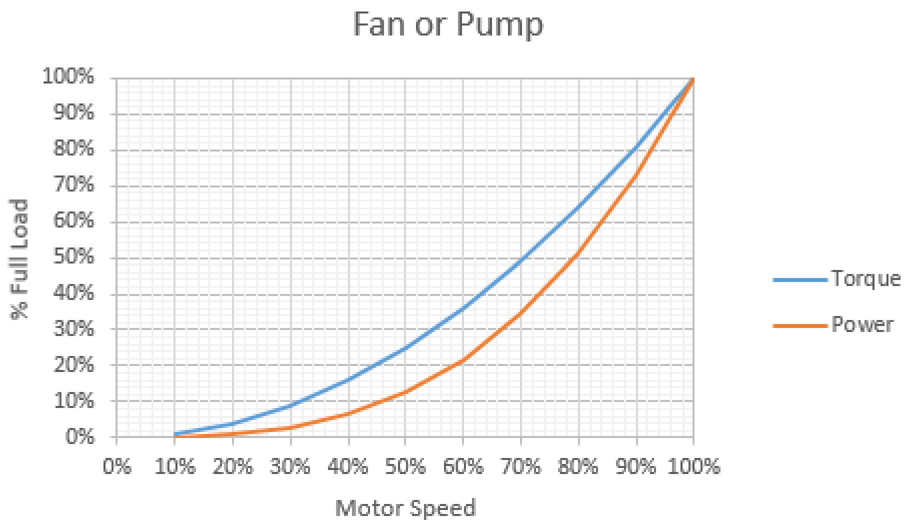
Cube Law Between Speed and Power

The relationship between the speed and power of a fan or a pump is called the Cube Law and can be built up step by step.

The flow is proportional to the speed: 10% slower = 90% flow.

The torque is proportional to the speed squared

The power is proportional to the speed cubed.



VFD

Question: 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

Answer:

The gradual increase in frequency and voltage during the startup phase minimizes the inrush current and mechanical stress on the motor and connected equipment. This results in a smoother and controlled acceleration of the motor, reducing wear and tear on the mechanical components.

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

$$N_s \propto f \qquad \alpha = \frac{120}{P}$$

Unit - IV

Development of Dynamic Models for Electric Drives

Development of Dynamic Models for Electric Drives

- The development of dynamic models for electric drives involves creating mathematical representations that describe the behavior and performance of the drive system over time.

- These models are essential for the analysis, design, and control of electric drives.

- The dynamic model typically includes equations that capture the relationships between the electrical, mechanical, and control components within the system.

- Steady- state condition
- Dynamic condition.

Development of Dynamic Models for Electric Drives

Process steps for Dynamic Models:

1. **Define System Components**
2. **Establish Assumptions**
3. **Develop an Electrical Model**
4. **Develop a Mechanical Model**
5. **Combine Electrical and Mechanical Models**
6. **Include Control System Dynamics**
7. **Validation and Parameterization**
8. **Nonlinearities and Advanced Features**
9. **Simulation**
10. **Sensitivity Analysis**
11. **Documentation**

Development of Dynamic Models for Electric Drives

1. **Define System Components:**

Identify and list the key components of the electric drive system. This may include the motor, power electronics (inverters, converters), mechanical load, and any control systems.

2. Establish Assumptions:

Make reasonable assumptions about the system to simplify the modeling process. This could involve neglecting certain factors or assuming specific characteristics to make the model more manageable.

Development of Dynamic Models for Electric Drives

3. Develop Electrical Model:

Create equations that describe the electrical behavior of the motor and associated power electronics. The electrical model typically includes the equations governing the voltage, current, and power relationships in the system. For DC motors, this may involve circuit equations, while for AC motors, it may involve equations based on the machine's characteristics.

4. Develop Mechanical Model:

Formulate equations that represent the mechanical aspects of the system. This includes modeling the inertia, friction, and any external mechanical loads. For rotational motion, Newton's laws and the mechanical power balance equation are commonly used.

Development of Dynamic Models for Electric Drives

5. Combine Electrical and Mechanical Models:

Integrate the electrical and mechanical models to represent the complete electromechanical system. This integration typically involves relating the electrical variables to the mechanical variables, considering the coupling effects between the two domains.

6. Include Control System Dynamics:

If the electric drive has a control system, incorporate the control algorithm and its dynamics into the model. This includes considering the response time, feedback loops, and any other relevant control parameters.

Development of Dynamic Models for Electric Drives

7. Validation and Parameterization:

Validate the dynamic model by comparing its predictions to experimental data or established benchmarks. Adjust model parameters based on experimental results to improve accuracy.

8. Nonlinearities and Advanced Features:

Depending on the complexity of the system, consider incorporating nonlinearities (e.g., saturation effects) and advanced features (e.g., sensorless control, dynamic braking) into the model to capture the system's behavior more accurately.

Development of Dynamic Models for Electric Drives

9. Simulation:

Use simulation tools (e.g., MATLAB/Simulink, PLECS) to simulate the developed dynamic model under various operating conditions. This helps in analyzing the system's performance and behavior over time.

10. Sensitivity Analysis:

Perform sensitivity analysis to understand how changes in different parameters affect the system's performance. This aids in optimizing the system for specific requirements.

11. Documentation:

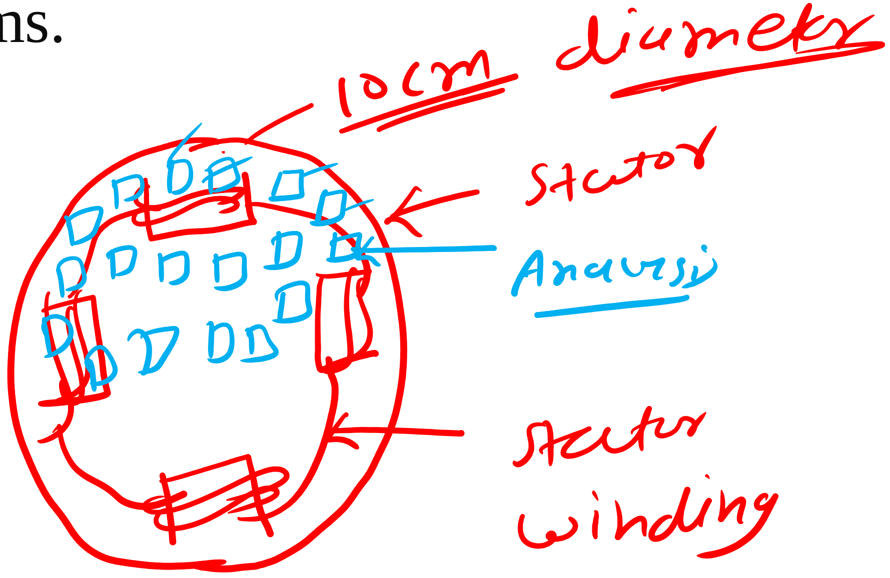
Document the developed dynamic model, including equations, assumptions, and parameter values. This documentation is crucial for future analysis, design iterations, and system understanding.

Simulation Tools to Check the Performance of Electric Drive

Simulation Tools to Check the Performance of Electric Drive

- Several simulation tools are widely used for studying the performance of electric drive systems.
- These tools provide a virtual environment for modeling, analyzing, and simulating the behavior of electric drive components and systems.

1. **MATLAB/Simulink**
2. **PSIM**
3. **LabVIEW**
4. **Ansys Maxwell**
5. **PSCAD**



Types of Duty Cycles

Types of Duty Cycles

- Nowadays, in almost every application, electric motors are used, and to control them electrical drives are employed.

- But the operating time for all motors is not the same. Some of the motors run all the time, and some of the motor's run time is shorter than the rest period.

- Depending on this, the concept of **motor duty class** is introduced and on the basis of this duty cycles of the motor can be divided into eight categories such as

Types of Duty Cycles

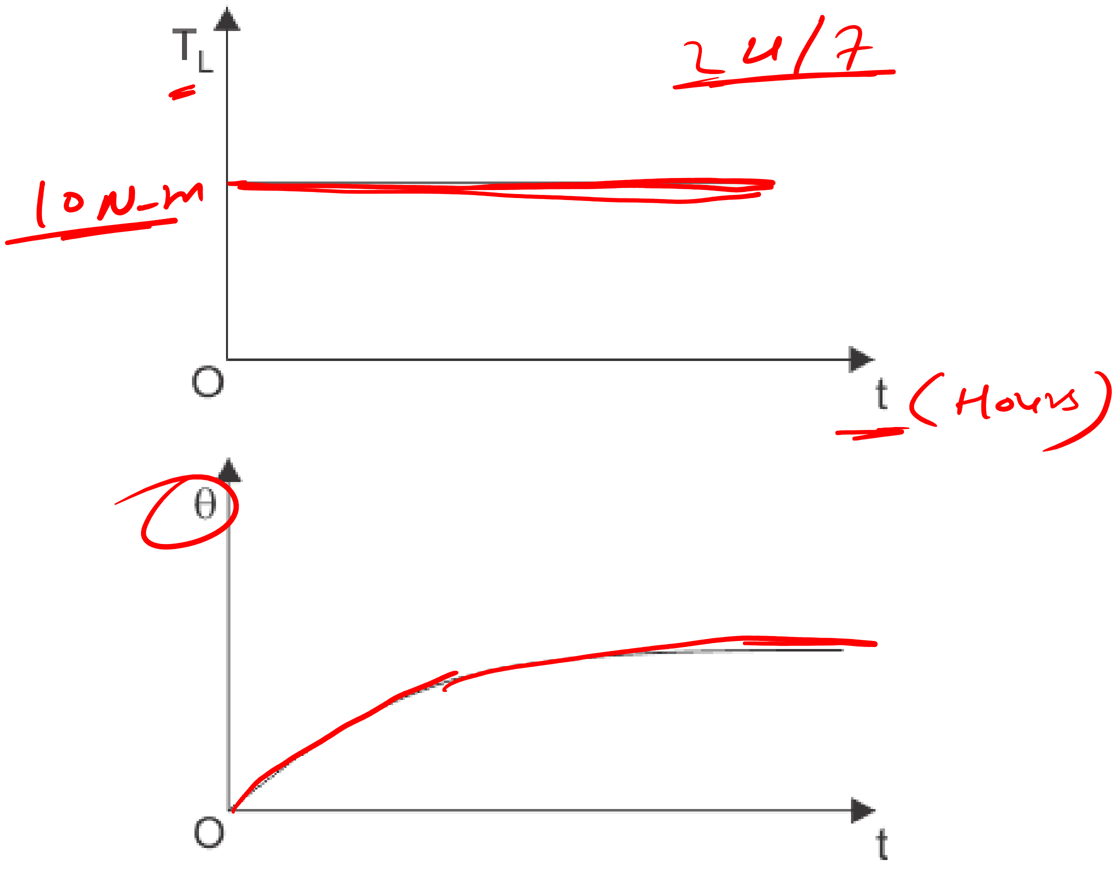
1. **Continuous duty**
2. **Short-time duty**
3. Intermittent periodic duty
4. **Intermittent periodic duty with starting**
5. Intermittent periodic duty with starting and braking
6. **Continuous duty with intermittent periodic loading**
7. Continuous duty with starting and braking
8. **Continuous duty with periodic speed changes**

Types of Duty Cycles

1. Continuous Duty Cycle

- This duty denotes that, the motor is running long enough, and the electric motor temperature reaches the steady state value.

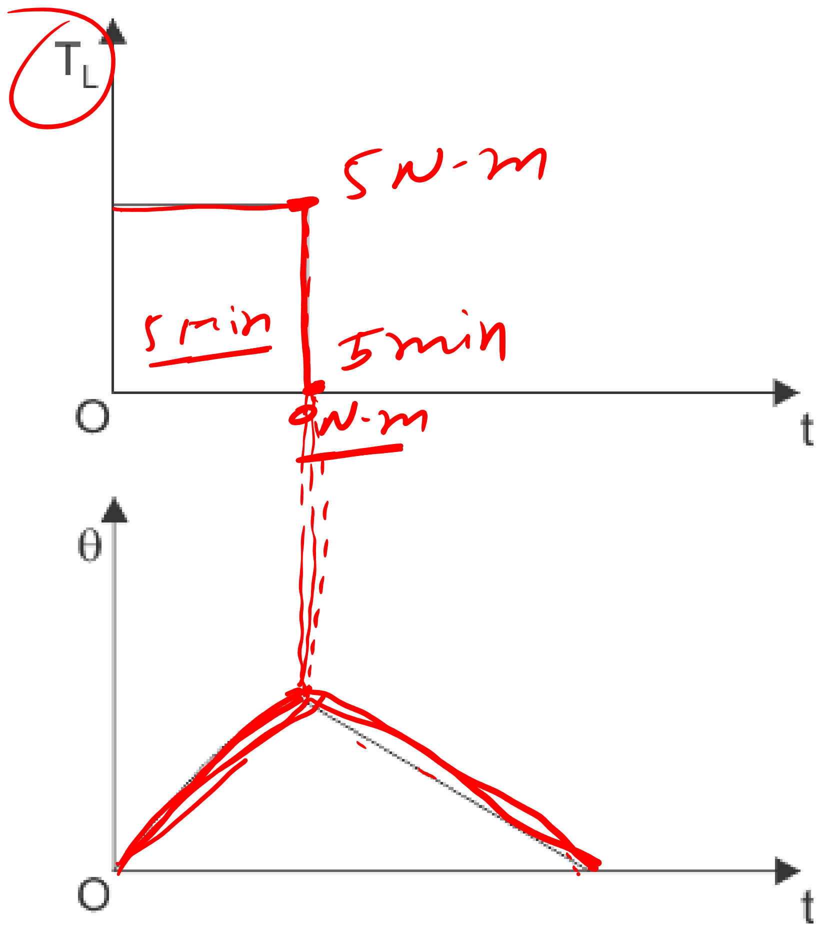
- *These motors are used in paper mill drives, compressors, conveyors etc.*



Types of Duty Cycles

2. Short-Time Duty Cycle

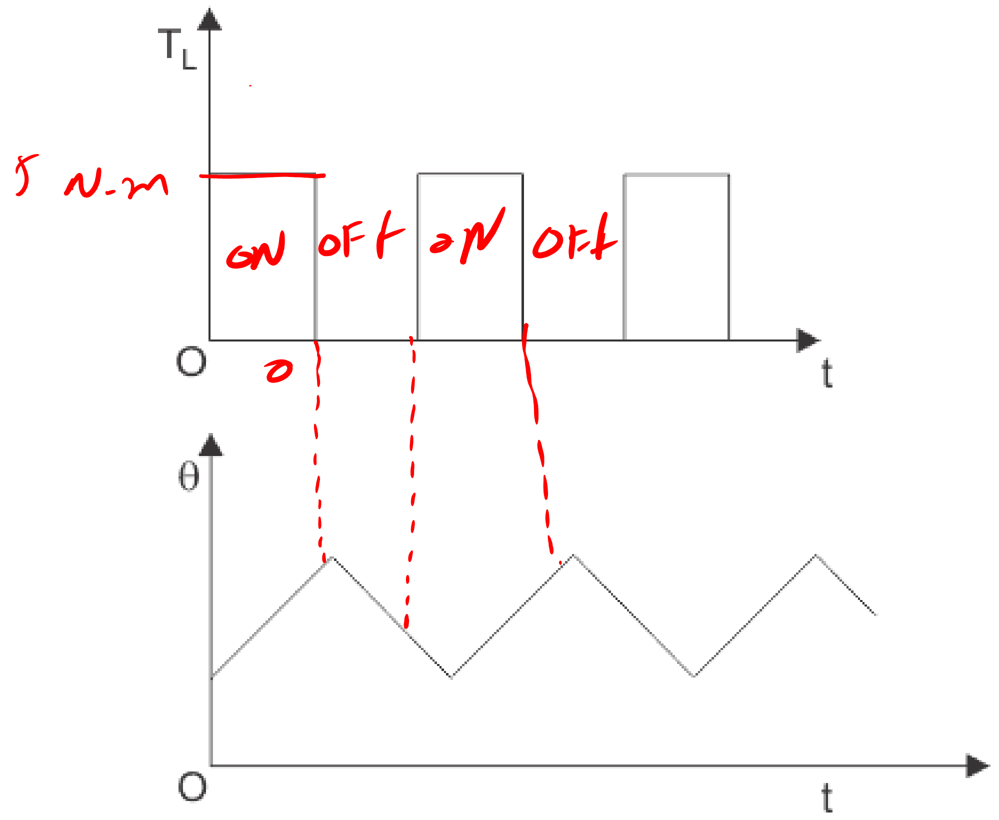
- In these motors, the time of operation is very low and the heating time is much lower than the cooling time.
- So, the motor cooks off to ambient temperature before operating again.
- *These motors are used in crane drives, drives for household appliances, valve drives etc.*



Types of Duty Cycles

3. Intermittent Periodic Duty Cycle

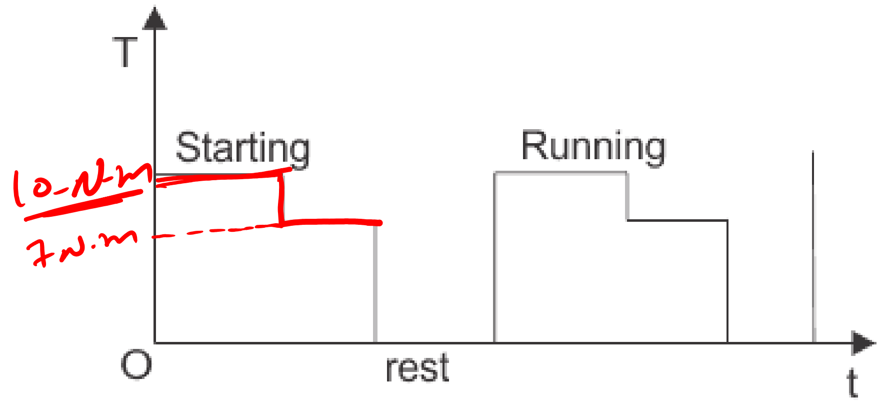
- Here the motor operates for some time and then there is a rest period.
- In both cases, the time is insufficient to raise the temperature to steady state value or cool it off to ambient temperature.
- *This is seen at press and drilling machine drives.*

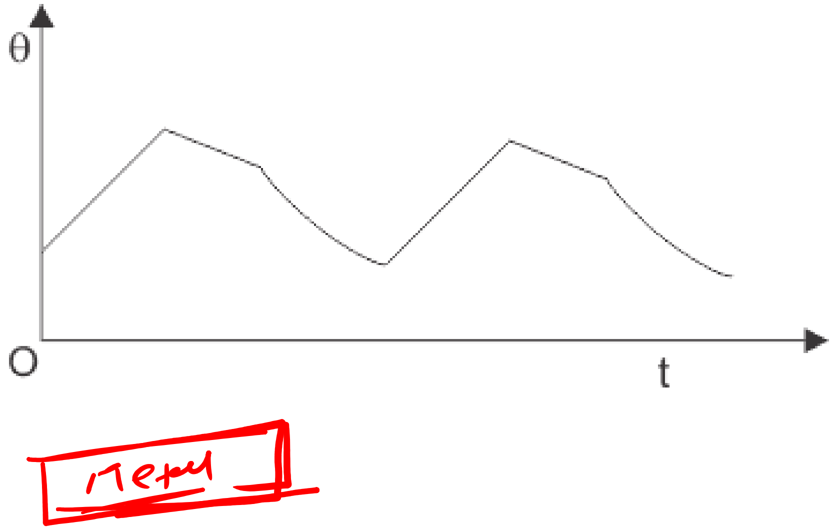


Types of Duty Cycles

4. Intermittent Period Duty with Starting

- In this type of duty, there is a period of starting, which cannot be ignored and there is a heat loss at that time.
- After that there is a running period and rest period which are not adequate to attain the steady state temperatures.
- *This motor duty class is widely used in metal cutting and drilling tool drives, mine hoists etc.*

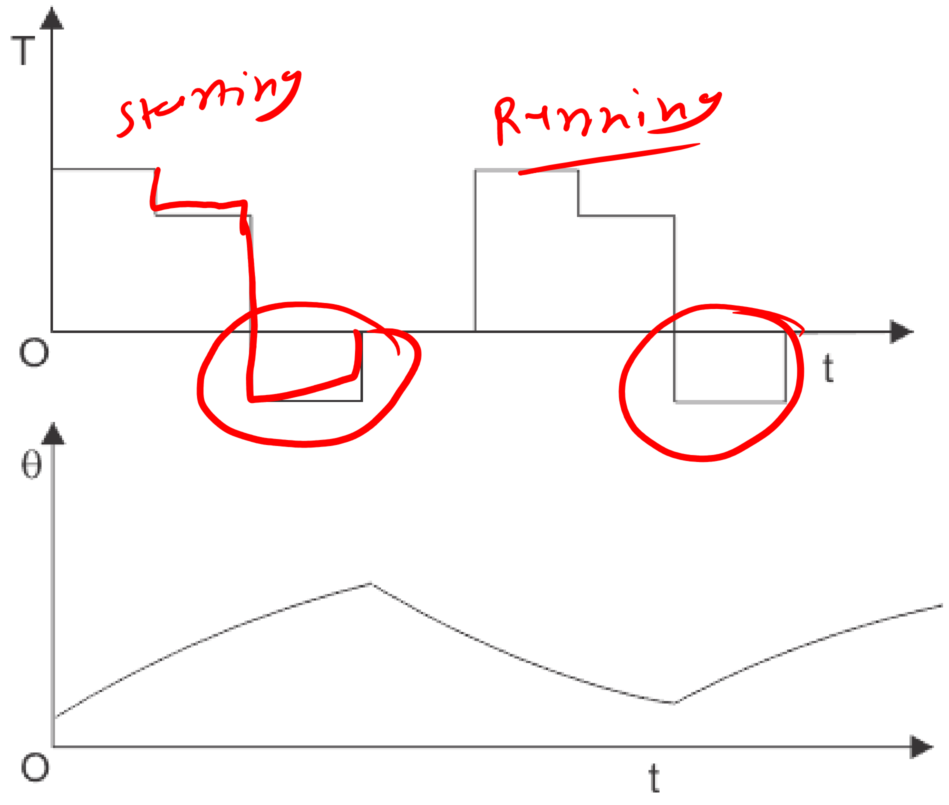




Types of Duty Cycles

5. Intermittent Periodic Duty with Starting and Braking

- In this type of drive, heat loss during starting and braking cannot be ignored.
- So, the corresponding periods are the starting period, operating period, braking period, and resting period, but all the periods are too short to attain the respective steady state temperatures,
- *These techniques are used in billet mill drive, manipulator drive, mine hoist etc.*



Types of Duty Cycles

6. Continuous Duty with Intermittent Periodic Loading

- In this type of motor duty, everything is the same as the periodic duty but here a no-load running period occurs instead of the rest period.

- *Pressing, and cutting are examples of this system.*

Types of Duty Cycles

7. Continuous Duty with Starting and Braking

- It is also a period of starting, running and braking and there is no resting period.

- *The main drive of a steel mill is an example.*

Types of Duty Cycles

8. Continuous Duty with Periodic Speed Changes

- In this type of motor duty, there are different running periods at different loads and speeds.

- But there is no rest period and all the periods are too short to attain the steady state temperatures.

Key Points from Today's Class

- Space Vector PWM Method
- Difference Between VSI and CSI
- Cube Law Between Speed and Power
- Development of Dynamic Models for Electric Drives
- Simulation Tools to Check the Performance of Electric Drive
- Types of Duty Cycles

Key Points from Next Class

In the next class, we will be discussing on the

- ❖ Calculation of Motor Rating for Duty Cycles
- ❖ Overload Factor Calculation for Short and Intermittent Duty Cycles
- ❖ Use of Load Diagrams

Thank you so much for your attentions

Q & A