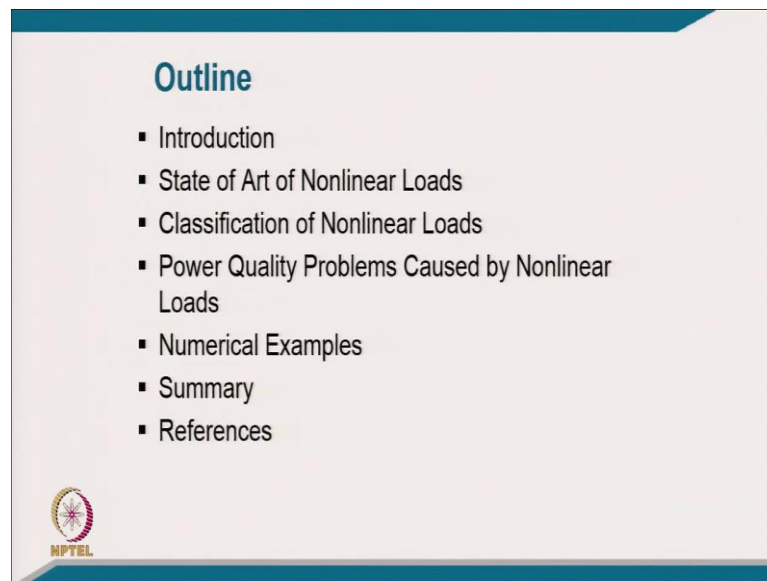


Power Quality
Prof. Bhim Singh
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 15
Loads which Cause Power Quality Problems

Welcome to the course on Power Quality.

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Well, we will like to start with the introduction and state of art on the non-linear load, classification of non-linear load, then power quality problems caused by non-linear loads, then followed by numerical examples, summary, and references.

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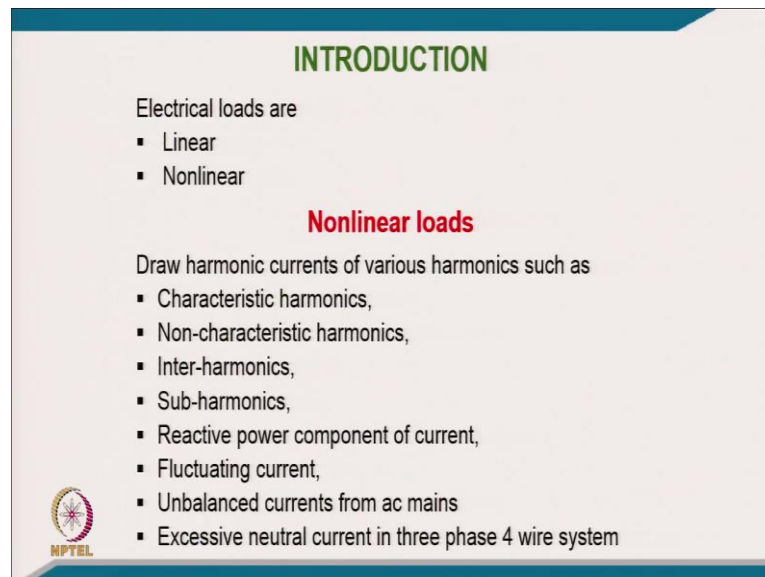
OBJECTIVES

- Nonlinear Loads and Power Quality Indices
- Configurations of Nonlinear Loads
- Analysis of Nonlinear Loads
- Single-Phase Nonlinear Loads
- Three-Phase Nonlinear Loads
- Power Quality Problems Caused by Nonlinear Loads

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Coming to the objectives of this topic, we will talk about the non-linear load and power quality indices; then we will go to the configuration of non-linear load, analysis of non-linear load, then single phase non-linear load, three phase non-linear load, and power quality problem caused by non-linear load.

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INTRODUCTION


Electrical loads are

- Linear
- Nonlinear

Nonlinear loads

Draw harmonic currents of various harmonics such as

- Characteristic harmonics,
- Non-characteristic harmonics,
- Inter-harmonics,
- Sub-harmonics,
- Reactive power component of current,
- Fluctuating current,
- Unbalanced currents from ac mains
- Excessive neutral current in three phase 4 wire system

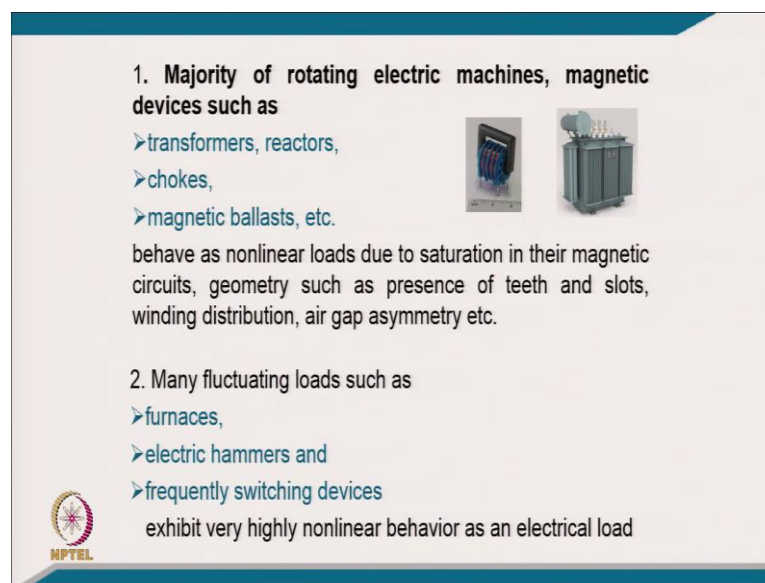
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Two categories of load, linear load and non-linear load. The concept of linear electrical load where the current is proportional to the voltage, we call it linear relation.

But the non-linear load draw the harmonic currents of various multiple harmonics of the fundamental frequency of the supply voltage.

Then we also have non characteristic harmonics, inter harmonics, and sub harmonics. Then in many such non-linear load, we have a reactive power consuming loads also. The typical example may be a thyristor converter. Moreover, there are unbalanced current drawing loads. Well, in three phase four wire system there may be excessive neutral current due to unbalance and harmonics.

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1. Majority of rotating electric machines, magnetic devices such as


- transformers, reactors,
- chokes,
- magnetic ballasts, etc.

behave as nonlinear loads due to saturation in their magnetic circuits, geometry such as presence of teeth and slots, winding distribution, air gap asymmetry etc.

2. Many fluctuating loads such as

- furnaces,
- electric hammers and
- frequently switching devices


exhibit very highly nonlinear behavior as an electrical load



Majority of rotating electrical machine and magnetic devices, such as transformer reactors, choke and magnetic ballast behave as a non-linear load due to the saturation in their magnetic circuit.

Another category of non-linear load is the many fluctuating load, such as furnaces, electric hammers and other frequently switching devices.

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3. **Non-saturating electrical loads** such as power capacitors behave as nonlinear loads at ac mains.

- They create a number of power quality problems due to switching, resonance with magnetic components in the system .
- They are overloaded due to harmonic currents caused by presence of harmonic voltages in the supply system.

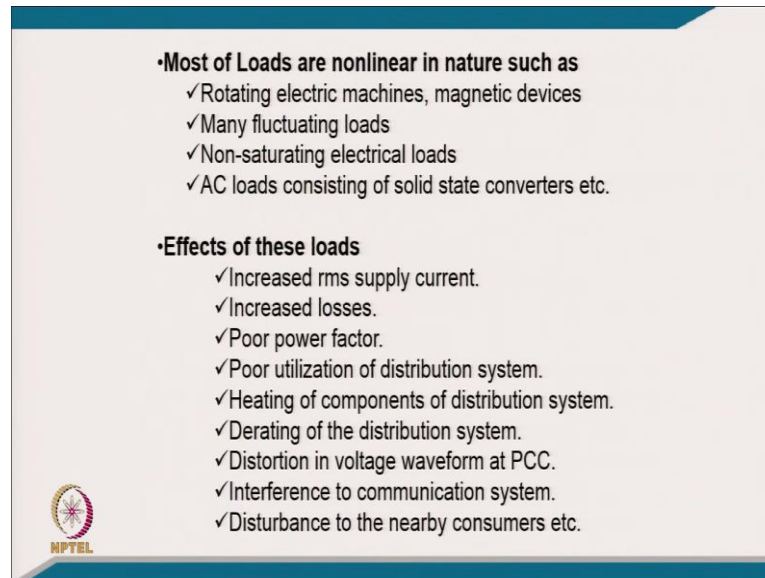
4. **AC loads consisting of solid state converters** is widely used to feed controlled power to electrical loads such as lighting devices with electronic ballasts, controlled heating elements, magnet power supplies, battery chargers, fans, computers, copiers, TVs, switched mode power supplies (SMPS) in computers and other equipment furnaces, electroplating, electrochemical processes, adjustable speed drives (ASDs) in electric traction, air conditioning systems, pumps, waste water treatment plants, elevators, conveyers, cranes, etc.

Now, coming to the third type of non-linear load is the non saturating electrical loads, such as power capacitor. In a power capacitor as the frequency increases its impedance reduces, and even a small voltage harmonics cause large current harmonics.

If some harmonics are present in the load that coincide with the resonance frequency of this source impedance and power capacitor circuit; then this can amplify that particular harmonic manifold.

Coming to the fourth category of non-linear load, the AC load consisting the solid state converter. Controlled heating elements, computers power supply, battery chargers, LEDs, air conditioning system, waste water treatment plant, elevators, conveyors, cranes etc., draw nonlinear currents. Whether it is energy efficient lighting or energy efficient fan, they behave as a non-linear load and draw the harmonics current from the supply system.

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•Most of Loads are nonlinear in nature such as

- ✓ Rotating electric machines, magnetic devices
- ✓ Many fluctuating loads
- ✓ Non-saturating electrical loads
- ✓ AC loads consisting of solid state converters etc.

•Effects of these loads

- ✓ Increased rms supply current.
- ✓ Increased losses.
- ✓ Poor power factor.
- ✓ Poor utilization of distribution system.
- ✓ Heating of components of distribution system.
- ✓ Derating of the distribution system.
- ✓ Distortion in voltage waveform at PCC.
- ✓ Interference to communication system.
- ✓ Disturbance to the nearby consumers etc.



Nonlinear loads cause power quality problems such as increased RMS current supply current, increasing the losses. Moreover the utilization of the distribution system will be poor. Meanwhile, derating and losses of distribution equipments will increase. It also degrades the power factor. Moreover, it leads to interference in the communication system.

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Nonlinear Loads

- Fluorescent lighting and other vapor lamps with electronic ballasts

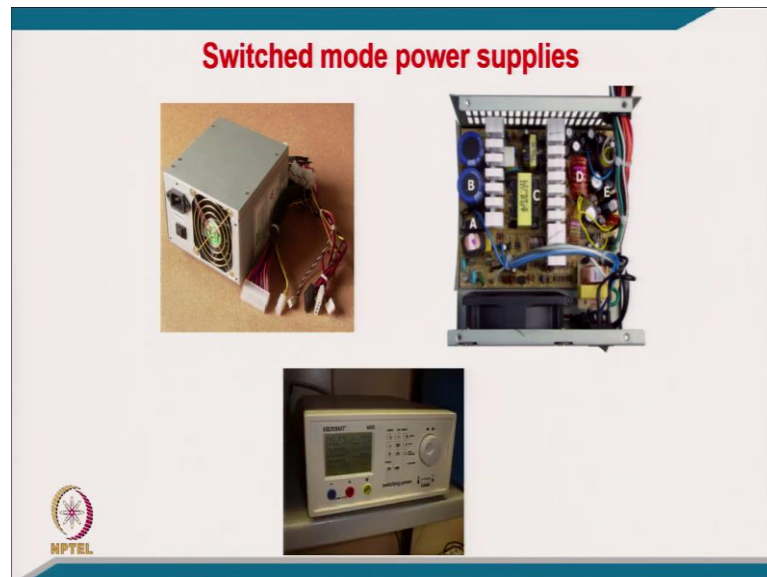




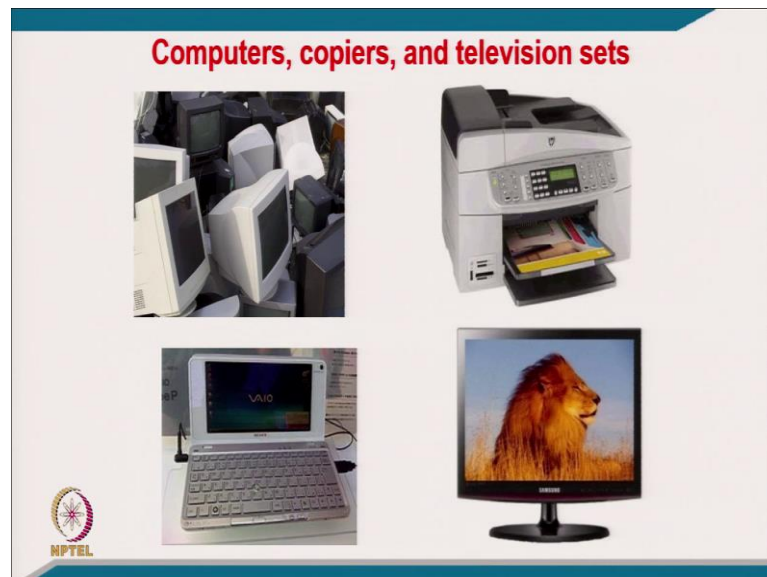
Few typical the kinds of non-linear load are the fluorescent lamp, lighting lamp, other vapor lamp with electronic ballasts, switched mode power supply of computers, printers,

scanners, fax machines, etc., welding machines, solid state controlled ceiling fans, microwave ovens, induction heating devices, medical equipments, air conditioning system, battery chargers, electric traction, furnaces, harmonic injection by renewables, and so on.

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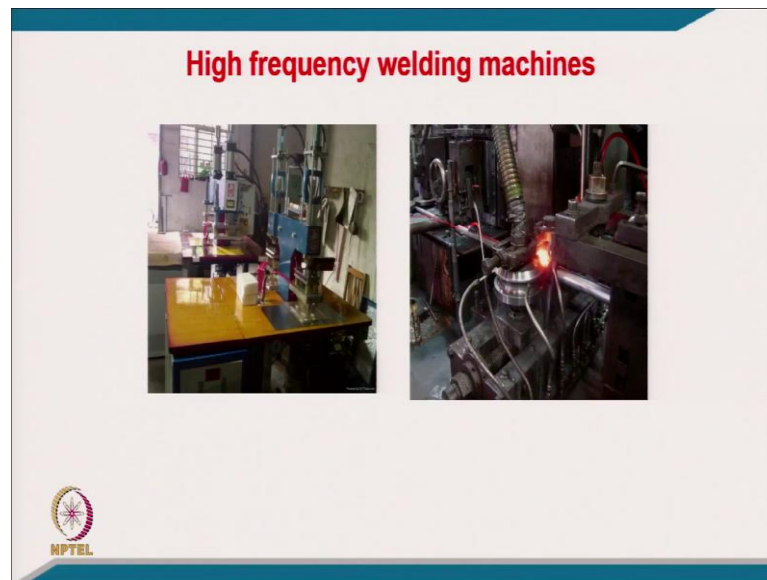
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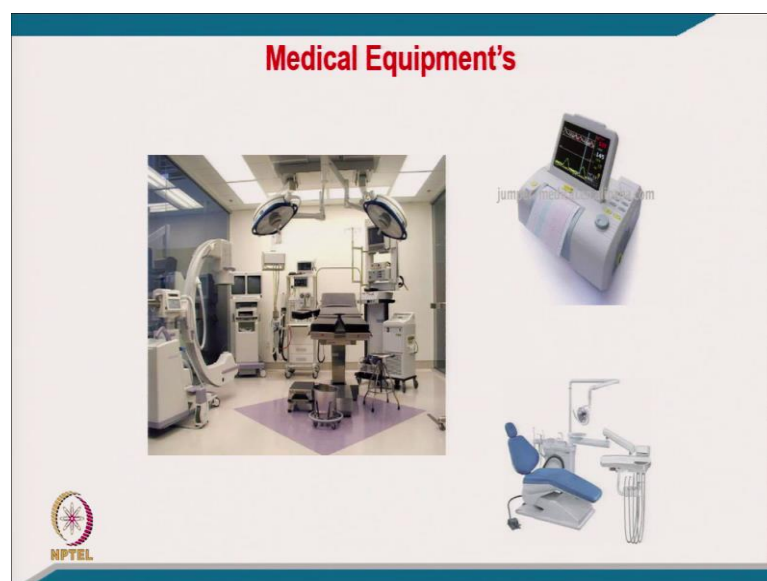
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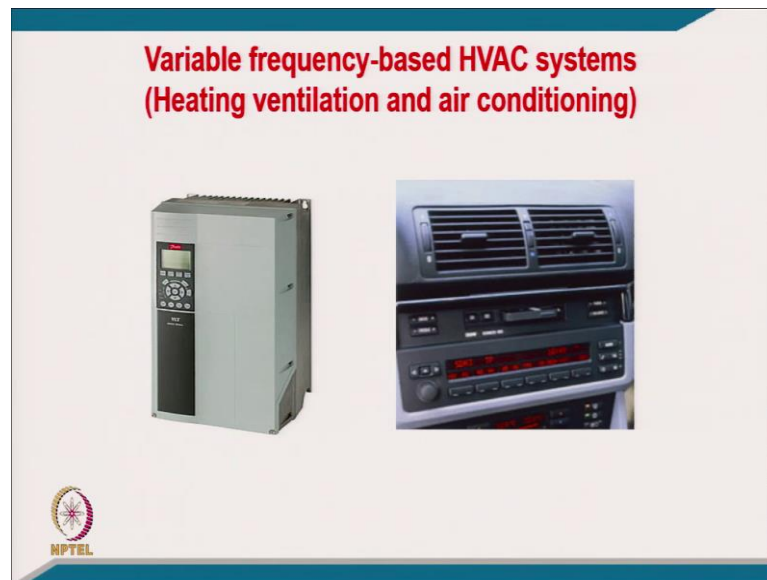
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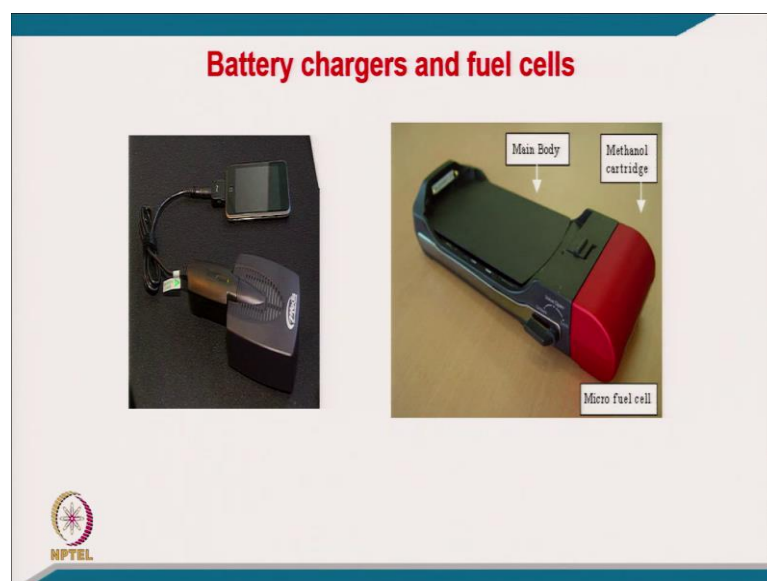
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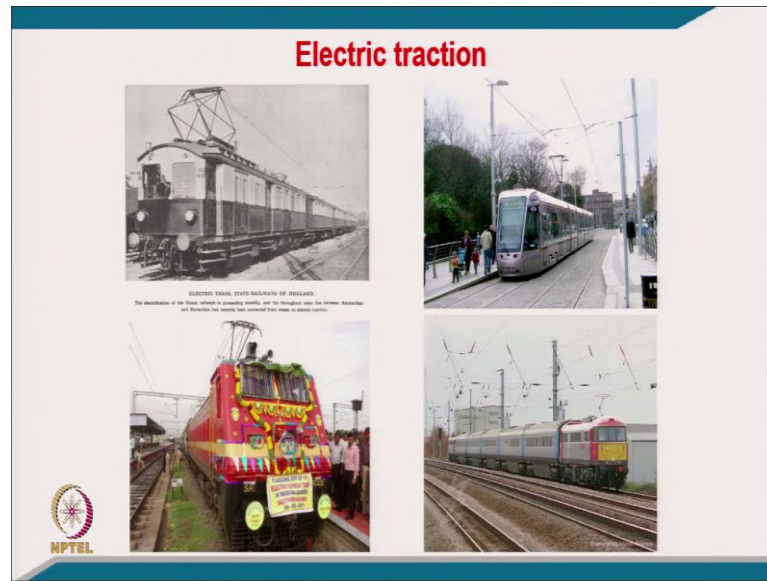
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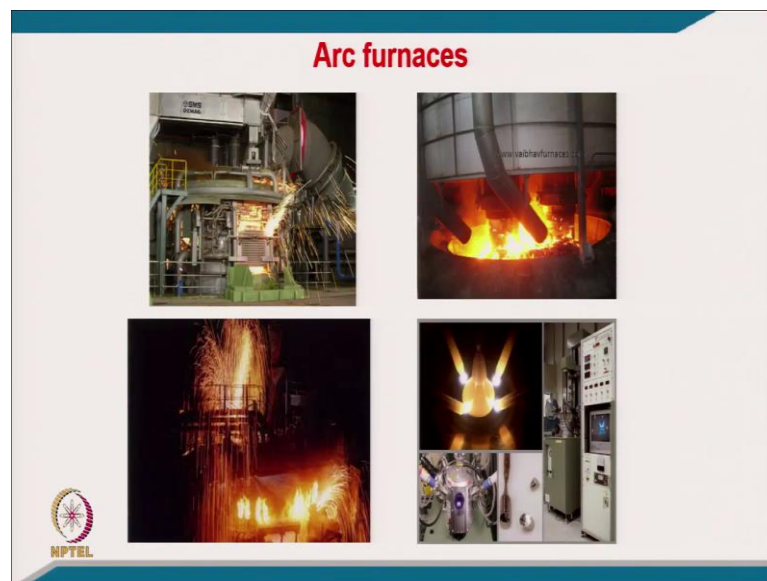
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Cycloconverters


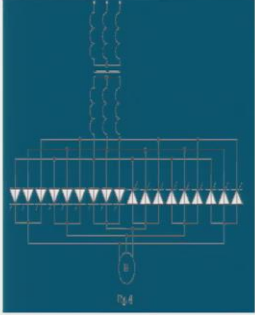





Fig 4




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Plasma power supplies




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Wind and solar power generation




The slide features two photographs. The left photograph shows a white boat on a body of water with a small wind turbine mounted on its deck. The right photograph shows a dark-colored truck with a large array of solar panels mounted on its roof, parked in a desert-like environment with a wind turbine visible in the background. The text 'PortaWatts.com' is overlaid on the bottom right of the right photograph.




The NPTEL logo is located in the bottom left corner of the slide.

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HVDC transmission systems

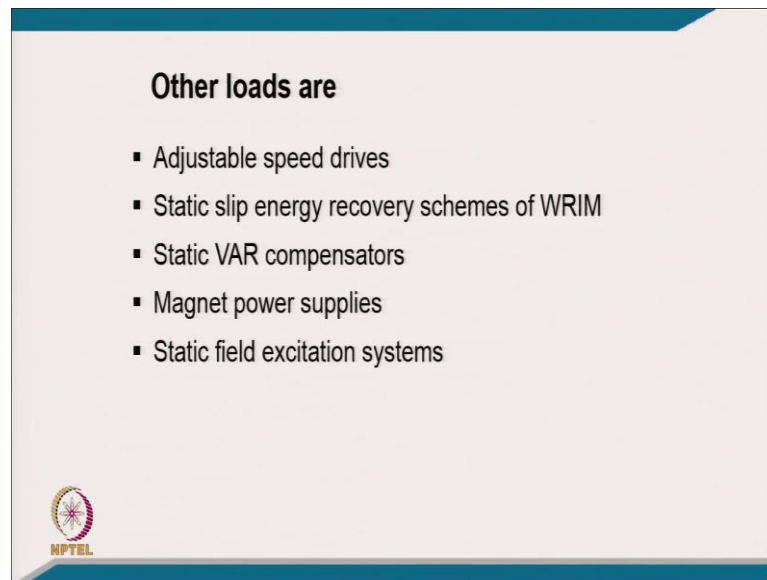


The slide contains two images. On the left is a photograph of a large, yellow and blue HVDC transmission tower. On the right is a photograph of a high-voltage AC transmission tower. Below the AC tower photograph is a schematic diagram of an asynchronous HVDC link. The diagram shows two AC systems, System 1 and System 2, connected to a Rectifier and an Inverter respectively. These are connected to a central DC link represented by a zigzag line. Text above the diagram states: 'Frequency of both systems can be independent' and 'Power flow can be controlled by controlling the firing angle of thyristors'. The diagram is labeled 'Asynchronous HVDC link'.




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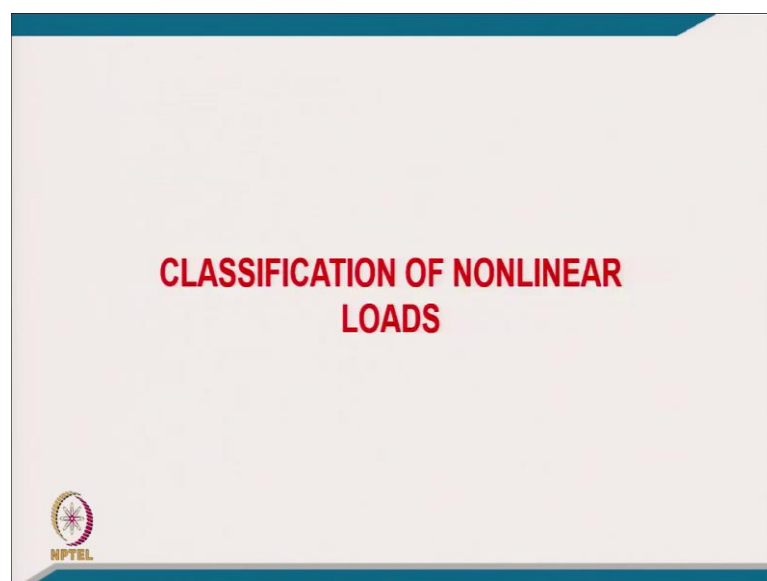


Other loads are


- Adjustable speed drives
- Static slip energy recovery schemes of WRIM
- Static VAR compensators
- Magnet power supplies
- Static field excitation systems


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**CLASSIFICATION OF NONLINEAR
LOADS**



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Coming to the classification of non-linear loads, we classify them into many categories,

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Classified based on




- i) Non solid state devices type or with solid state devices.
- ii) Converter types such as
 - ac-dc converter type,
 - ac voltage controller type
 - cycloconverter type.
- iii) Their nature based
 - stiff current fed type
 - stiff voltage fed type
 - mix of them.
- iv) The number of phases



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Non Solid-State Devices Type Nonlinear Loads

- Most of the electrical machines and magnetic devices
- **A number of physical phenomena in these electrical machines cause their behavior as nonlinear loads.**
 - ✓ Saturation in magnetic material of the machines and electromagnetic devices,
 - ✓ Skin and proximity effects in conductors,
 - ✓ Non-uniform air-gap in rotating machines,
 - ✓ Effect of teeth and slotting etc
- Results in **harmonic currents** under steady state and transient conditions.



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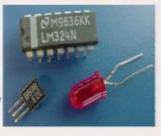

Solid-State Devices Type Nonlinear Loads

➤ They draw **non sinusoidal current** from ac mains

- ✓ harmonic currents,
- ✓ reactive power component of current along with fundamental active power component of current.

They use various

- ✓ ac-dc converters,
- ✓ ac voltage controllers,
- ✓ cycloconverter or
- ✓ combination of them in their front end converter.



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Converter Based Nonlinear Loads

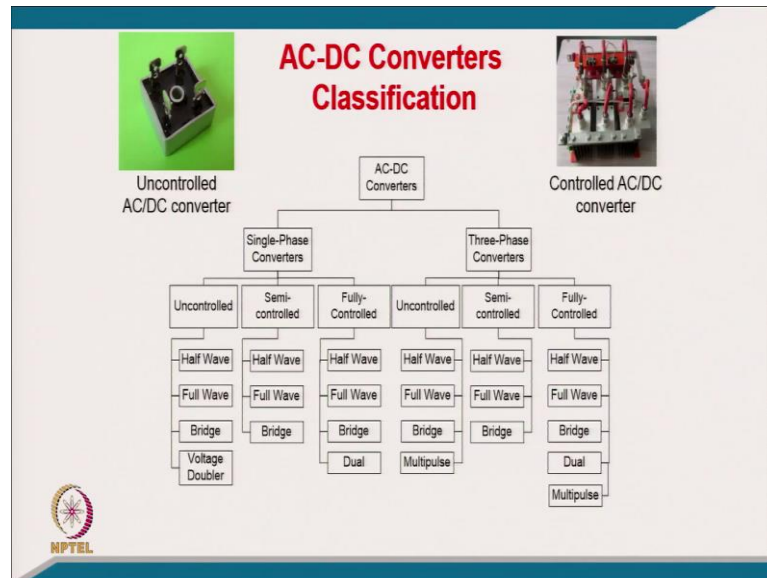
- ac-dc converters
- ac voltage controllers
- cycloconverter or
- combination of them



Cycloconverter generator



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Many non-linear load consist of your AC DC converter. Large number of loads use ac dc converter as front end converter from few watts to mega Watt rating.

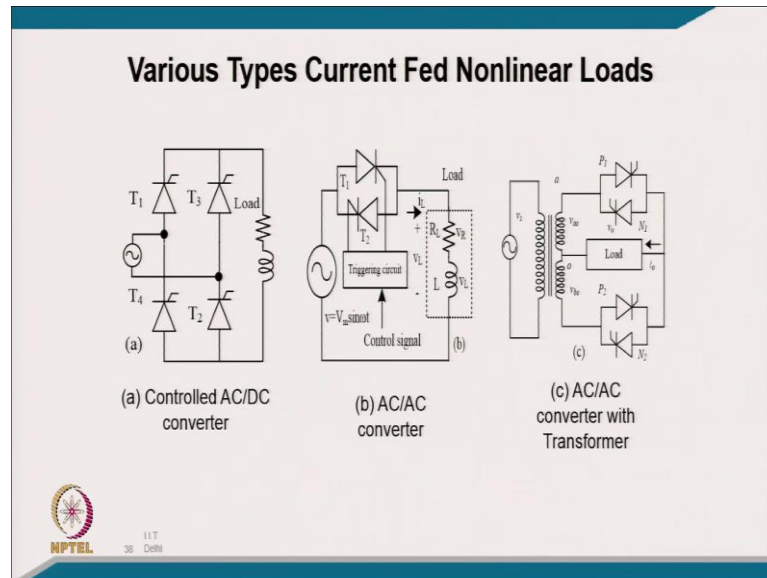
Here we have a classification of the AC DC converter like uncontrolled and controlled pulse converter.

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AC-DC Converter Based Nonlinear Loads

- Large number of loads use ac-dc converters as front end converters from **few watts to MW rating**.
- **Various circuit configurations**
 - ✓ single-phase
 - ✓ three-phase
 - ✓ uncontrolled
 - ✓ semi controlled
 - ✓ fully controlled
 - ✓ half wave
 - ✓ full wave
 - ✓ bridge converter circuits

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Various Types Current Fed Nonlinear Loads: For example


- ✓ microwave ovens
- ✓ SMPS
- ✓ computers
- ✓ fax machines
- ✓ battery chargers
- ✓ HVDC transmission system,
- ✓ electric traction
- ✓ adjustable speed drives etc.

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Various Types Current Fed Nonlinear Loads

- ✓ They draw current with excessive harmonics contents with high crest factor.
- ✓ They draw current with moderate harmonics and reactive power at low crest factor even less than sine wave.
- ✓ They exhibit poor power factor at ac mains due to harmonics only, or along with reactive power.



The loads that draw excessive harmonics content with the high crest factor; are voltage fed non-linear load. The current fed nonlinear loads draw the current with moderate harmonics and reactive power at low crest factor.



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AC Controllers Based Nonlinear Loads

✓ They draw the harmonics current along with the reactive power and cause poor power factor.

Practical examples are

- ✓ ac voltage regulator for fans
- ✓ lighting controllers
- ✓ heating controllers
- ✓ soft starters,
- ✓ static VAR compensators (SVCs) in TCR (Thyristor Controlled Reactors) etc.




AC voltage controller based non-linear load, draw the harmonics current along with the reactive power and cause the poor power factor. And practical examples are ac voltage regulator for fans, lighting controller, heating controllers, and static VAR compensator in thyristor controlled reactor.


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➤ speed controllers and energy saving controllers of the three-phase induction motors operating under light load conditions in number of applications such as


- ✓hack saw,
- ✓electric hammers,
- ✓wood cutting machines, etc



hack saw



wood cutting machines



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Cycloconverter Based Nonlinear Loads

They draw harmonics currents at not only higher order harmonics but at sub harmonics too, reactive power and exhibit a very poor power factor

Practical examples of such nonlinear loads are

- Cycloconverter fed large rating synchronous motor drives in cement mills, ore crushing plants,
- large rating squirrel cage induction motors,
- slip energy recovery scheme of WRIM drives,
- VSCF systems (variable speed constant frequency generating systems) etc.



Another is the cycloconverter based non-linear load; they draw the harmonics current at not only higher order, but at the sub harmonics too and exhibit a very poor factor. Practical examples of such non-linear load are cycloconverter fed large rating synchronous motor drive in cement mill, ore crushing plant; large rating squirrel cage induction motor; slip recovery scheme of wound rotor induction motor drive; variable speed constant frequency generation system.


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Nature Based Classification

- Stiff current fed
- Stiff voltage fed
- Mix of them.

➤The **stiff current fed loads** normally consist of ac-dc converters with constant dc current load, with predetermined harmonic pattern in ac mains with reactive power burden.

➤The **stiff voltage fed loads** consist of generally ac-dc converters with large dc capacitor at dc bus to provide ideal dc voltage source for the remaining process of solid state conversion and draw peaky current from ac mains with high crest factor.




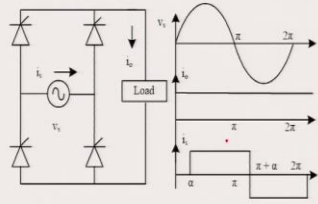
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Now, stiff current fed, which is like a thyristor converter with the highly inductive load; I mean they behave like as a current fed, in the sense dc side current is constant. Stiff voltage source is diode rectifier with the capacitive filter on dc side.

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Current Fed Type of Nonlinear Loads


- Generally have predetermined kind of **pattern of harmonics**.
- Sometimes they have **reactive power burden** on the ac mains.
- They have **flat current waveform** drawn from ac mains.
- **Low value of its crest factor**.




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For Example

- ✓ ac-dc converters feeding
 - dc motor drives,
 - magnet power supplies,
 - field excitation system of the alternators,
- ✓ controlled ac-dc converters used to derive dc current source for feeding CSI supplying large rating ac motor drives, HVDC transmission systems etc.



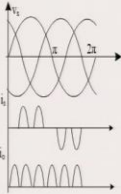
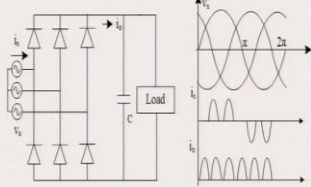
magnet power supplies




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Voltage Fed Type of Nonlinear Loads

- They behave as **sink of harmonics currents**.
- Typical example : an **ac-dc converter with large dc capacitor**.
- They generally do not have reactive power requirement but they much greater amount of harmonics currents drawn from ac mains.



Three-Phase Converter Based Voltage Fed Type of Nonlinear Load.



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Practical examples of such loads are

- switched mode power supplies (SMPS),
- battery chargers;
- front end converters of voltage source inverter fed ac motor drives,
- electronics ballasts,
- most of the electronics appliances.



SMPS



battery chargers



electronics ballasts



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The practical example of such loads are switched mode power supply, battery charger, front end converter for voltage source inverter fed ac motor, electronic ballast, most of electronics appliances; like electronic ballast or typically your switched mode power supply comes under the category of battery charger or so with this like.


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Mixed of Current Fed and Voltage Fed Type of Nonlinear Loads

- Most of the practical electrical loads consisting solid state converters behave of these types of nonlinear loads.



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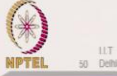
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And mixed kind of current fed and voltage fed load mostly practical electrical load consisting solid state converter behave of these kind of non-linear load.

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Supply System Based Classification

- Single-phase (two wire)
- three-phase (three wire) systems
- three-phase (four wire) systems

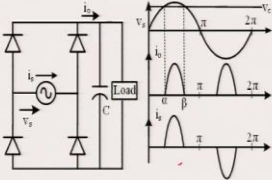


And supplies system based classification we already talk about like a single phase two wire, three phase three wire, three phase four wire.

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Two Wire Nonlinear Loads

- ✓ single-phase diode rectifiers
- ✓ semi converters and
- ✓ thyristor converters etc.



Single-phase Converter Based
Voltage Fed Type of Nonlinear Load

- They draw harmonics currents.
- Sometimes they draw reactive power from ac mains.

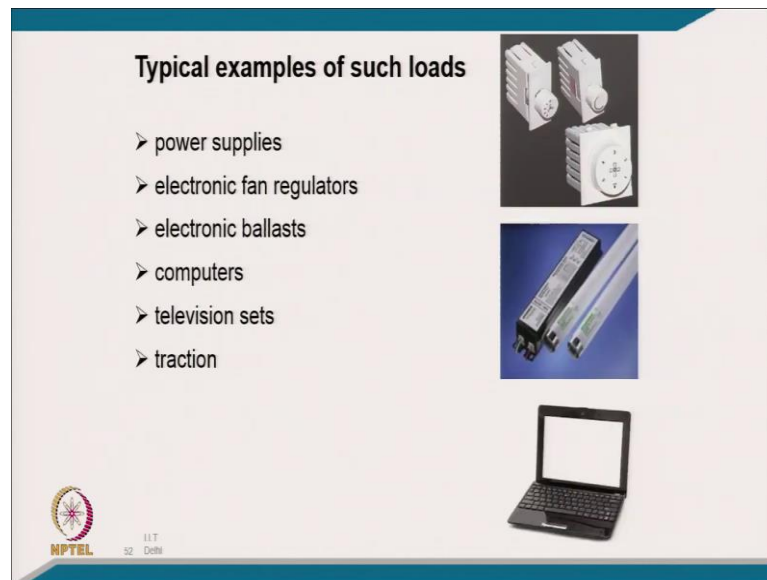


And coming to like a single phase, typically two wire non-linear load is like single phase diode rectifier, semi converter, thyristor converter. Peak current and with crest factor quite high is drawn from ac mains.

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Typical examples of such loads

- power supplies
- electronic fan regulators
- electronic ballasts
- computers
- television sets
- traction



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The type of examples such load are power supply, electronics fan regulator for BLDC, then electronic ballast, computers, television, traction of this kind of load, like I mean laptop or other.

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Three Wire Nonlinear Loads

- ✓ They inject harmonics currents.
- ✓ Sometimes they draw reactive power from ac mains.
- ✓ Sometimes have also unbalancing.
- ✓ Consume major amount of electric power.

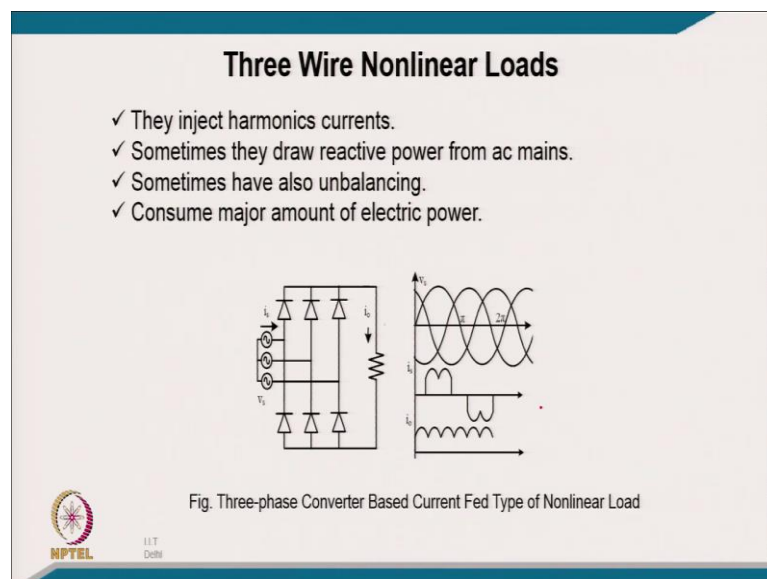


Fig. Three-phase Converter Based Current Fed Type of Nonlinear Load


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They inject the harmonics current, sometime they draw reactive power from ac mains, sometime they have also unbalanced current or unbalancing current.

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Typical examples are

- ✓ ASDs using dc motors and ac motors,
- ✓ HVDC transmission systems,
- ✓ Wind power conversion.

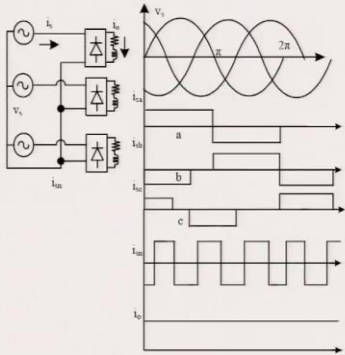


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Typical examples are adjustable speed drive using dc motors and ac motor, HVDC system, wind power conversion system.

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Four Wire Nonlinear Loads




Three-Phase Four Wire Converter Based Current Fed Type of Nonlinear Loads

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Power Quality Problems Caused by Nonlinear Loads

1. Increased rms supply current.
2. Increased losses.
3. Poor power factor.
4. Poor utilization of distribution system.
5. Heating of components of distribution system.
6. De-rating of the distribution system.
7. Distortion in the voltage waveform at the PCC, which indirectly affect many equipment.




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The power quality problems due to nonlinear loads are listed in the pasted slides.

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8. Interference to controllers of many other types of equipment.
9. Capacitor bank failure due to overload, resonance, harmonic amplification and nuisance fuse operation.
10. Excessive neutral current.
11. Harmonic voltage at the neutral point.
12. Mal-operation of protection systems such as relays Voltage regulation and voltage fluctuations.



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13. Imbalance in three-phase voltages.

14. Dearing of cables and feeders.

15. The voltage imbalance creates substantial problems to electrical machines due to

- negative sequence currents,
- noise,
- vibration,
- torque pulsation,
- rotor heating etc. of course their derating.

