Name:

Class:

ID-Nr.:

BS-7
Power systems technology

كلية المدربين التقنيين
Technical Trainers College

Electronics and Electrical Technology
Power systems technology
BS-7

Target definition

The trainee will be able to describe, calculate and design transformers.

The trainee will be able to describe measuring and testing procedures relating to protection systems and carry out measurements and tests

The trainee will be able to describe power distribution systems.

The trainee will be able to determine conductor resistance and voltage drop at power transmission systems.

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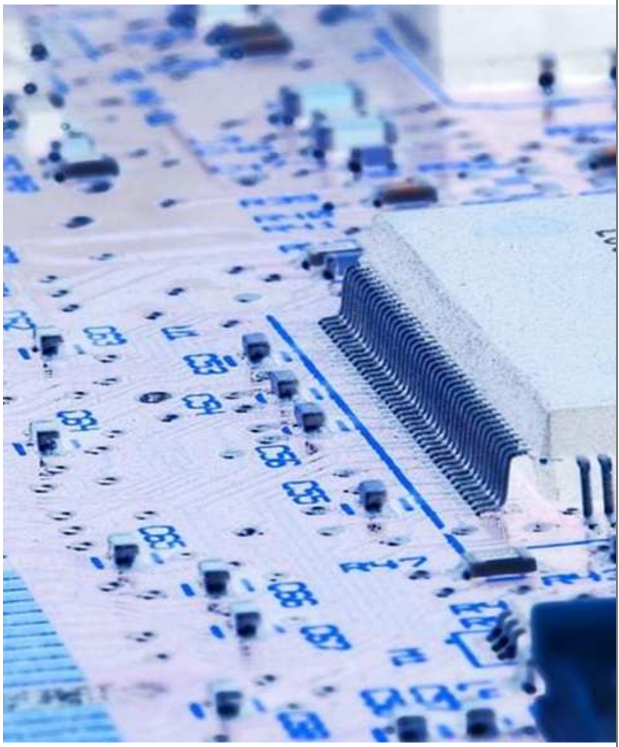

Electric generation

Electric transmission

Electric distribution

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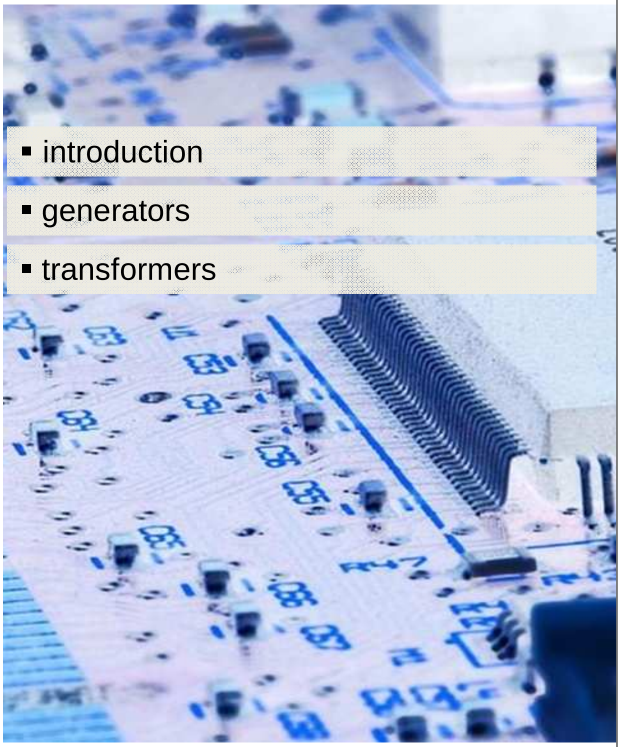
Electric generation

Electric transmission

Electric distribution



- introduction
- generators
- transformers

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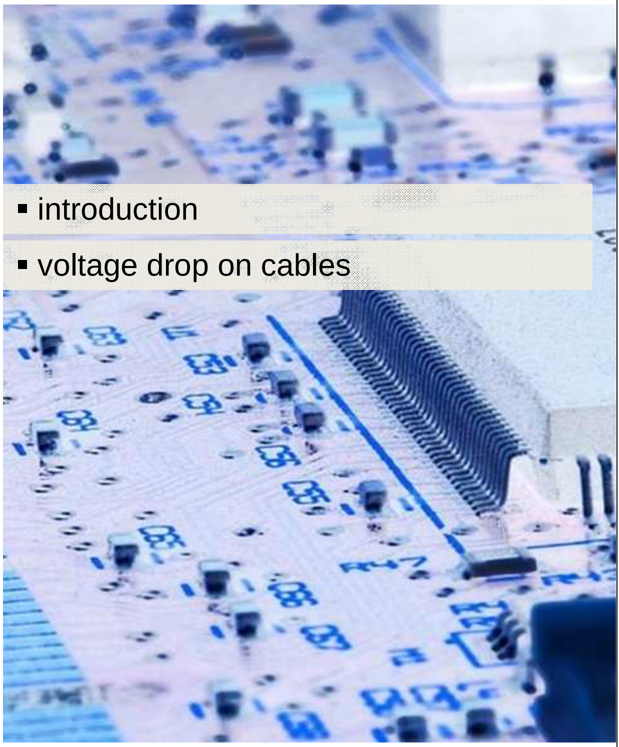
Electric generation

Electric transmission

Electric distribution



- introduction
- voltage drop on cables

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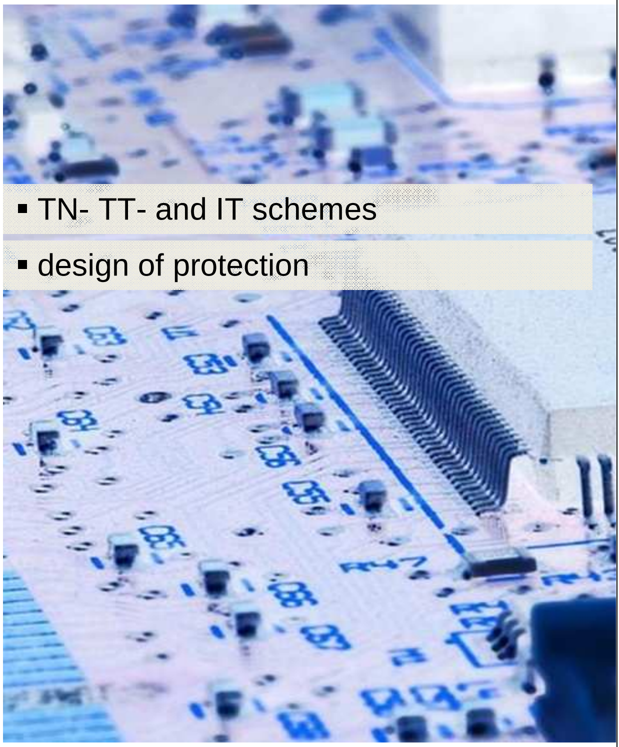
Electric generation

Electric transmission

Electric distribution



- TN- TT- and IT schemes
- design of protection

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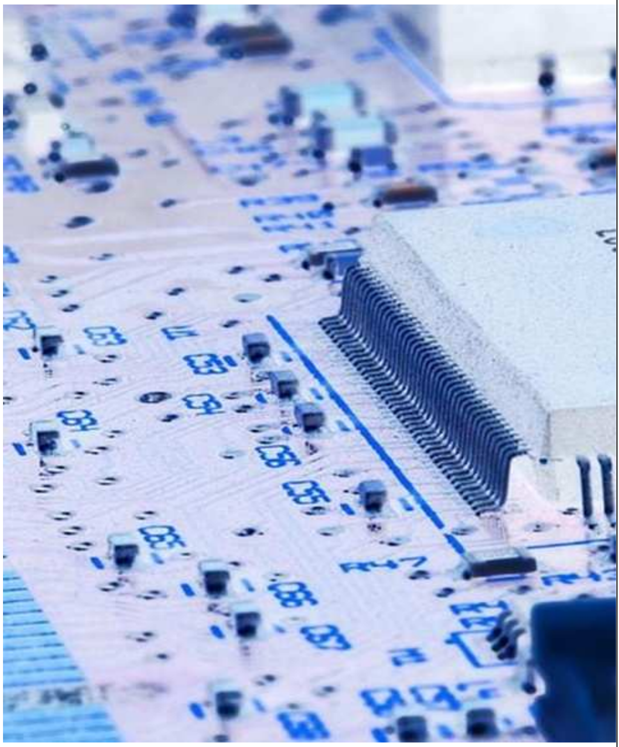
Electric generation

Electric transmission

Electric distribution

- introduction
- generators
- transformers



Electronics and Electrical Technology
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introduction

Power systems technology

- **Generation**
- **Transmission**
- **Distribution**

Generating electrical energy

Transporting electrical energy from its sources to load centers with high voltages to reduce losses.

Distributing electrical energy from substations to end customers.

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A power system is an interconnected network with components converting nonelectrical energy continuously into the electrical form and transporting the electrical energy from generating sources to the loads/users. A power system serves one important function and that is to supply customers with electricity as economically and as reliably as possible. It can be divided into three sub-systems:

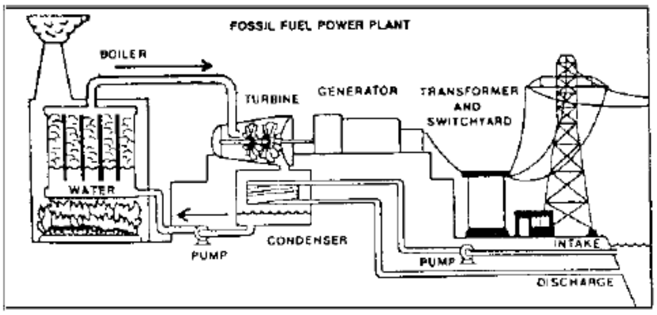
1.Generation - Generating and/or sources of electrical energy.

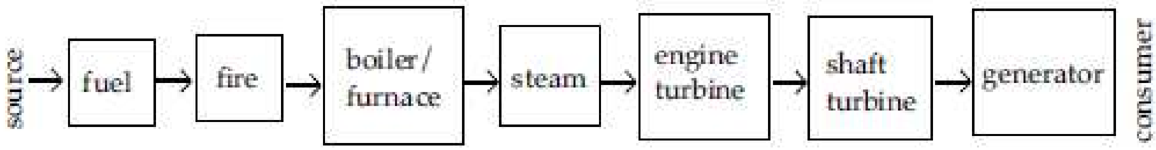
2.Transmission - Transporting electrical energy from its sources to load centers with high voltages (115 kV and above) to reduce losses.

3.Distribution - Distributing electrical energy from substations (44 kV ~ 12 kV) to end users/customers.

Power plants

Fossil power plants
Gas turbines power plants
Diesel power plants
Waste to energy power plant
Wind power plants
Nuclear power plants
Geothermal power plants





A power station is an industrial facility for the generation of electric power.

At the center of nearly all power stations is a generator, a rotating machine that converts mechanical energy into electrical energy by creating relative motion between a magnetic field and a conductor.

The energy source harnessed to turn the generator varies widely. It depends chiefly on which fuels are easily available and on the types of technology that the power company has access to.

Work in groups, 5 per class. Each group has to present an other power plant. This presentation (plus student hand out) counts 30% for the final grading

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Electric generation

1. Now you are the teacher! Prepare a presentation to explain
- **functionality,**
- **advantages,**
- **disadvantages and**
- **environmental compatibility**

of a certain power plant.

2. Plan your presentation to explain your task for about 25 minutes. You can use whiteboards, cards or your own PowerPoint presentation. Also some other Ideas are welcome.

3. Prepare a handout for the students.

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Wind power plant
Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity.

Solar power plant
Solar power is the conversion of sunlight into electricity, either directly using photovoltaic or indirectly using concentrated solar power.

Nuclear power plant
Nuclear power is produced by controlled nuclear reactions. Commercial and utility plants currently use nuclear fission reactions to heat water to produce steam, which is then used to generate electricity.

Fossil fuel power plant
A fossil fuel power station is a power station that burns fossil fuels such as coal, natural gas or oil to produce electricity.

Hydro power plant
Hydropower or water power is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes.

The paperclip motor

- **Building something with our own hands often provides a new quality of insight, not to mention fun.**
- **With a few inexpensive materials, you can build your own d.c. electric motor.**

The instructions describe how to assemble a fully-fledged electrical machine using the most elementary of means. With just a few components and a little handwork, even young students are able to construct and start-up a motor in a matter of minutes.

This ingeniously simple motor consists of just a length of wire, a magnet and the power supply unit. It performs rotary motion in a seemingly mysterious way.

These assembly instructions provide an explanation with the aid of certain physical fundamentals related to electromagnetism.

Work in groups, 3-4 students per group. Each group has to present one well working motor and a description how to assembling this motor (about 3-4 pages). See on the following pages an example.

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Electric generation

1. **Develop a simple motor and improve the design. For a first try see an example at the following pages.**
2. **If your motor is working, develop a student hand out, how to make a motor as your design. Add a**
   - ❑ **Material list,**
   - ❑ **A description how to make (in easy words)**
   - ❑ **A description about the functionality**

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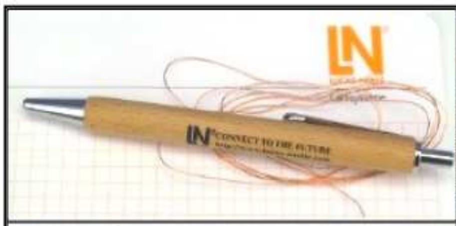
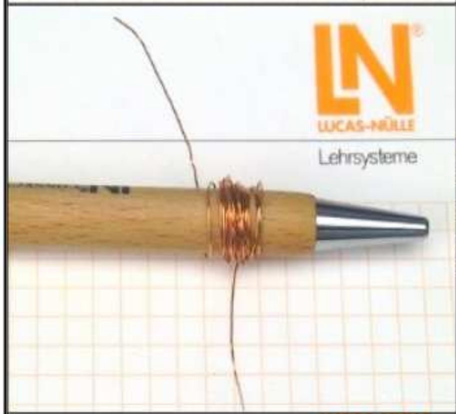
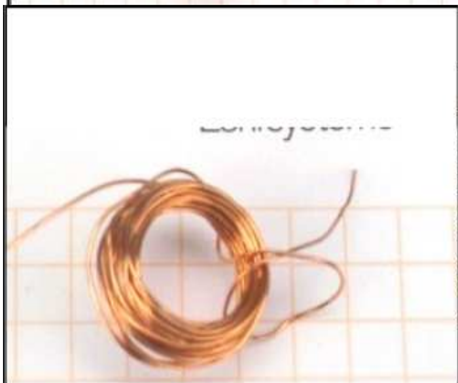
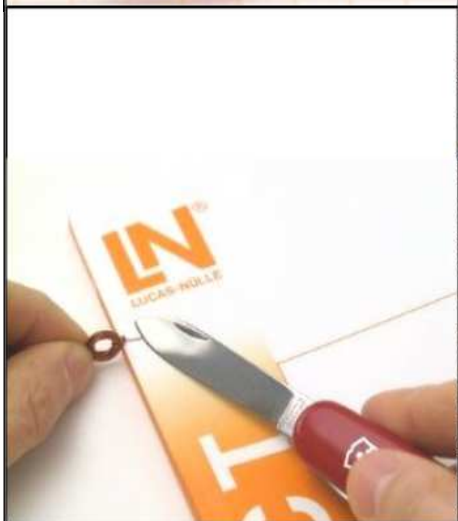
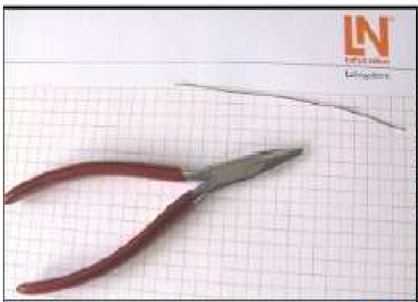
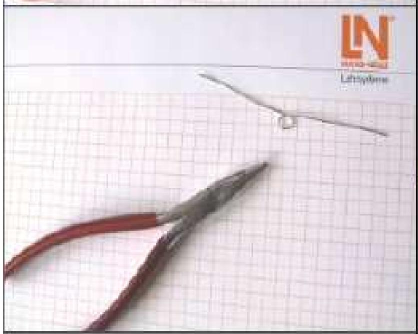
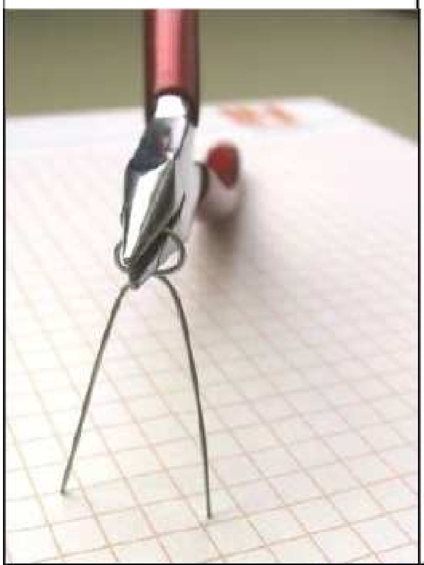
Assembling the rotor

First of all, the rotor is put together. It consists of a coil, and this is the part which will turn later.

	The rotor is made of enamelled copper wire. This requires about 120 cm (plus a spare 30 cm) of this wire.To make the rotor nice and round, we will use a ballpoint pen as a winder. This pen should ideally - but not necessarily - be 8 mm to 12 mm in diameter.
	Wind the wire 25 to 30 times uniformly around the ballpoint pen, letting the ends of the wire protrude by at least 3 cm.Uniform winding only improves appearance, not functionality.
	Carefully slide the winding off the ballpoint pen without deforming it.
	To ensure that the winding retains its shape, firmly wrap both its ends around its body and knot them as shown in the illustration. To further enhance stability, you can fix the knots with super glue or adhesive tape.It is important for the wire ends to be diametrically opposite, because the coil will later turn on the axis formed by these ends.
	Now comes the trick that makes the motor actually work. This step is decisive and the problem lies here in 99% of all cases where the motor later refuses to function. Accordingly, please read and implement the following instructions very carefully.Hold one end of the coil down on a table or preferably at the edge of a book on the table. The coil itself must be positioned upright, not flat. Using a knife, scratch the enamel insulation off the top (but only the top) half of the wire. In this process, turn the coil slightly to and fro so that the entire top half is exposed.The shiny copper surface must be visible where you have scratched off the enamel.Perform the same action on the other end of the wire. On all accounts make sure that both exposed halves face up. If only one of them faces up, the other down, no current will flow and the motor will not turn.

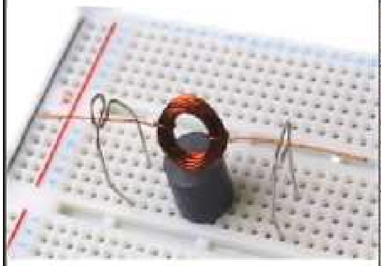
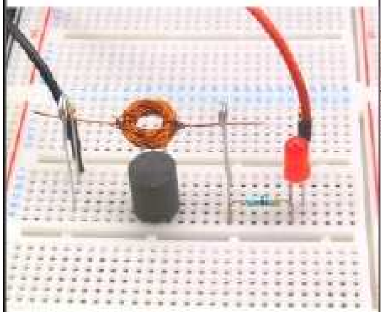
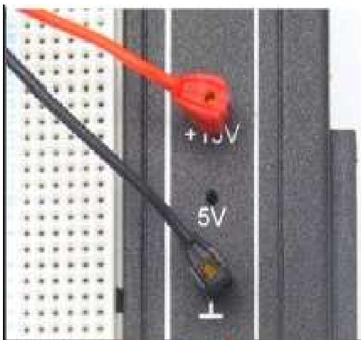
Assembly of the stator and magnet

The next step involves the production of a simple bearing for our rotating coil. As two such bearings are needed for the finished motor, the following procedure needs to be carried out twice:

	We need a section of bare or insulated copper wire approximately 10 cm in length, and a small pair of pliers to shape the wire.Any insulation on the wire first needs to be removed.
	Make a small loop.
	Bend the wire ends down as illustrated. Trim the ends to equal lengths with the pliers' side cutter.
	
	The looped wire should have a total height of 30 to 35 mm plus a slight reserve to allow subsequent trimming if necessary.

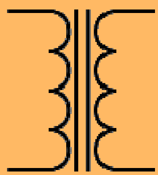
Final assembly and connection to the power supply

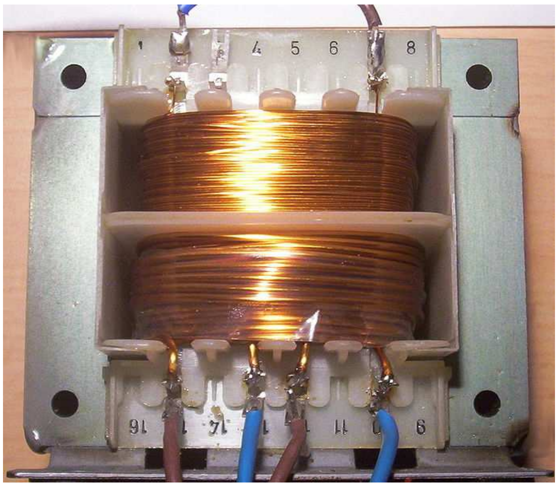
A few further steps are necessary to set the motor in motion.

	As shown in the neighbouring illustration, insert both "bearings" into the breadboard at a mutual spacing of 25 - 30 mm. Mount the rotor in the bearing loops, first inserting one end of the axis, then the other end. After that, align the bearings so that the motor is horizontal.Position the permanent magnet underneath the coil so that it almost touches the coil but still allows it to turn freely. The magnet can also be affixed to the breadboard using double-sided adhesive tape.
	Fit the 47 Ω resistor on the breadboard as shown. • *Although this resistor is not absolutely necessary for the motor to run, it protects LEDs by acting as a current limiter.* Fit the LED on the breadboard as shown, ensuring correct polarity. The flat side of the diode housing should face the resistor. • *An LED is a type of diode and functions like a valve, enabling a flow of current in one direction, disabling it in the other direction.* • *Although the LED is not absolutely necessary for the motor to run, it serves to indicate whether or not a current is flowing. This is especially important in the beginning, in order to establish whether any current is flowing at all via the exposed halves or whether re-work*ing is required here.
	Connect the red and black experiment leads to the 15V power supply as illustrated. If you now turn the rotor slowly with your hand, the LED should come on when the bared wire halves on the rotating coil make contact with the bare loops. Once this contact is interrupted again as the coil turns further, the LED should also go off again. • *If this does not happen, check the polarity of your LED; if necessary, re-finish the exposed wire halves.*
	If you crank the motor now, it should spin at a considerable rate.
Additional experiments	(1) Turn the magnet around. (2) Reverse the polarity of the supply voltage.

transformers

- are static devices that transfers electrical energy from one circuit to another through inductively coupled conductors.
- symbol





A transformer is a static device that transfers electrical energy from one circuit to another through inductively coupled conductors.

A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic field through the secondary winding. This varying magnetic field induces a varying electromotive force (EMF) or "voltage" in the secondary winding. This effect is called mutual induction.

If a load is connected to the secondary, an electric current will flow in the secondary winding and electrical energy will be transferred from the primary circuit through the transformer to the load.

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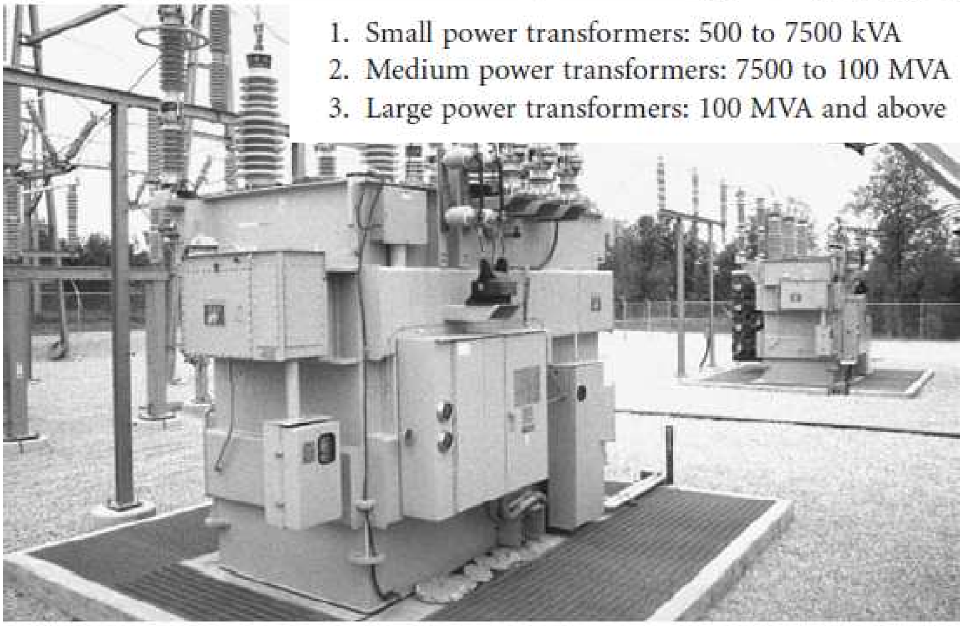
Electric generation

1. Small power transformers: 500 to 7500 kVA
2. Medium power transformers: 7500 to 100 MVA
3. Large power transformers: 100 MVA and above



20 MVA, 161:26.4 × 13.2 kV with LTC, three phase transformers.

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Transformers range in size from a thumbnail-sized coupling transformer hidden inside a stage microphone to huge units weighing hundreds of tons used to interconnect portions of power grids.

All operate with the same basic principles, although the range of designs is wide. While new technologies have eliminated the need for transformers in some electronic circuits, transformers are still found in nearly all electronic devices designed for household voltage.

Transformers are essential for high voltage power transmission, which makes long distance transmission economically practical.

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Electric generation

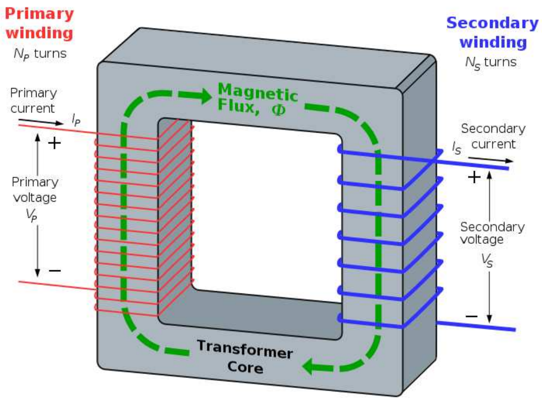
The ideal transformer

- **Does not have any losses**
- **Voltage**

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = a \quad \text{(ratio)}$$

- **current**

$$\frac{N_P}{N_S} = \frac{I_S}{I_P} = a \quad \text{(ratio)}$$



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In an ideal transformer, the induced voltage in the secondary winding (Vs) is in proportion to the primary voltage (Vp), and is given by the ratio of the number of turns in the secondary (Ns) to the number of turns in the primary (Np) as follows:

If the secondary coil is attached to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Ideally, the transformer is perfectly efficient; all the incoming energy is transformed from the primary circuit to the magnetic field and into the secondary circuit. If this condition is met, the incoming electric power must equal the outgoing power:

$$P_{INCOMING} = P_{OUTGOING}$$

The non ideal transformer

- **Ideal :**

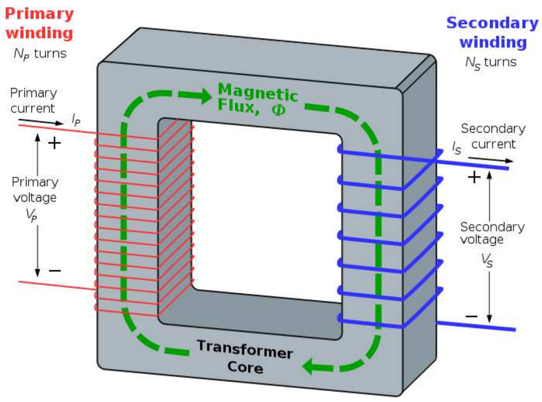
  $$V_P \cdot I_P = V_S \cdot I_S$$

  $$P_P = P_S$$

- **Non ideal**
  losses are divided into losses in the windings, termed copper loss and others.

  $$V_P \cdot I_P \neq V_S \cdot I_S$$

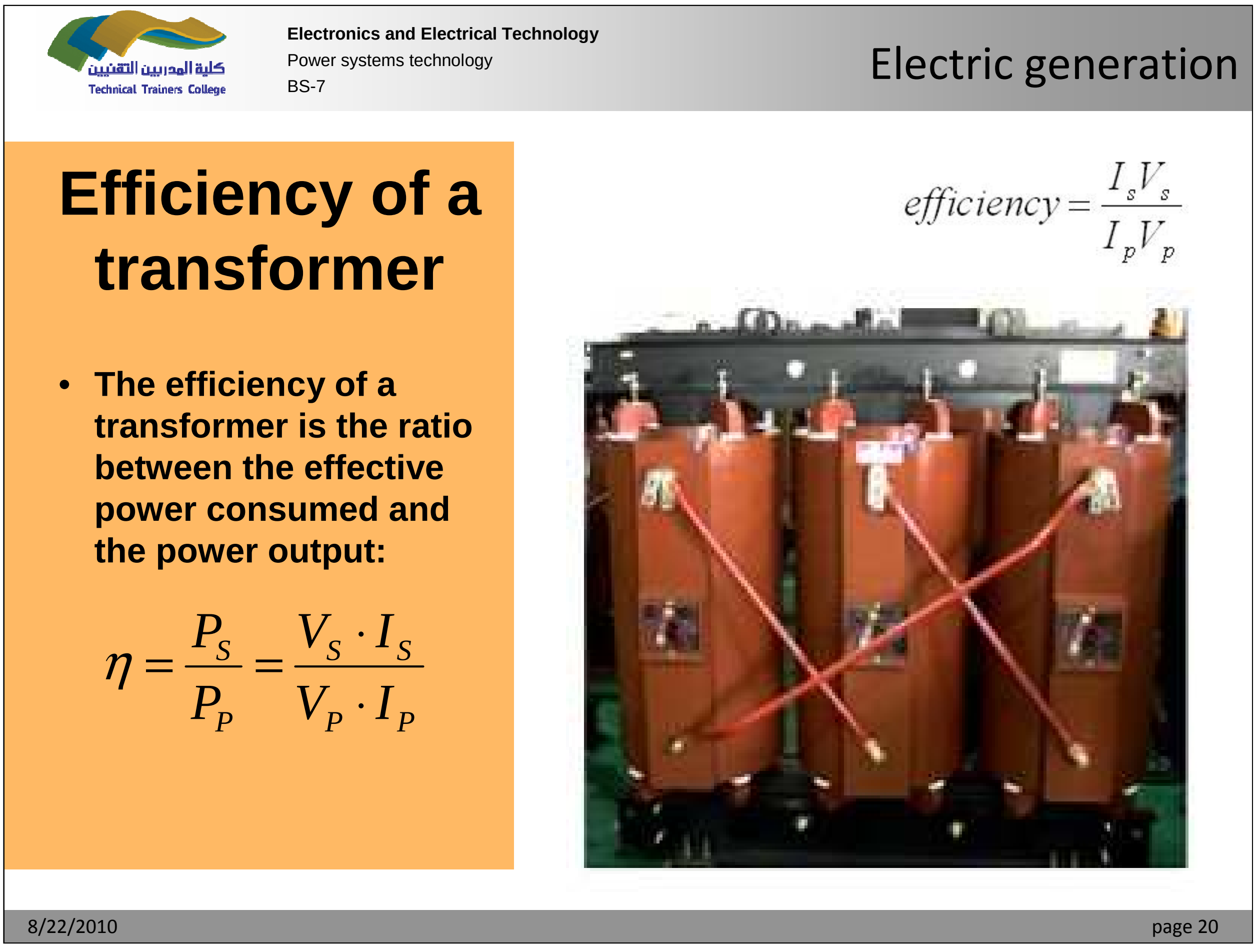
  $$P_P \neq P_S$$



$$P_P > P_S$$

Transformer losses are divided into losses in the windings, termed copper loss, and those in the magnetic circuit, termed iron loss. Losses in the transformer arise from:

Winding resistance
Hysteresis losses
Eddy currents
Mechanical losses
Stray losses



The efficiency of a transformer is the ratio between the effective power consumed and the power output:

$$\eta = \frac{P_S}{P_P}$$

Since every transformer is inevitably subject to some losses, the efficiency is always less than one. The losses are composed of iron losses and winding losses. The efficiency is given by the following equation:

$$\eta = \frac{P_S}{P_P + P_{VFe} + P_{VCu}}$$

The effective power output is derived from the apparent power S as follows:

$$P_S = P_P \cdot \cos\varphi$$

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Electric generation

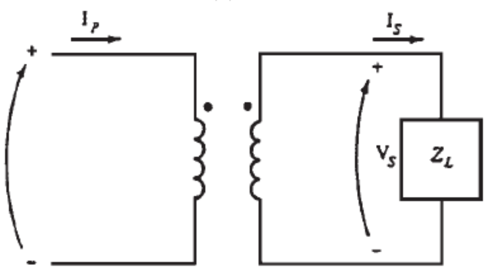
Impedance transformation

- Is the ratio of voltage and current

$$Z_P = \frac{V_P}{I_P} = Z_{L'}$$

Primary impedance

$$Z_P = \frac{{N_P}^2 \cdot Z_L}{{N_S}^2}$$



$$Z_L = \frac{V_S}{I_S}$$

Secondary impedance (load impedance)

$$Z_L = \frac{{N_S}^2 \cdot Z_P}{{N_P}^2}$$

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IMPEDANCE TRANSFORMATION THROUGH A TRANSFORMER

The *impedance* of a device is defined as the ratio of the phasor voltage across it to the phasor current flowing through it.

$$Z_L = \frac{\mathbf{V}_L}{\mathbf{I}_L}$$

Since a transformer changes the current and voltage levels, it also changes the impedance of an element. The impedance of the load shown in Fig. 28.3 (*b*) is

$$Z_L = \frac{\mathbf{V}_S}{\mathbf{I}_S}$$

the primary circuit apparent impedance is

$$Z_L' = \frac{\mathbf{V}_P}{\mathbf{I}_P}$$

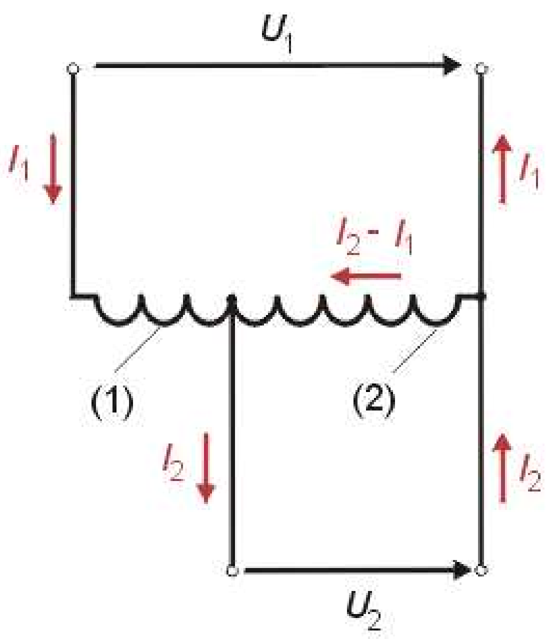
Since the primary voltage and current can be expressed as

$$\mathbf{V}_P = a\mathbf{V}_S \qquad \mathbf{I}_P = \frac{\mathbf{I}_S}{a}$$

Auto transformer

- **special type of transformer in which the primary and secondary windings are actually the same coil.**
- **no electrical isolation between the primary and secondary.**

$$\frac{V_1}{V_2} = \frac{N_{1+2}}{N_2}$$

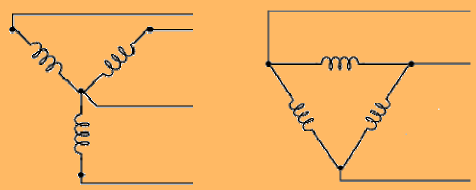


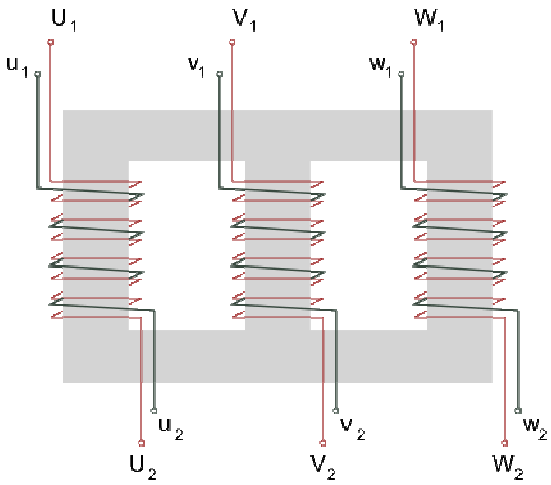
Autotransformers represent a special type of transformer in which the primary and secondary windings are actually the same coil. That means there is no electrical isolation between the primary and secondary. The single coil is arranged in a series circuit with a parallel branch.

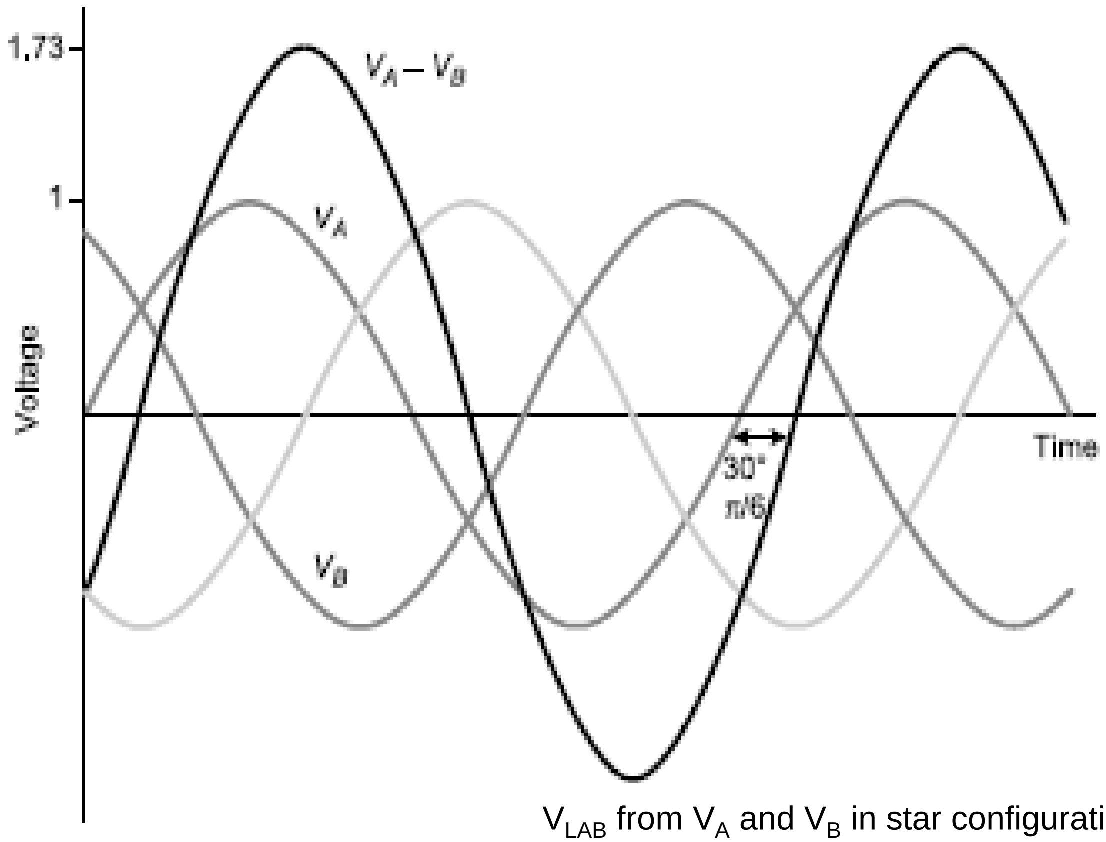
The circuit is reminiscent of a voltage divider using resistors. This similarity is only superficial, though, because the way the circuit works is entirely different. The applied voltage can only be separated into smaller components with a voltage divider, i.e. reduced, whereas an autotransformer also allows the voltage to be increased.

Three phase transformers

- 6 windings,
- 3 primary- and 3 secondary windings
- Delta or star configuration possible



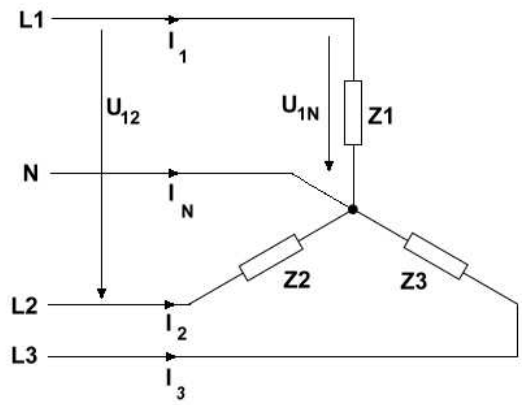




V_{LAB} from V_A and V_B in star configuration

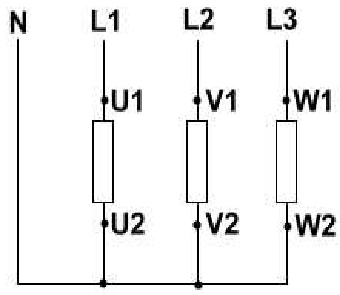
WYE circuit

- If all the phase impedances of Z1, Z2 and Z3 are equal, then the load is said to be symmetrical.
- For a symmetrical load: All the phase voltages are equal and the voltage at the WYE point is zero
- Voltages between two phases are not equal to the phase voltages



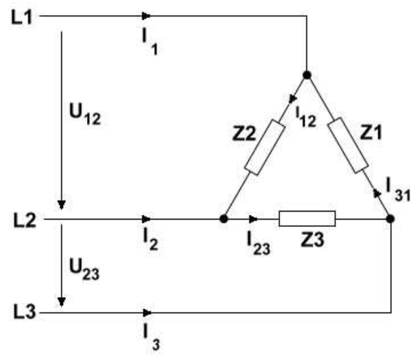
For an asymmetric load, the phase voltages are only equal if a neutral line is connected. Current then flows in the neutral line. If there is no neutral line, the phase voltages will be different and the WYE point will appear when measured to be at a different place because of the measurable voltage between the real WYE point and the neutral.

According to standards, the leading ends of the phase lines of a three-phase consumer are designated U1, V1, W1 and the trailing ends U2, V2, W2.

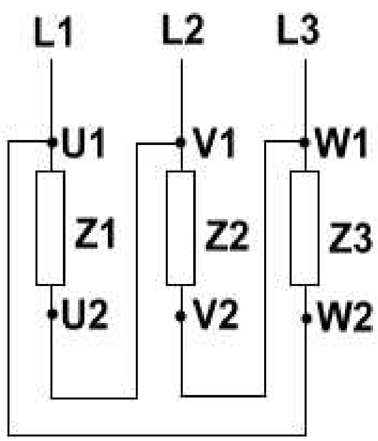


DELTA circuit

- In a delta circuit the phase impedances of the consumer are connected one after the other in a ring or a triangle.
- The outer conductors L1, L2 and L3 are each connected to the ends of two phase impedances.
- Voltages between two phases are taken directly from the phase lines: VL = VP



According to standards, the leading ends of the phase lines of a three-phase consumer are designated U1, V1, W1 and the trailing ends U2, V2, W2. This results in the following connection scheme for a practical delta circuit:



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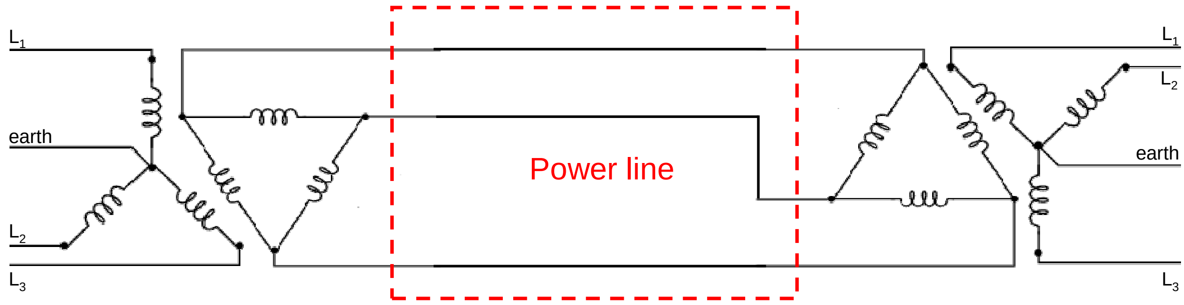
Electric generation

3 phase transformer types

- D is delta winding (mostly capital letter)
- y is wye winding (mostly small letter)
- 5 is phase shift between primary and secondary (times 30º)



$$\frac{V_P}{V_S} = \frac{\sqrt{3} \cdot N_P}{N_S}$$

Yd5
Y to D transformer
150º phase shift

$$\frac{V_P}{V_S} = \frac{N_P}{\sqrt{3} \cdot N_S}$$

Dy5
D to Y transformer
150º phase shift

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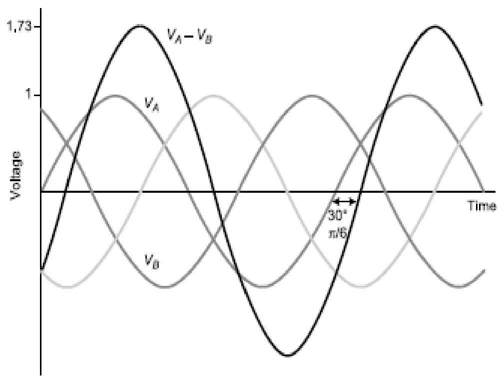
For the Yd5 group, the primary winding is connected in star configuration while the secondary is in delta set-up. One disadvantage of delta circuitry is that the number of windings and the insulation must deal with the entire mains voltage. In addition, the orientation of the secondary voltages need to be carefully observed. Vector groups of this nature are primarily used as machine transformers for coupling a power station generator to the mains.



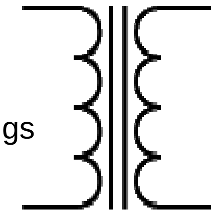
V_{LAB} from V_A and V_B in star configuration

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes

Electric generation

Given is a circuit with an ideal transformer. Determine the primary voltage and the ratio.

1610 windings



84 windings
$12V_{rms}$

Preparation all students: 5 minutes
Presentation results: teacher 3 minutes

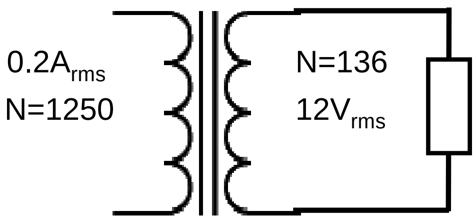
What are the three main divisions of an electric power system?

Preparation all students: 5 minutes
Presentation results: Student, 5 minutes

Electronics and Electrical Technology
Power systems technology
BS-7

Electric generation

Given is a circuit with an ideal transformer. Determine the secondary current and the ratio.



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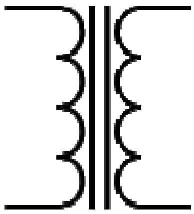
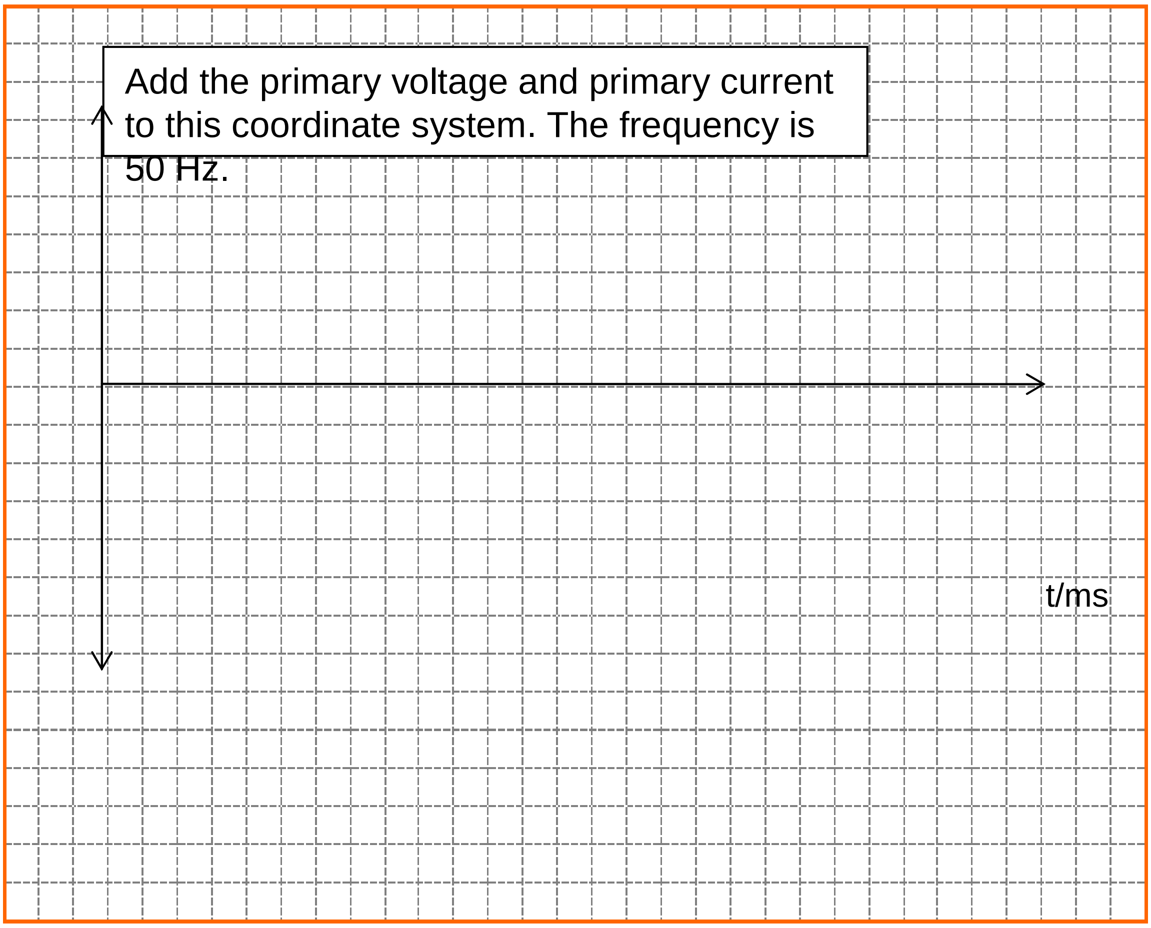
Preparation all students: 15 minutes
Presentation results: Student, 10 minutes, discussion phase shift in RCL circuits

Electric generation

Given is a ideal transformer with no load. What is the phase shift between primary voltage and primary current? Draw the chart.



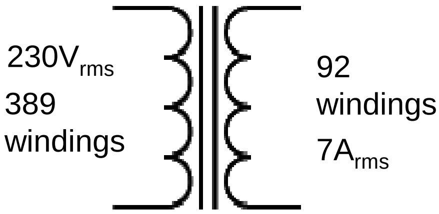
A	Current and voltage are very nearly in phase.
B	The current is about 90° behind the voltage.
C	The current is about 90° ahead of the voltage.
D	The current is about 45° behind the voltage.



Preparation all students: 5 minutes
Presentation results: Student, 5 minutes,

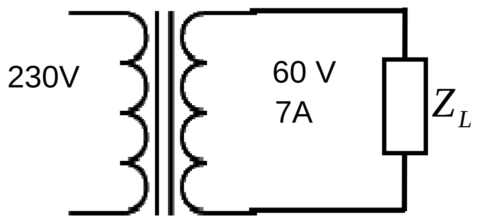
Electric generation

Given is a circuit with an ideal transformer. Determine the secondary voltage, the primary current and the ratio.



Preparation all students: 5 minutes
Presentation results: Student, 5 minutes,

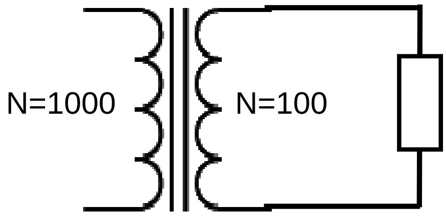
Given is a circuit with an ideal transformer. Determine the primary current, the load impedance and the primary impedance.



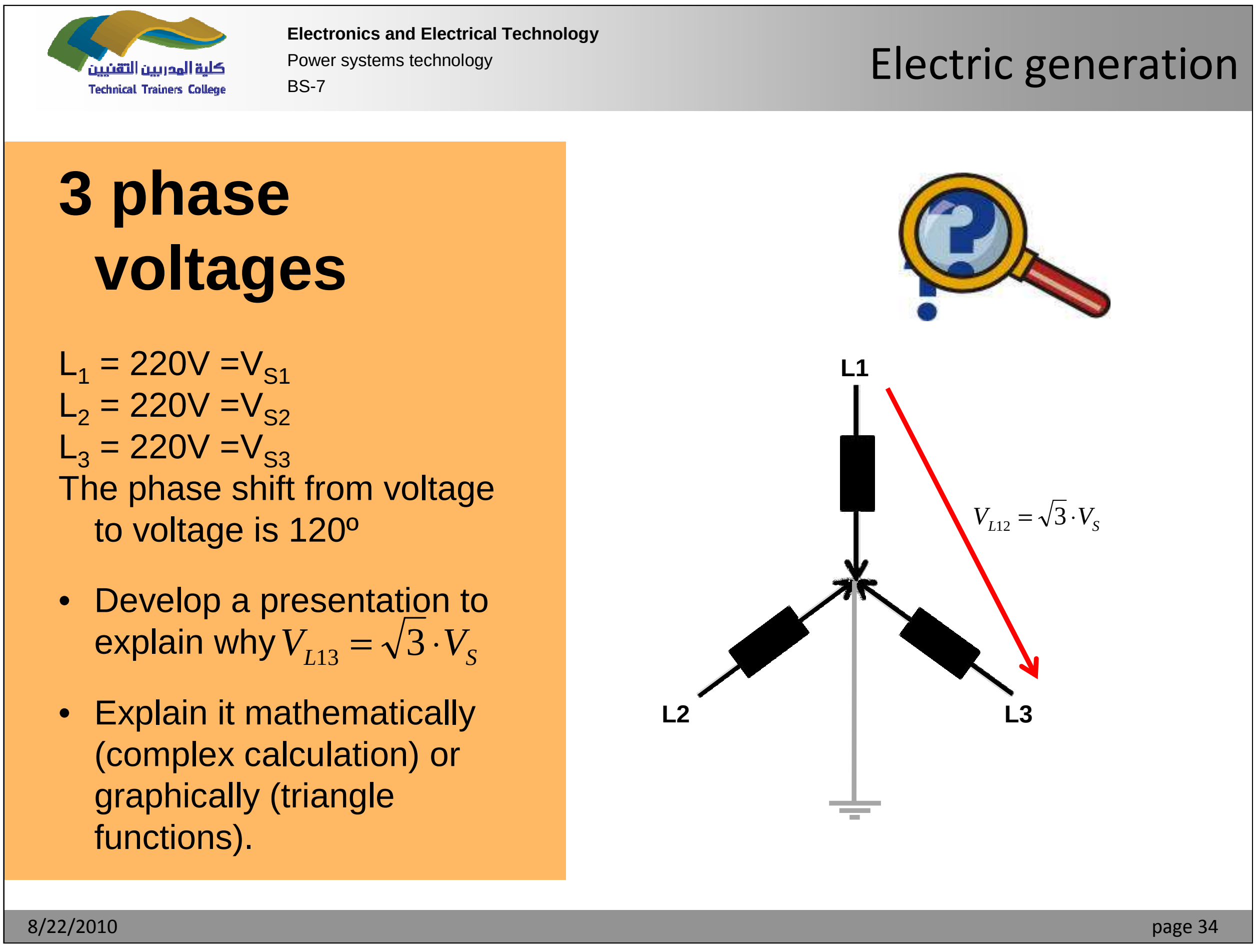
Preparation all students: 5 minutes
Presentation results: Student, 5 minutes,

Electric generation

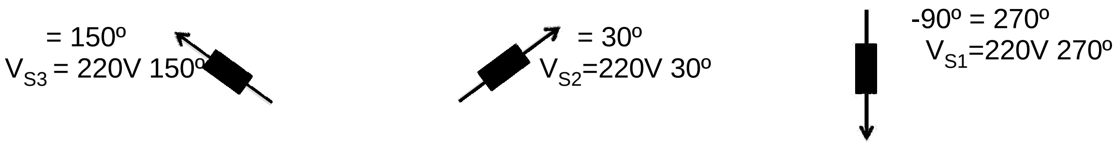
Given is a circuit with an ideal transformer. The load resistance is 100 OHM. Determine the primary impedance.



Preparation all students: 20 minutes, group work
Presentation results: 2 groups, 10 minutes per group,



Mathematically background, example V_{L23}



<u>Difference because, voltages in opposite direction</u>

$$V_{L23} = 220\angle 30^\circ - 220\angle 150^\circ$$

<u>Convert polar coordinates to rectangular coordinates</u>

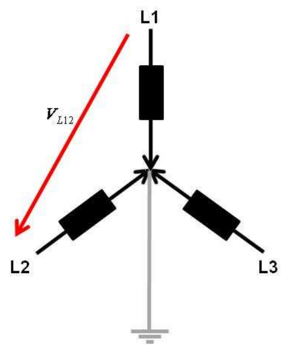
$220\angle 150^\circ$	$220\angle 30^\circ$
$real = 220 \cdot \cos 150^\circ = -190.5$	$real = 220 \cdot \cos 270^\circ = 190.5$
$img = 220 \cdot \sin 150^\circ = 110$	$img = 220 \cdot \sin 270^\circ = 110$

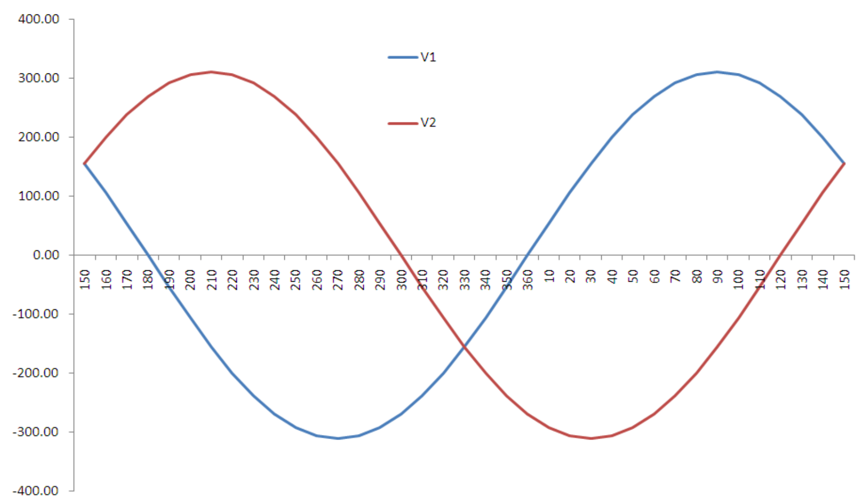
<u>result</u>

$$V_{L23} = (-190.5 + j110) - (190.5 - j110)$$
$$V_{L23} = -381 + j0$$
$$V_{L23real} = \sqrt{r^2 + i^2} = 381V$$
$$V_{L23img} = 0^\circ$$

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

Given a graph with V_{L1} and V_{L2}. The phase shift is 120 degrees (300º-180º). V_{L1} = V_{L2} = 220V. Determine V_{L12} and add it to the graph.

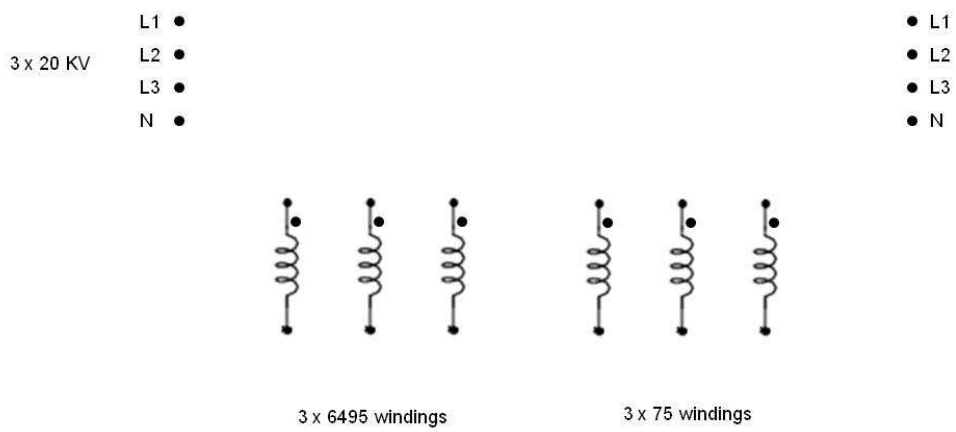




Preparation all students: 15 minutes
Presentation results: Student, 5 minutes,

Given a Dy11 transformer with $V_P = 20KV$.

a)Draw the circuit.
b)Determine the output voltage



V_{LAB} from V_A and V_B in star configuration

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

Given a Yd5 transformer.
V_P = 20KV **N_P = 4320** **V_S = 400V**

Determine the secondary windings.

V_{LAB} from V_A and V_B in star configuration

Preparation all students: 5 minutes
Presentation results: Student, 5 minutes,

Electric generation

Given a Yy0 transformer.

$V_P = 220V$ $N_P = 4320$ $V_S = 220V$

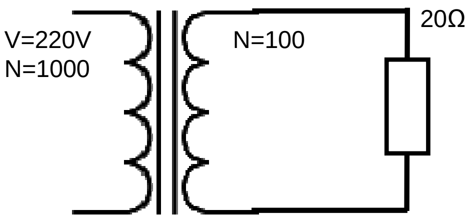
Determine the secondary windings.

V_{LAB} from V_A and V_B in star configuration

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

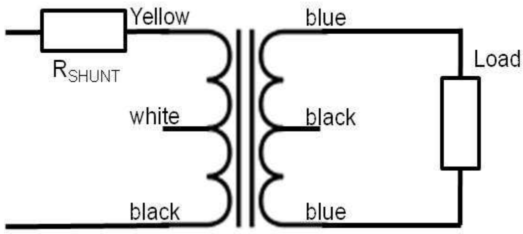
Given a ideal single transformer. A 20 Ω resistor is as a load connected.

a)Determine secondary and primary current.
b)What is the shift in phase between the secondary voltage and secondary current?



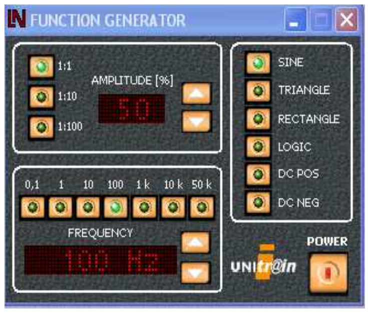
The objective of this exercise is to investigate the functionally of a single phase transformer.

1. Work in groups, each of 2 students and setup the following equipment:

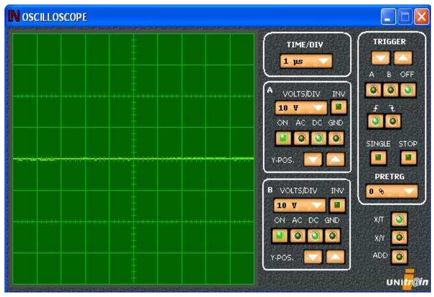


- ❑ Connect the output of the function generator to the primary input yellow and blue in series to a shunt resistor.

	selected value
R_{SHUNT}	47 Ω
R_{LOAD}	not connected
V_{Source}	$8V_{PP}$
frequency	50 Hz



- ❑ Start the oscilloscope to measure the primary voltage V_P with channel A

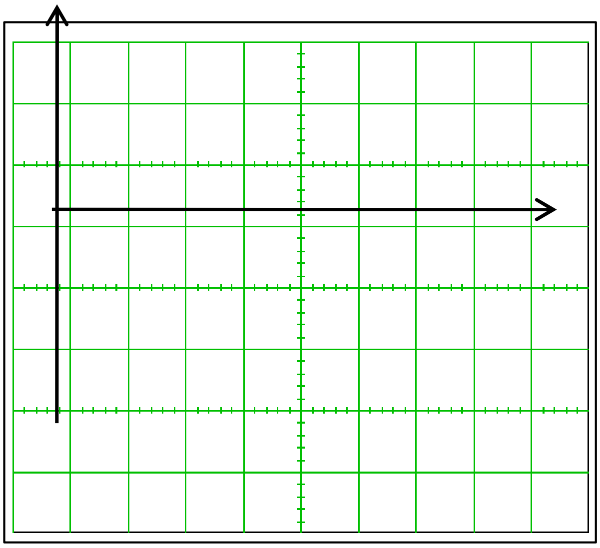


- ❑ Use the channel B to measure the voltage across the shunt resistor.

2. Explain, how you can determine the phase shift between I_P and V_P? What must be the result?

Answer:

The objective of this exercise is to investigate the functionally of a single phase transformer.



3. Measure the phase shift and draw the graph.
4. What is the primary and secondary current with no Load?

	No load connected
I_P	
I_S	

5. Disconnect channel A from the primary winding and connect this channel to the secondary winding, connected to blue – blue. Measure V_S, V_P is still $8V_{PP}$.
6. Determine the ratio of this transformer. What is the secondary voltage, if the primary voltage = 220V? Do not connect 220V! Only calculating!

	No load connected	
V_P	$8V_{PP}$	$220V_{rms}$
V_S		
ratio		

7. Explain with your own words how to determine the efficiency and determine it.

Answer:

Electronics and Electrical Technology
Power systems technology
BS-7

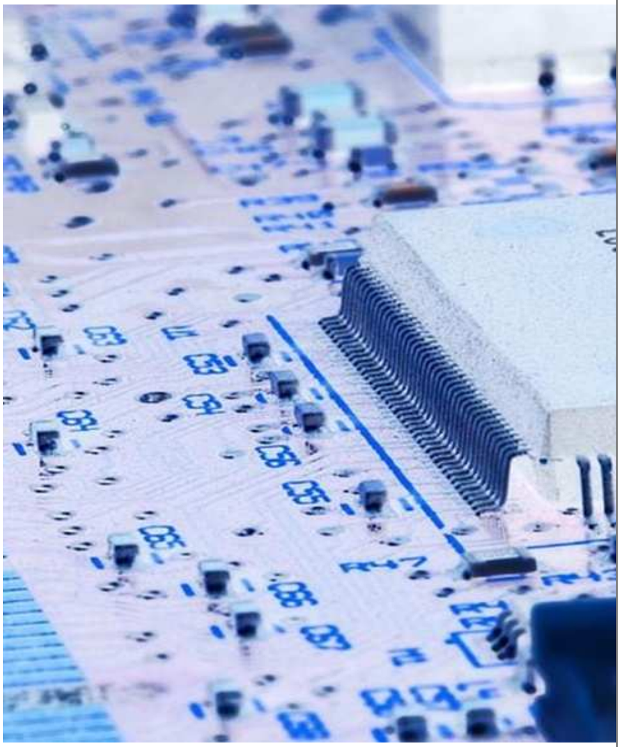
BS-7 power systems technology

Electric generation

Electric transmission

Electric distribution

- introduction
- voltage drop on cables



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Overhead power transmission lines are classified in the electrical power industry by the range of voltages:

Low voltage
less than 1000 volts, used for connection between a residential or small commercial customer and the utility.

Medium Voltage
(Distribution) – between 1000 volts (1 kV) and to about 33 kV, used for distribution in urban and rural areas.

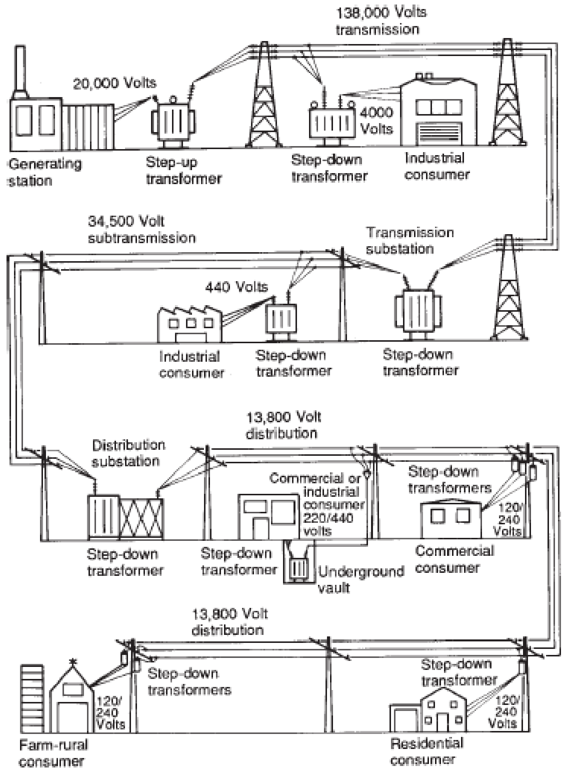
High Voltage
(sub transmission less than 100 kV; sub transmission or transmission at voltage such as 115 kV and 138 kV), used for sub-transmission and transmission of bulk quantities of electric power and connection to very large consumers.

Extra High Voltage
(transmission) – over 230 kV, up to about 800 kV, used for long distance, very high power transmission.

Ultra High Voltage
higher than 800 kV.

Electric transmission

- ❑ **Main transformation**
  69 KV - 750 KV
- ❑ **Sub transformation**
  13.8 KV - 138 KV
- ❑ **Primary distribution**
  2.4 KV - 34.5 KV
- ❑ **Secondary distribution**
  120V - 480V



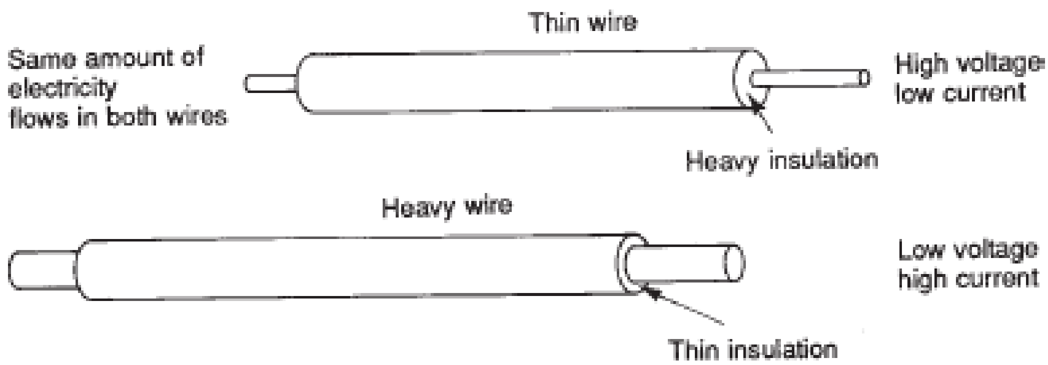
Typical voltage in use

Main Transmission	*Sub Transmission*	*Primary Distribution*	*Distribution Secondary*
69,000 V	13,800 V	2,400 V	120 V
138,000 V	23,000 V	4,160 V	120/240 V
220,000 V	34,500 V	13,800 V	240 V
345,000 V	69,000 V	23,000 V	277/480 V
500,000 V	138,000 V	34,500 V	480 V
750,000 V			

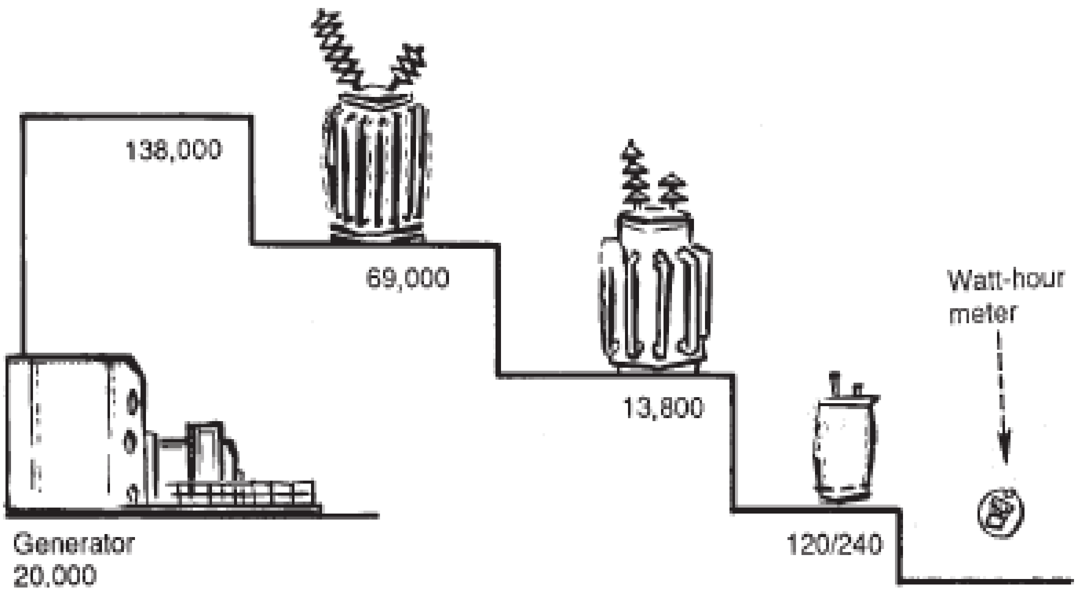
Line characteristics

High voltage:
Low current but heavy insulation

Low voltage:
Thin insulation but high current



There are two general ways of transmitting electric current-overhead and underground. In both cases, the conductor may be copper or



Preparation all students, group work: 20 minutes
Presentation results: 2 groups, 5 minutes per group,

Technical Trainers College
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Electronics and Electrical Technology
Power systems technology
BS-7

Electric transmission

Compare the flow of water in a pipe with that of electric current in a wire. What is the relationship between

- **water pressure and voltage,**
- **Pipe diameter and conductor diameter,**
- **Thickness of pipe and insulation?**

Prepare a presentation. You can use whiteboards, cards or your own PowerPoint presentation.

Prepare a handout for the students.

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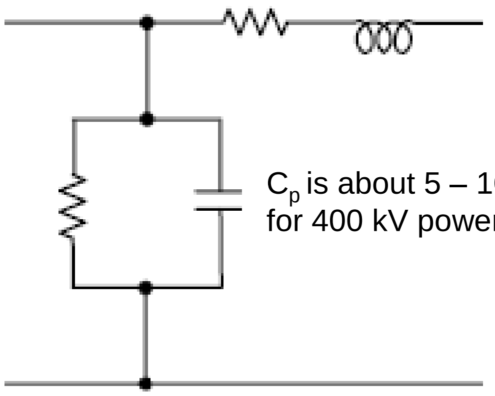
Transmission line modeling

A long line consists:

- **Resistance**
- **Capacitance**
- **inductance**



C_p is about 5 – 10 nF per km for 400 kV power lines

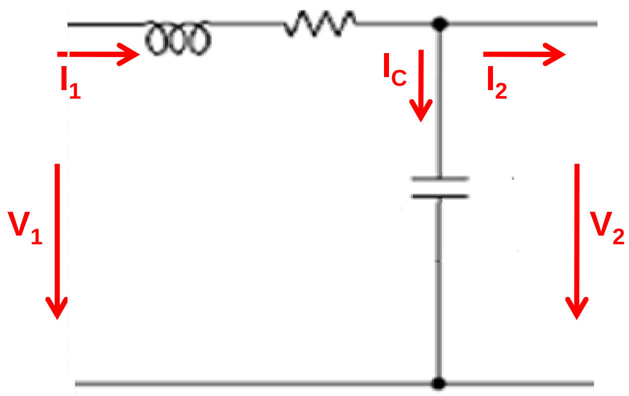
The real component of resistance is primarily determined by the cross section, length and material making up the line.

The inductive reactance results from the frequency together with the inductance L of the wire.

When the line is fully loaded, the effect of the line capacitance is small.

Transmission line modeling with no load.

- Voltage at the end can be larger than at the start
- It may exceed the permitted values



$I_2 = 0$
$I_1 = I_C$

Voltage difference between U_{in} and U_{out}

$$V_\Delta = I_C \cdot R_{LT} = I_C \cdot (R + jX)$$

$$V_{out} = V_{in} + V_\Delta$$

Consider the phase angles

$\underline{I}_2 = 0$, $\underline{I}_{LT} = \underline{I}``_C$ and $\underline{I}_1 = \underline{I}`_C + \underline{I}``_C$

for the currents and

$\underline{U}_Z = \underline{I}_{LT}\,(R+jX) = \underline{I}_{LT} \cdot \underline{Z}$

for the difference in voltage between points 1 and 2.

The qualitative conversion of these equations into a vector diagram is shown in Fig. 4. It can be seen that the voltage at the end, can be larger than at the start and, in some circumstances, it may exceed the permitted values.

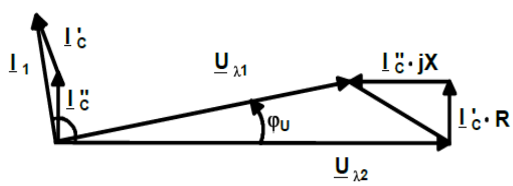
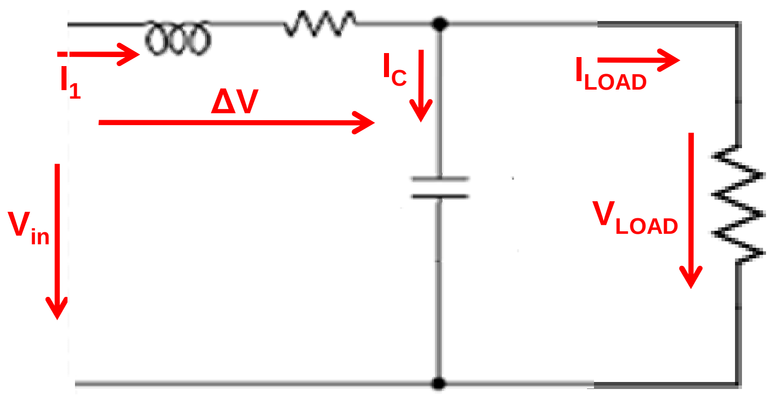


Fig. 1.4 Vector diagram for an unloaded line ($\underline{I}_2$=0)

$\underline{U}_{\lambda 1}$ = Voltage at start of the line
$\underline{U}_{\lambda 2}$ = Voltage at end of the line
$\underline{I}`C$ and $\underline{I}``C$ = Charging currents for the partial capacitances
R = Actual resistance of the line
X = Inductive reactance of the line
$\underline{I}_1$ = Current at the start of the line
φ_U = Phase angle of the voltage

Transmission line modeling with resistor load.

- Voltage at the end of the line is smaller than voltage at start
- Voltage angle is usually less than 5 degrees



$$V_{in} = V_{out} + V_{RLINE} + V_{jXLINE}$$

The vector diagram in Fig. 5 with the current $\underline{I}_2$ in phase with the voltage $\underline{U}_{\lambda 2}$ is obtained from the circuit in Fig. 1 because a purely resistive load is assumed ($\cos\varphi_2 = 1$). Due to the resistance R and the inductive reactance, X in the line, partial voltage $\underline{I}_2 \cdot R$ and an orthogonal voltage $\underline{I}_2 \cdot j\omega L = \underline{I}_2 \cdot jX$, the phase of which is in advance of the real component. According to Kirchhoff`s Laws, the voltage $\underline{U}_{\lambda 1}$ at the start of the line is given by the following equation:

$$\underline{U}_{\lambda 1} = \underline{U}_{\lambda 2} + \underline{I}_2 R + \underline{I}_2 jX$$

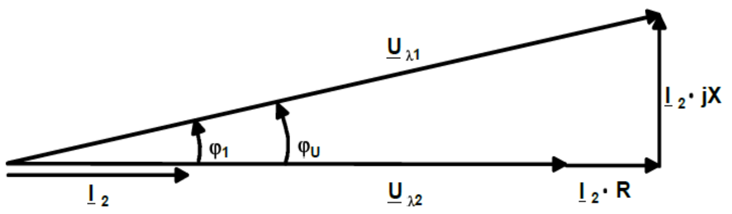
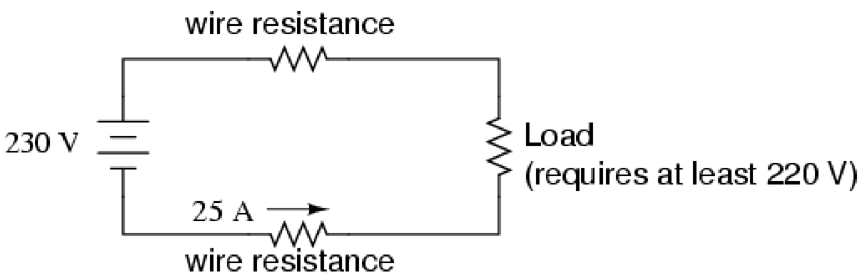


Fig. 1.5 Vector diagram of a line with a real load ($\varphi_2 = 0$), neglecting C_B

$\underline{U}_{\lambda 1}$ = Voltage at start of the line
$\underline{U}_{\lambda 2}$ = Voltage at the end of the line
$\underline{I}_2 R$ = Part-voltage at R of the line
$\underline{I}_2 jX$ = Part-voltage at X of the line
φ_1 = Phase angle, current at the start of the line
φ U = Phase angle of the voltages, $\underline{U}_{\lambda 1}$ and $\underline{U}_{\lambda 2}$; where, $\varphi_1 = \varphi_2$

Wire resistance

The voltage drops resulting from wire resistance may cause an engineering problem.



This intrinsic material property, independent of size or shape, is called resistivity and is denoted by ρ (the Greek lowercase rho).

Aluminum conductors reinforced with steel (known as ACSR) are primarily used for medium and high voltage lines and may also be used for overhead services to individual customers. Aluminum conductors are used as it has the advantage of better resistivity/weight than copper, as well as being cheaper. Some copper cable is still used, especially at lower voltages and for grounding.

While larger conductors may lose less energy due to lower electrical resistance, they are more costly than smaller conductors. An optimization rule called Kelvin's Law states that the optimum size of conductor for a line is found when the cost of the energy wasted in the conductor is equal to the annual interest paid on that portion of the line construction cost due to the size of the conductors. The optimization problem is made more complex due to additional factors such as varying annual load, varying cost of installation, and by the fact that only definite discrete sizes of cable are commonly made.

Wire resistance

- **R** **resistance in Ω**
- **P** **(Greek letter rho) resistivity in Ωmm²/m**
- **l** **Length in m**
- **A** **cross section area of the wire in mm²**

$$R = \rho \cdot \frac{l}{A}$$

material	Resistivity Ωmm²/m
silver	0.0158
copper	0.01786
gold	0.0221
aluminum	0.0286
steel	0.13
lead	0.208
blood	$1.6 * 10^6$
human	$3.3 * 10^7$
water	$1*10^{10}$
glass	$1 * 10^{16}$

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This formula relates the resistance of a conductor with its specific resistance (the Greek letter "rho" (ρ), which looks similar to a lower-case letter "p"), its length ("l"), and its cross-sectional area ("A"). Notice that with the length variable on the top of the fraction, the resistance value increases as the length increases (analogy: it is more difficult to force liquid through a long pipe than a short one), and decreases as cross-sectional area increases (analogy: liquid flows easier through a fat pipe than through a skinny one). Specific resistance is a constant for the type of conductor material being calculated.

The specific resistances of several conductive materials can be found in the following table. We find copper near the bottom of the table, second only to silver in having low specific resistance (good conductivity):

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Power systems technology
BS-7

Electric transmission

Overhead power lines

The voltage drops resulting from wire resistance may cause an engineering problem.

A typical conductor for a 110 kV power line contains

- 7 steel wires in the core with cross section 60 mm^2
- Covers up with 30 aluminum wires with cross section of 257 mm^2

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This intrinsic material property, independent of size or shape, is called resistivity and is denoted by ρ (the Greek lowercase rho).

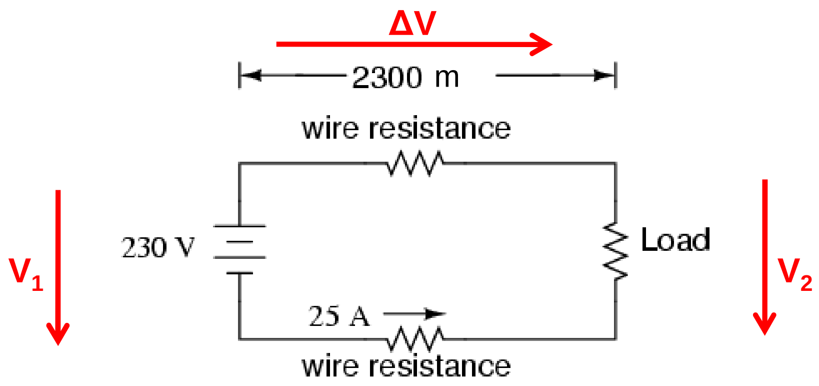
Aluminum conductors reinforced with steel (known as ACSR) are primarily used for medium and high voltage lines and may also be used for overhead services to individual customers. Aluminum conductors are used as it has the advantage of better resistivity/weight than copper, as well as being cheaper. Some copper cable is still used, especially at lower voltages and for grounding.

While larger conductors may lose less energy due to lower electrical resistance, they are more costly than smaller conductors. An optimization rule called Kelvin's Law states that the optimum size of conductor for a line is found when the cost of the energy wasted in the conductor is equal to the annual interest paid on that portion of the line construction cost due to the size of the conductors. The optimization problem is made more complex due to additional factors such as varying annual load, varying cost of installation, and by the fact that only definite discrete sizes of cable are commonly made.

Voltage drop on cables

$$\Delta V = V_1 - V_2$$

$$\Delta V = R_{WIRE} \cdot I = \frac{I \cdot \rho \cdot 2 \cdot l}{A}$$



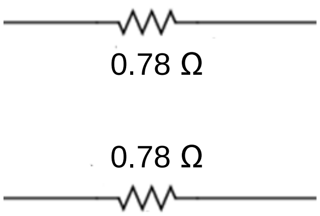
AWG Size	Diameter (Mils)	Cross section (circular mils)	Resistance (ohms/1000 ft) 20 °C		Weight (lb 1000 ft)	
			Copper	Aluminum	Copper	Aluminum
0000	460	211,600	.049	0.080	640.5	195.0
00	365	133,000	.078	0.128	402.8	122.0
0	325	106,000	.098	0.161	319.5	97.0
1	289	83,700	.124	0.203	253.3	76.9
2	258	66,400	.156	0.256	200.9	61.0
3	229	52,600	.197	0.323	159.3	48.4
4	204	41,700	.249	0.408	126.4	38.4
5	182	33,100	.313	0.514	100.2	30.4
6	162	26,300	.395	0.648	79.46	24.1
7	144	20,800	.498	0.817	63.02	19.1
8	128	16,500	.628	1.03	49.98	15.2
9	114	13,100	.792	1.30	39.63	12.0

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

Electric transmission

Given is a 2x700 m long copper wire. The resistance for each wire is 0.78 Ω.

a)Determine the cross section area.
b)Determine the diameter.



Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

Electric transmission

A typical conductor for a 110 kV power line contains 7 steel wires in the core with cross section 60 mm², covers up with 30 aluminum wires with cross section of 257 mm²

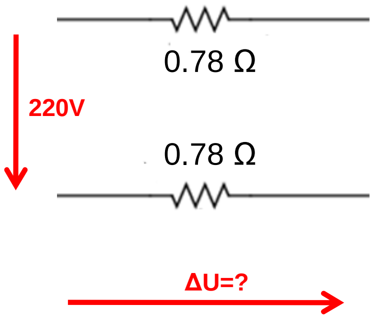
Determine the overall resistance for 150 km

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

Electric transmission

Given is a 2x700 m long copper wire. The resistance of each wire is 0.78 Ω.

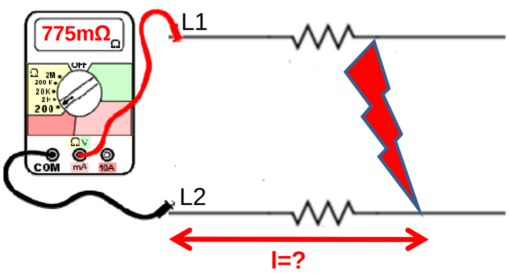
a)Determine the voltage drop, if the current is 12 A.
b)Determine the voltage drop in percent, if the source voltage is 220V.



Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

An $70mm^2$ aluminum earth cable has a short. You measure between L_1 and L_2 775 mΩ.

Where (how far from the measuring point) is the short?



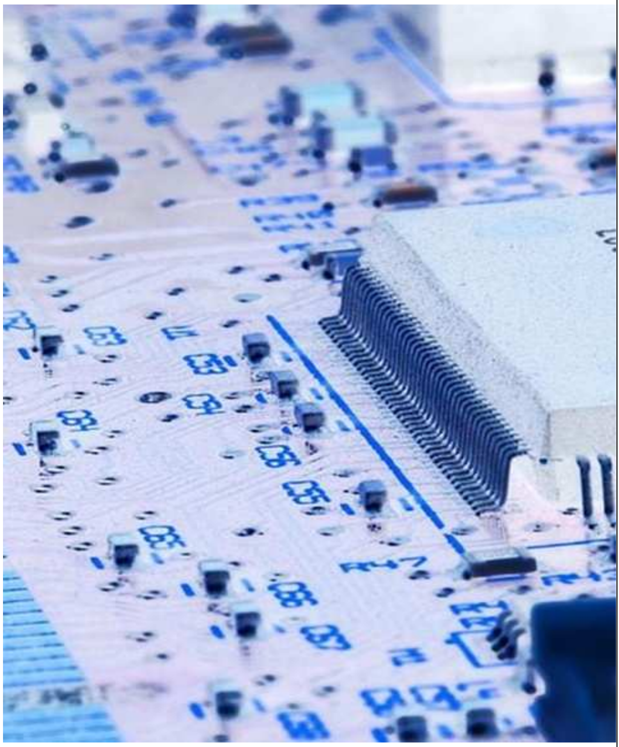
BS-7 power systems technology

Electric generation

Electric transmission

Electric distribution

- TN- TT- and IT schemes
- design of protection



Distribution schemes

- Different schemes how to connect to earth
- International standard of earthing arrangements
- IEC 60364
- using the two-letter codes TN, TT, and IT.

In electricity supply systems, an earthing system defines the electrical potential of the conductors relative to that of the Earth's conductive surface.

The choice of earthing system has implications for the safety and electromagnetic compatibility of the power supply. Note that regulations for earthing (grounding) systems vary considerably among different countries.

Distribution schemes

first letter

connection between earth and the power-supply equipment

second letter

connection between earth and the electrical device

letter	Symbol	description
1st	T	Direct connection of a point with earth
1st	I	No point is connected with earth
2nd	T	Direct connection of a point with earth
2nd	N	Direct connection to neutral at the origin of installation, which is connected to the earth

International standard IEC 60364 distinguishes three families of earthing arrangements, using the two-letter codes TN, TT, and IT.

EARTH (PE)

Ground or earth in an AC power system is a conductor that provides a low impedance path to the earth to prevent hazardous voltages from appearing on equipment. Normally a grounding conductor does not carry current. A protective earth (PE) connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred.

NEUTRAL (N)

Neutral is a circuit conductor that carries current in normal operation, which is connected to earth generally at the service panel with the main disconnecting switch or breaker.

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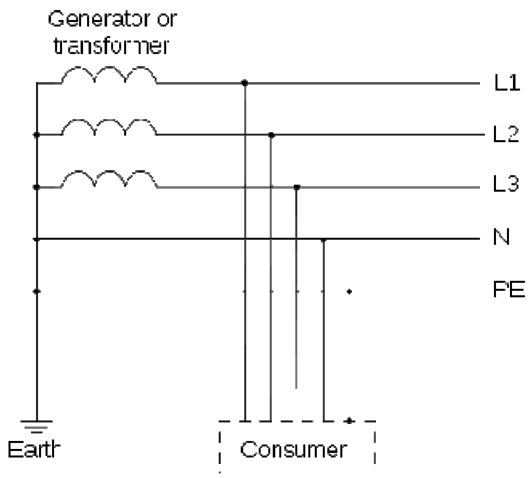
TN network

- one of the points in the generator is connected with earth
- usually the star point in a three-phase system.
- The body of the electrical device is connected with earth via this earth connection at the transformer.



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In a TN earthing system, one of the points in the generator or transformer is connected with earth, usually the star point in a three-phase system. The body of the electrical device is connected with earth via this earth connection at the transformer.

The conductor that connects the exposed metallic parts of the consumer is called protective earth (PE). The conductor that connects to the star point in a three-phase system, or that carries the return current in a single-phase system, is called neutral (N). Three variants of TN systems are distinguished:

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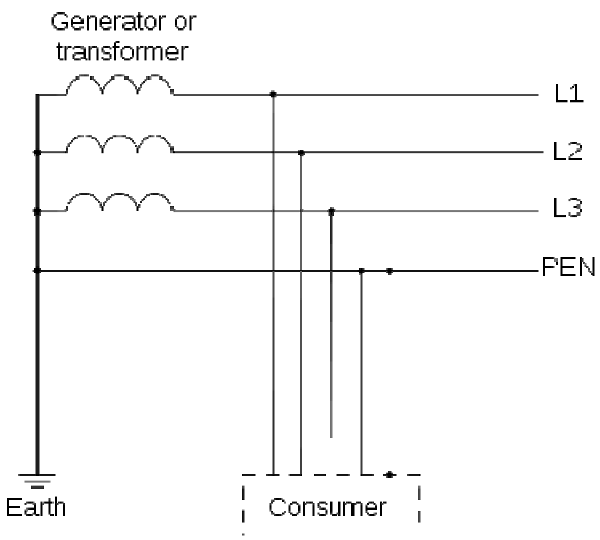
TN network

TN−S
PE and N are separate conductors

TN−C
A combined PEN conductor

TN−C−S
Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines.



TN-C network

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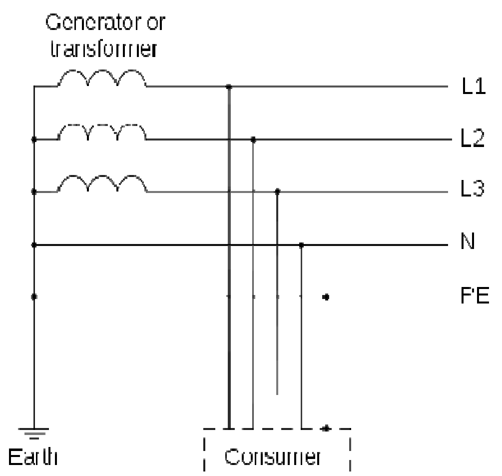
TN−S

PE and N are separate conductors that are connected together only near the power source.

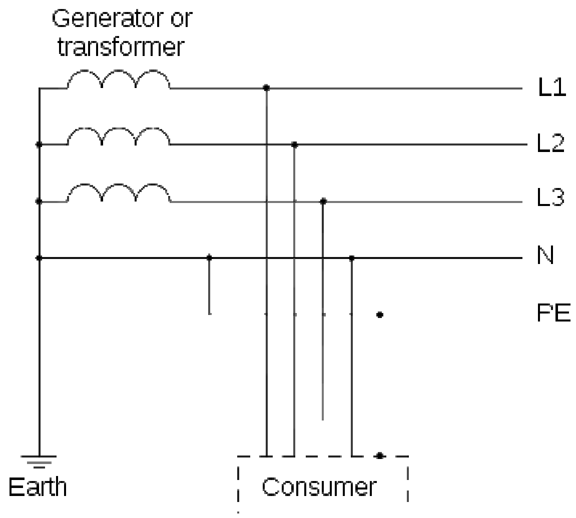


TN−C

A combined PEN conductor fulfills the functions of both a PE and an N conductor. Rarely used.

TN-C-S network

- Part of the system uses a combined PEN conductor
- is at some points split up into separate PE and N lines.
- separate PE and N conductors in fixed indoor wiring and flexible power cords



TN-C-S network

TN-C-S

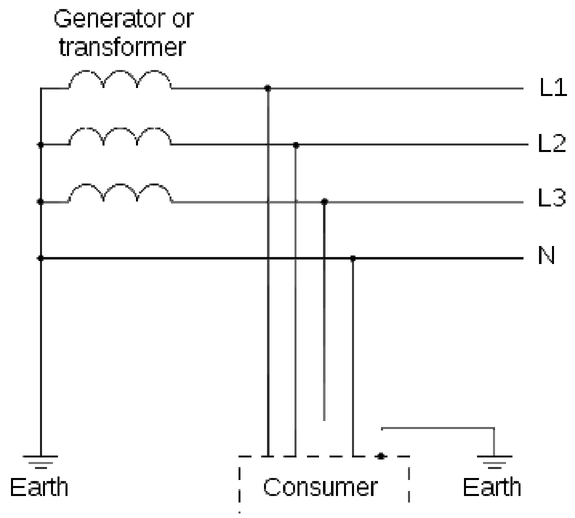
Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines.

The combined PEN conductor typically occurs between the substation and the entry point into the building, and separated in the service head.

In the UK, this system is also known as protective multiple earthing (PME), because of the practice of connecting the combined neutral-and-earth conductor to real earth at many locations, to reduce the risk of broken neutrals - with a similar system in Australia being designated as multiple earthed neutral (MEN).

TT network

- protective earth connection of the consumer is provided by a local connection to earth
- TT does not have the risk of a broken neutral.
- Only 4 wires from transformer to consumer



TT network

TT

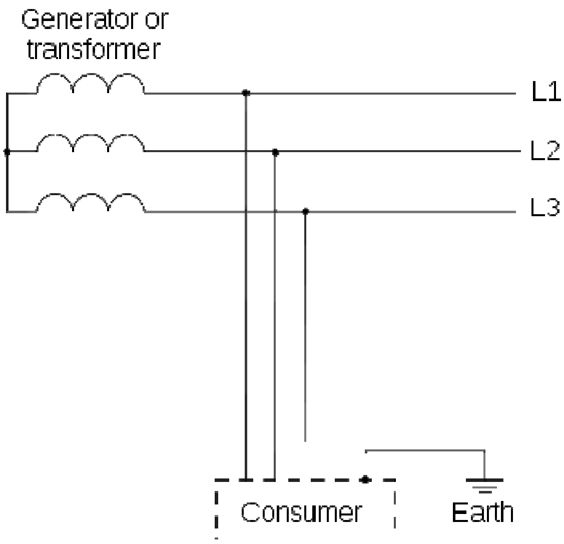
In a TT earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection at the generator.

TT does not have the risk of a broken neutral.

In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

IT network

- the distribution system has no connection to earth at all
- For safety reasons this network is not accepted under European norms.



IT network

TT

In a TT earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection at the generator.

TT does not have the risk of a broken neutral.

In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

Protection - fuses

- Fuses for overcurrent. A fuse interrupts excessive current so that further damage by overheating or fire is prevented.
- The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made.

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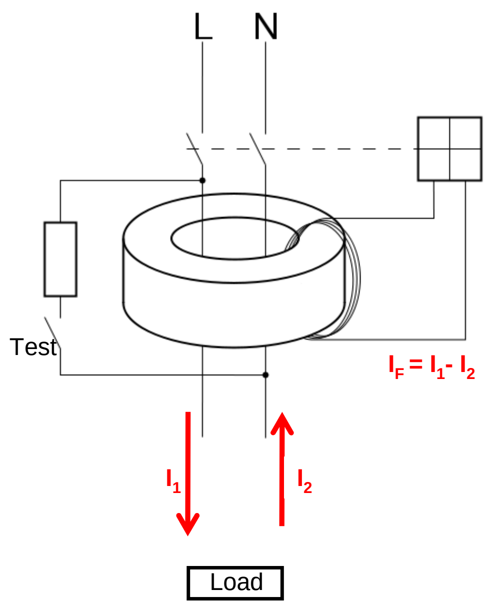
A fuse is a type of sacrificial overcurrent protection device. Its essential component is a metal wire or strip that melts when too much current flows, which interrupts the circuit in which it is connected. Short circuit, overload or device failure is often the reason for excessive current.

A fuse interrupts excessive current so that further damage by overheating or fire is prevented. Wiring regulations often define a maximum fuse current rating for particular circuits. Overcurrent protection devices are essential in electrical systems to limit threats to human life and property damage. Fuses are selected to allow passage of normal current and of excessive current only for short periods.

A fuse was patented by Thomas Edison in 1890 as part of his successful electric distribution system.

Protection - RCD

- Residual Current Device
- detecting the leakage current
- typically for 5–30 mA
- operate within 25-40 ms
- operate by measuring the current balance between two conductors using a differential current transformer.

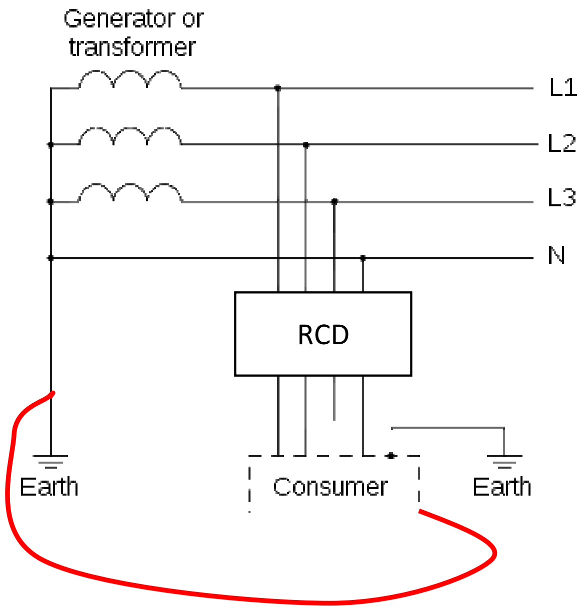


RCDs operate by measuring the current balance between two conductors using a differential current transformer. This measures the difference between the current flowing out the live conductor and that returning through the neutral conductor.

If these do not sum to zero, there is a leakage of current to somewhere else (to earth/ground, or to another circuit), and the device will open its contacts.

RCDs in TT networks

- Residual Current I_F depends on
  - contact voltage and
  - earthing resistance
- If the resistance to ground to big, the RCD is not working well.



$$I_F = U_C / R_{EARTH}$$

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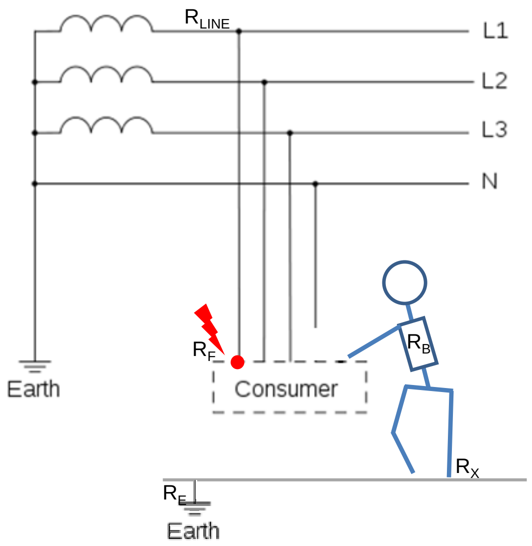
Direct body contact

The residual current is Line voltage divided by summary of all resistors

Resistance	description
R_{LINE}	
R_F	
R_B	
R_X	
R_E	

Exercise: Fill in the table

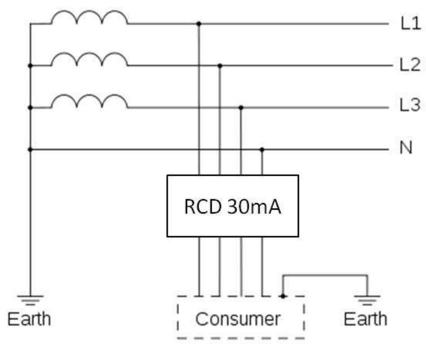


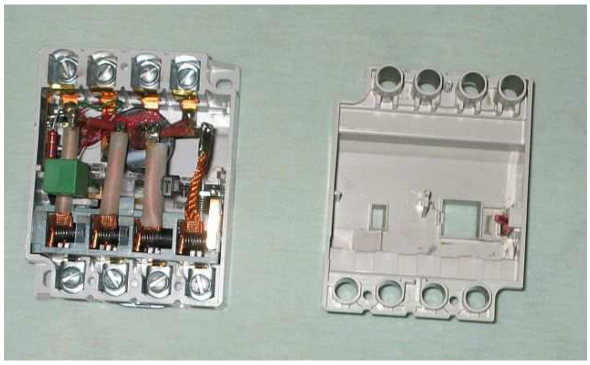
$$I_F = U_{Line} / (R_{Line} + R_F + R_B + R_X + R_E)$$

Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

In a TT network a RCD with I_F = 30 mA is working. The maximum contact voltage has to be 50V.

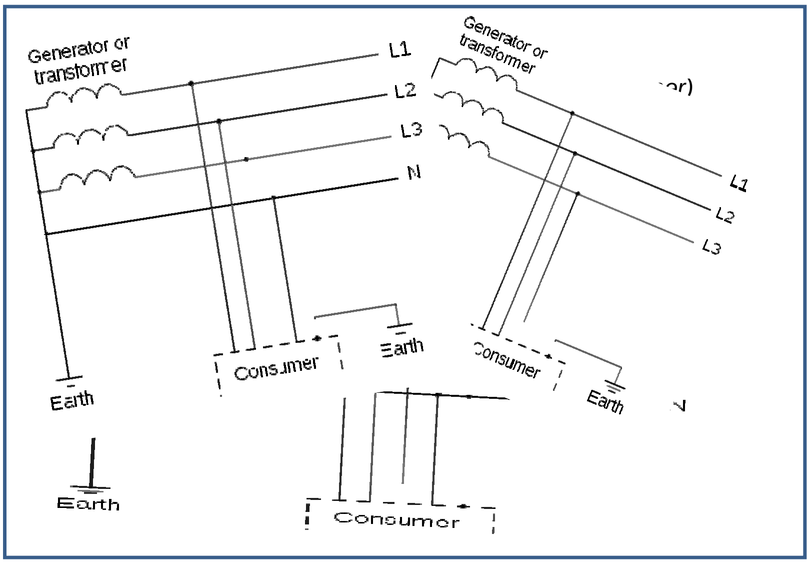
Determine the maximal earth resistance.





Preparation all students: 5 minutes
Presentation results: Student, 5 minutes,

Explain the abbreviations for the different types of mains networks (1st letter, 2nd letter, 3rd letter).



Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

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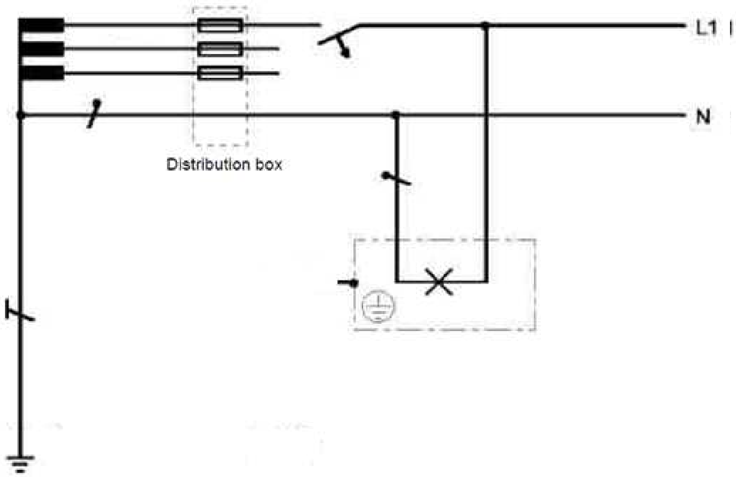
Complete the following TT mains network diagram.



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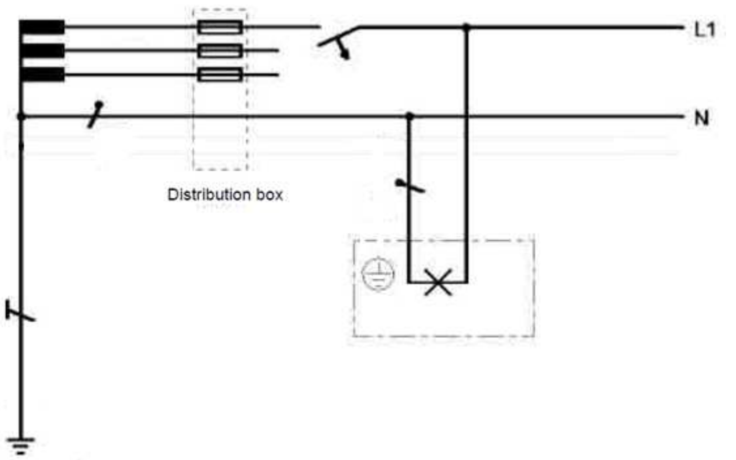
Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

Complete the following TN-S mains network diagram.



Preparation all students: 5 minutes
Presentation results: Student, 5 minutes,

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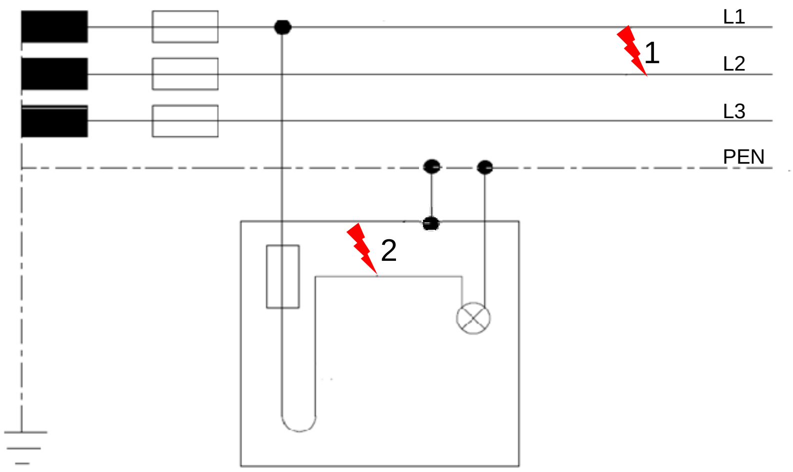
a) What is the name of this Network?

b) Which Fuse blows, if at point 1 a short?

c) Which Fuse blows, if at point 2 a short?



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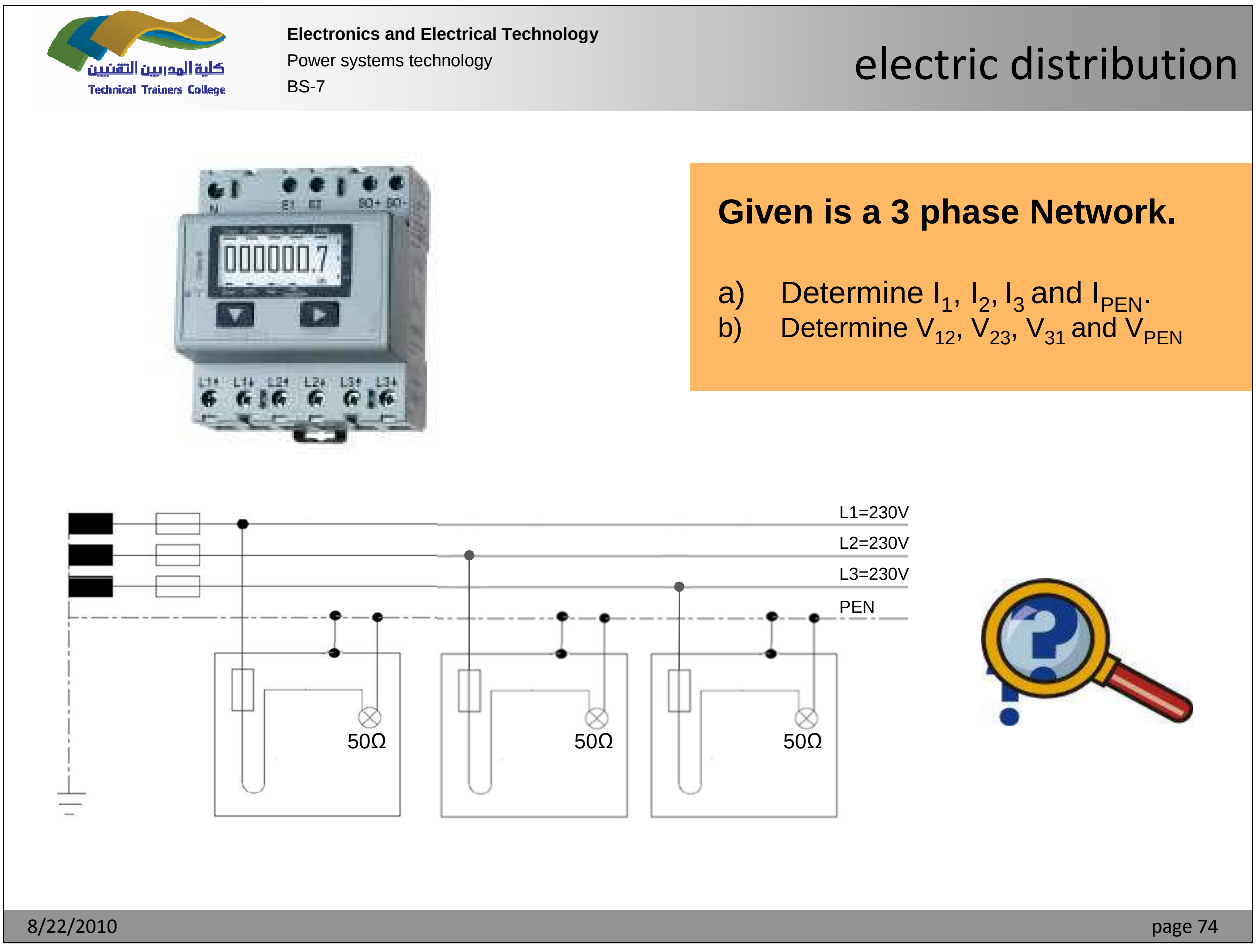
Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,



A fuse is a type of sacrificial overcurrent protection device. Its essential component is a metal wire or strip that melts when too much current flows, which interrupts the circuit in which it is connected. Short circuit, overload or device failure is often the reason for excessive current.

A fuse interrupts excessive current so that further damage by overheating or fire is prevented. Wiring regulations often define a maximum fuse current rating for particular circuits. Overcurrent protection devices are essential in electrical systems to limit threats to human life and property damage. Fuses are selected to allow passage of normal current and of excessive current only for short periods.

A fuse was patented by Thomas Edison in 1890 as part of his successful electric distribution system.

Preparation all students: 15 minutes
Presentation results: Student, 10 minutes,

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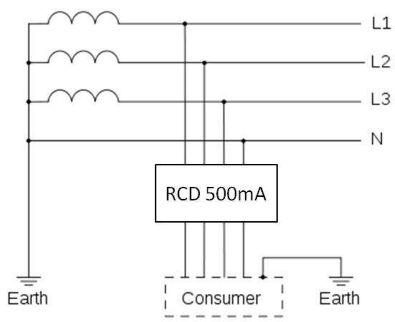
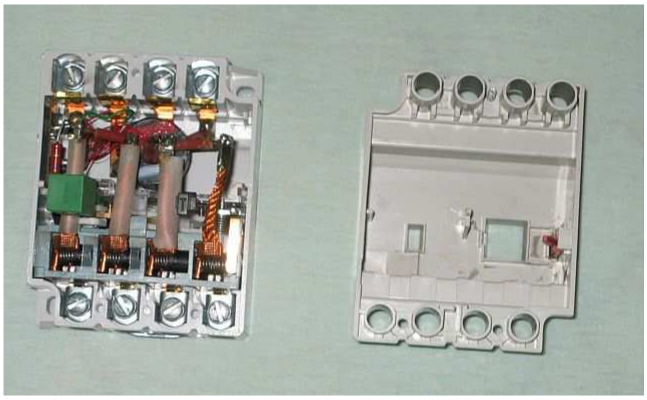
In a TT network a RCD with I_F = 500 mA is working. At 50V contact voltage the I_F is 0.34A.

a)Determine the real earth resistance.
b)Determine the necessary earth resistance for 50V U_C.



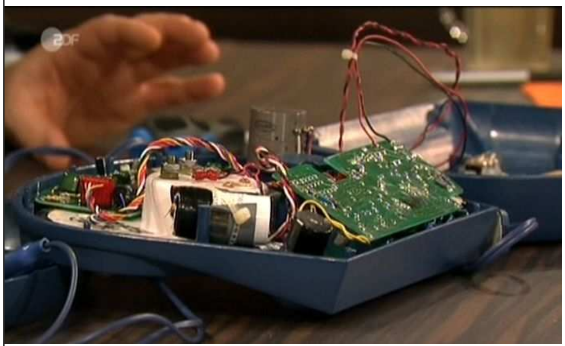


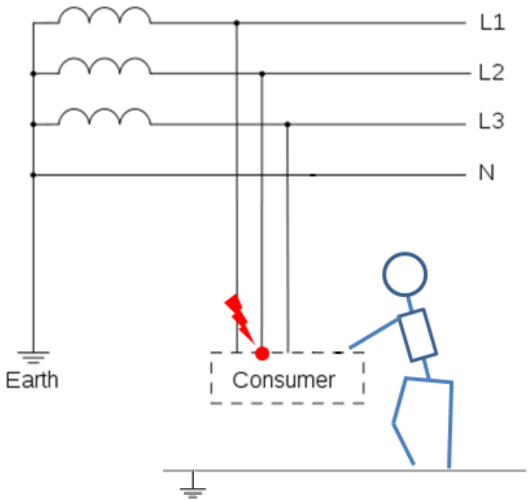
Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

electric distribution

The 230V consumer is not connected to the earth. A person touch this defective device.

Determine the current through the human
$R_{LINE}=2\Omega$, $R_F=100\Omega$, $R_X=3.9k\Omega$ $R_B=1\ k\Omega$, $R_E=48\Omega$





Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

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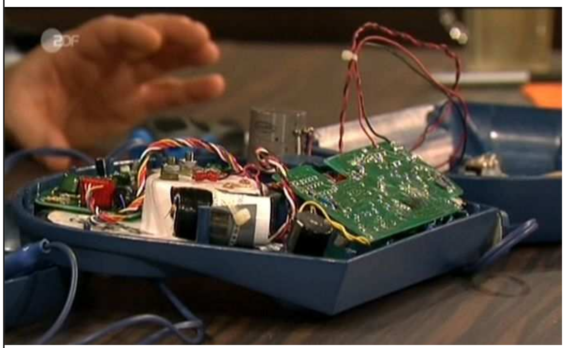
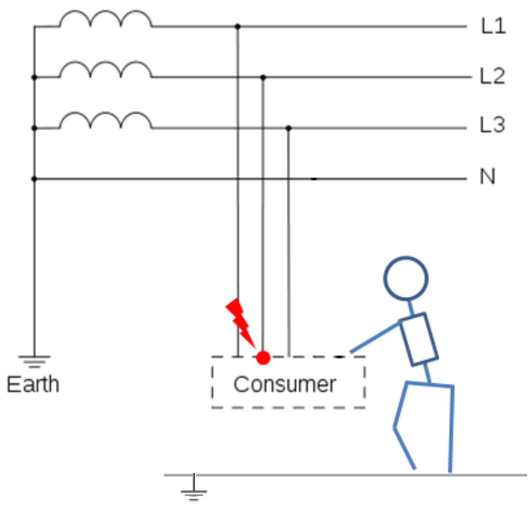
The 230V consumer is not connected to the earth. A person touch this defective device. The voltage across the human is 25V.

Determine the current through the human and the resistance to ground. $R_{LINE}=1\Omega$, $R_F=100\Omega$, $R_B=1.2\ k\Omega$, $R_E=69\Omega$





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Preparation all students: 10 minutes
Presentation results: Student, 5 minutes,

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Draw the circuit of a 3 phase TN-C network. Connect as load a simple lamp to L_1 and a 3 phase motor. Protect the loads with fuses.

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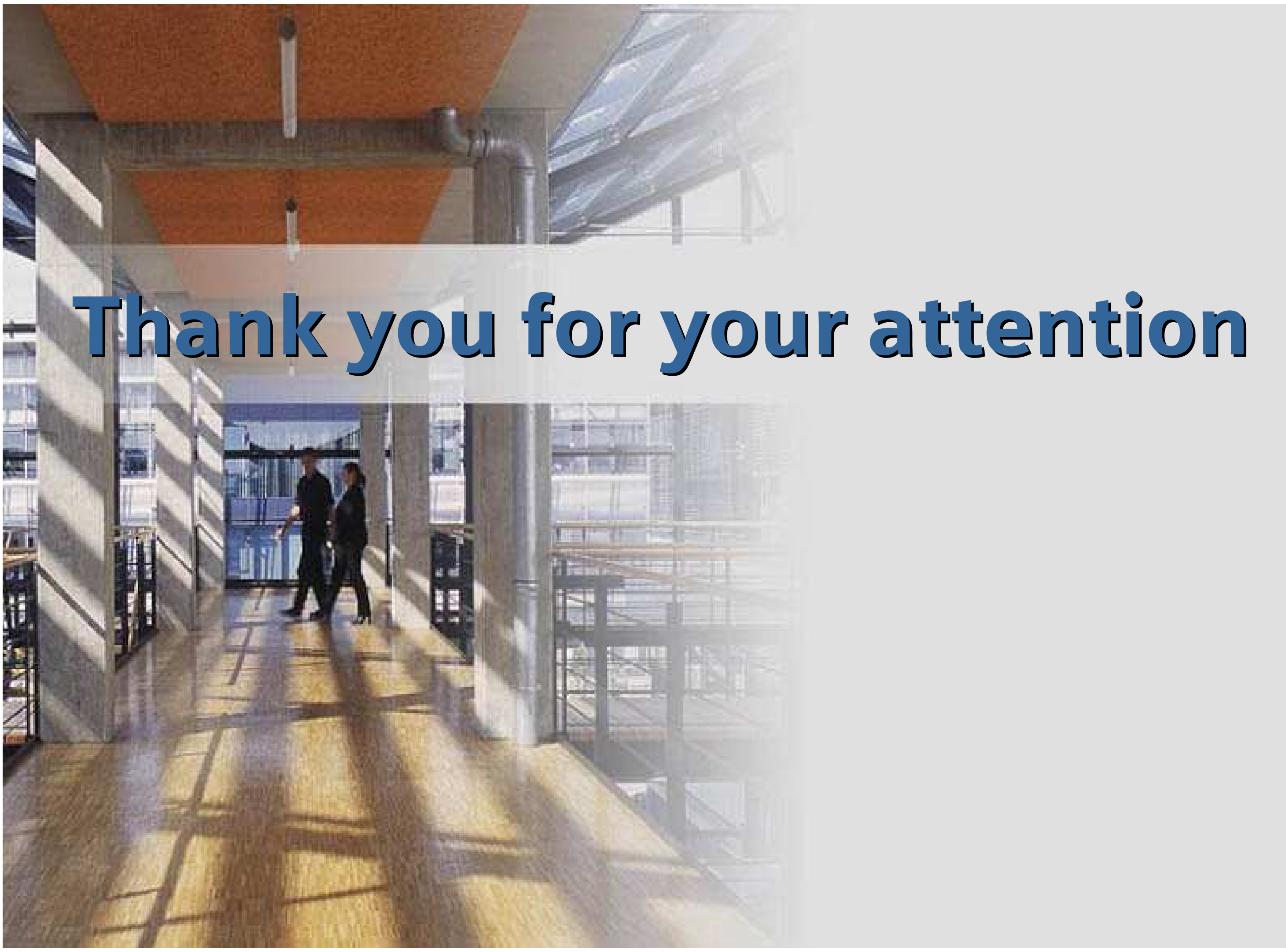

Thomas Hitzner
Dipl. Engineer, MBA
Germany