ELEC-E8422 Introduction to Electrical Energy Systems

Electrical Safety

Matti Lehtonen

Why are birds not electrocuted while sitting on power line?

Electrical Safety

THE EFFECTS OF 50 OR 60 Hz CURRENT:

Detection limit
- \- about 1 mA can be detected

Reactions in muscles
- \- about 3-5 mA causes uncontrolled reactions

Control of muscles lost
- \- around 10-12 mA muscular conrol is lost

Respiratory tetanus
- \- around 15-25 mA

Heart Fibrillation at higher currents. Limit value depends on the time exposed.

Other effects on human body

The mechanisms

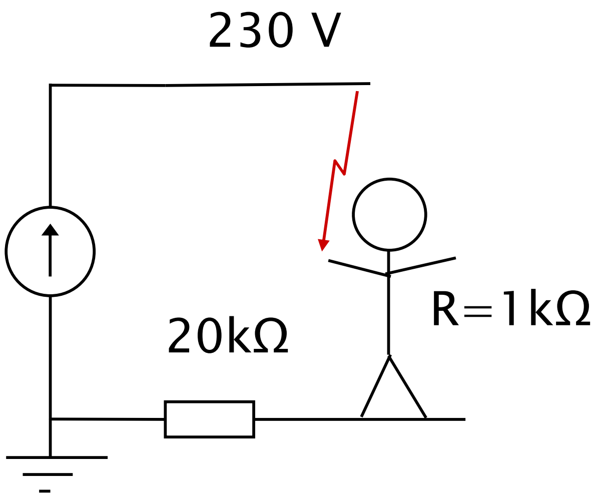
- Combustion
- Changes in blood
- Heart fibrillation

The 10% and 1% probability current of heart fibrillation

Time t/s	$I_{10\%}$ / mA	$I_{1\%}$ / mA
> 5	60	40
5	80	50
2	150	80
1	400	150
0,75	500	200
0,5	700	300
0,3	1000	500
0,15	1150	650

Example of an electrical shock

A person gets in touch with power system 230 V voltage.
The resistance between floor he/she is standing and system
Neutral (= earth) is 20 kΩ. Body resistance is 1 kΩ, including also
Contact between feet and floor. How big is the current thru the
Person? Consequences?

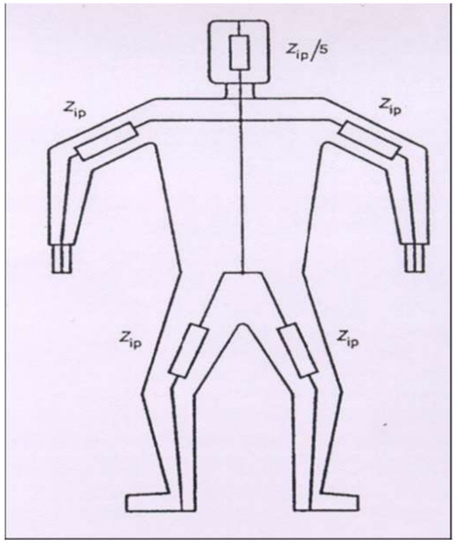


Thevenin´n menetelmä

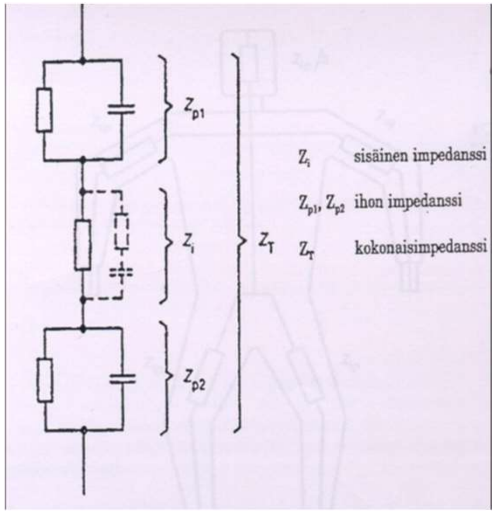
$$I = \frac{U_{Th}}{R + R_{Th}}$$

$$I = \frac{230\ V}{(1+20)\ k\Omega} \sim 11\text{mA}$$

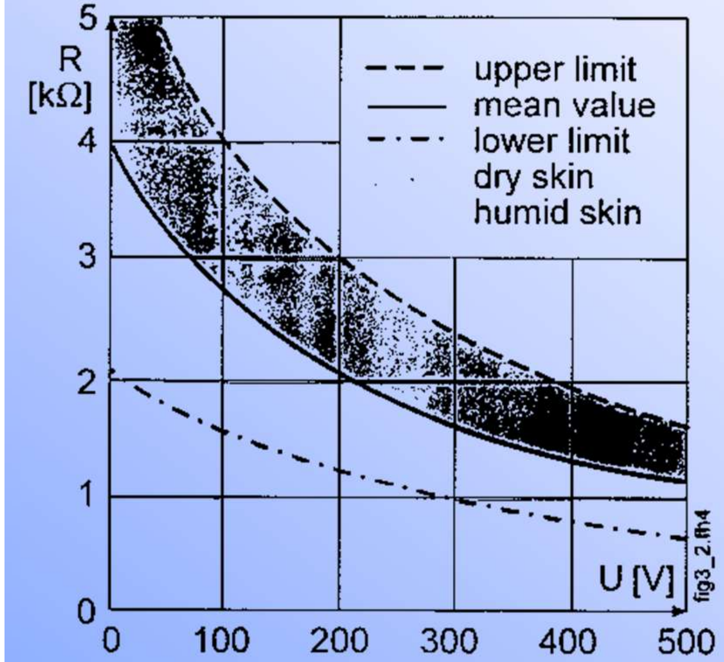
Electrical Safety

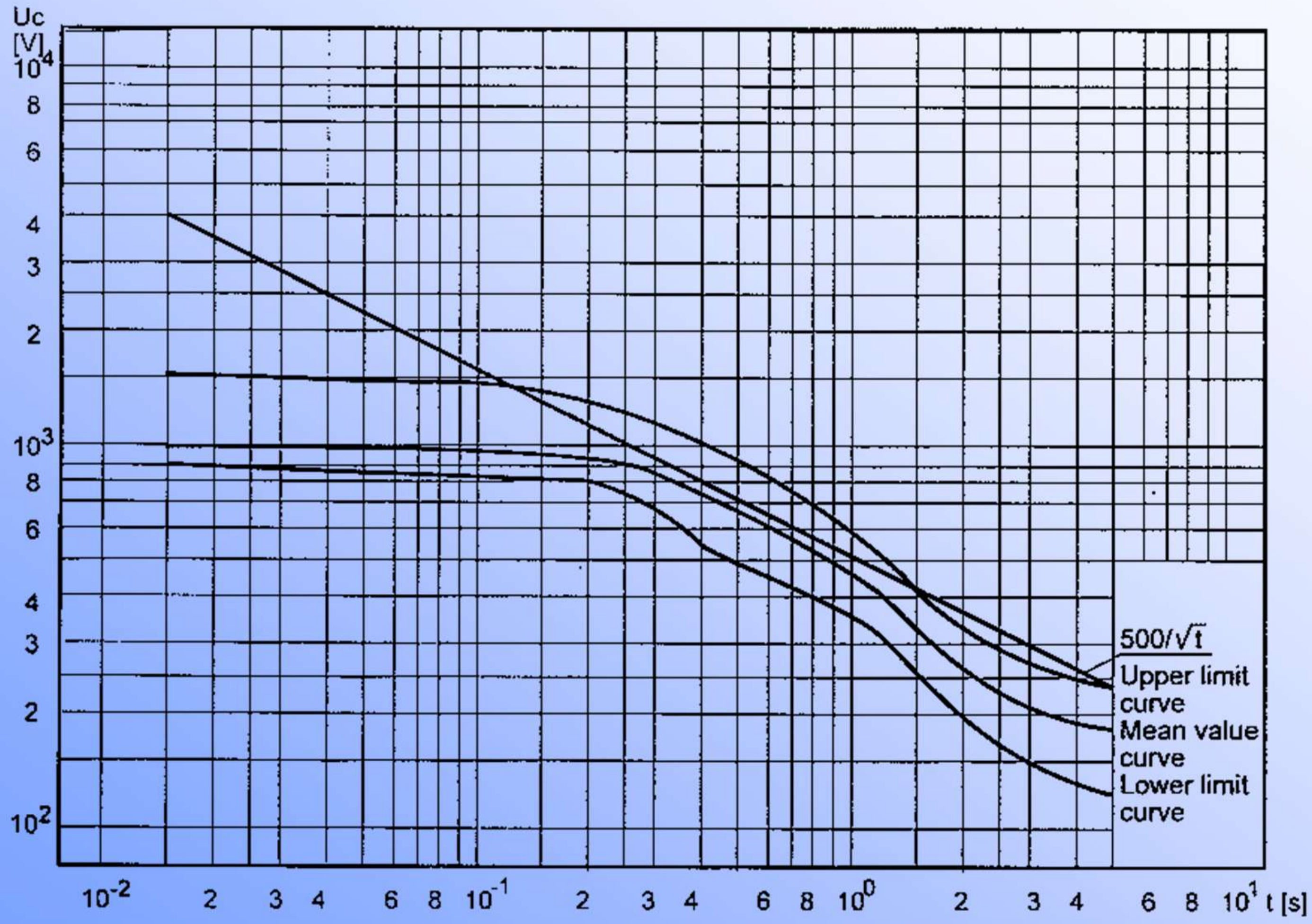


- The hazard of electricity depends on **current** and the its **duration**, as well as on the **path** current was flowing.
- The body impedance is non-linear and depends on voltage applied.
- Skin, blood, muscles, bones, etc have different resistivity. The body can be modeled by a combination of resistances and capacitances. In the Figure, Zi is the body internal impedance, Zp1 & Zp2 and skin impedances.



Body resistance at various voltages

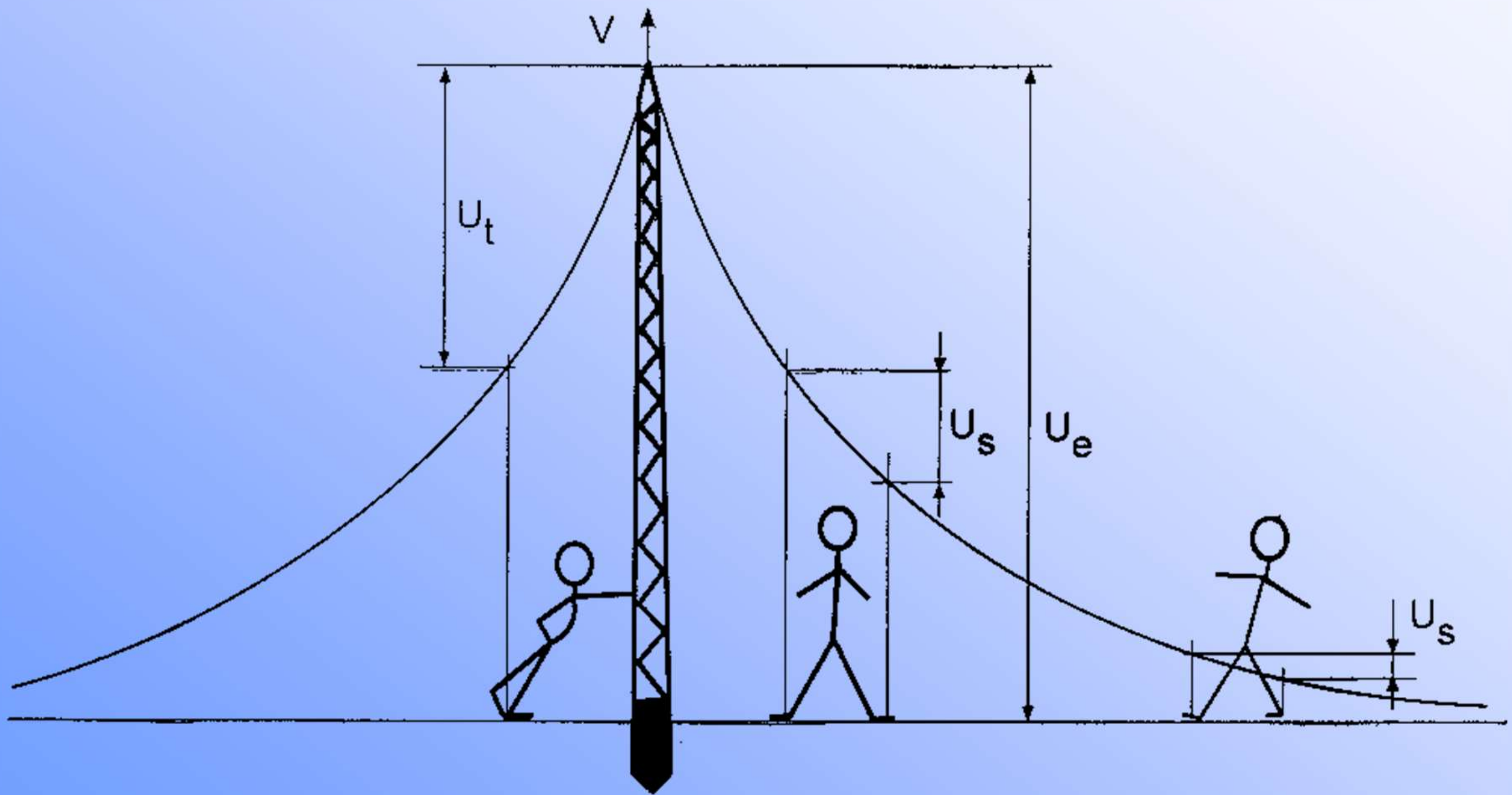




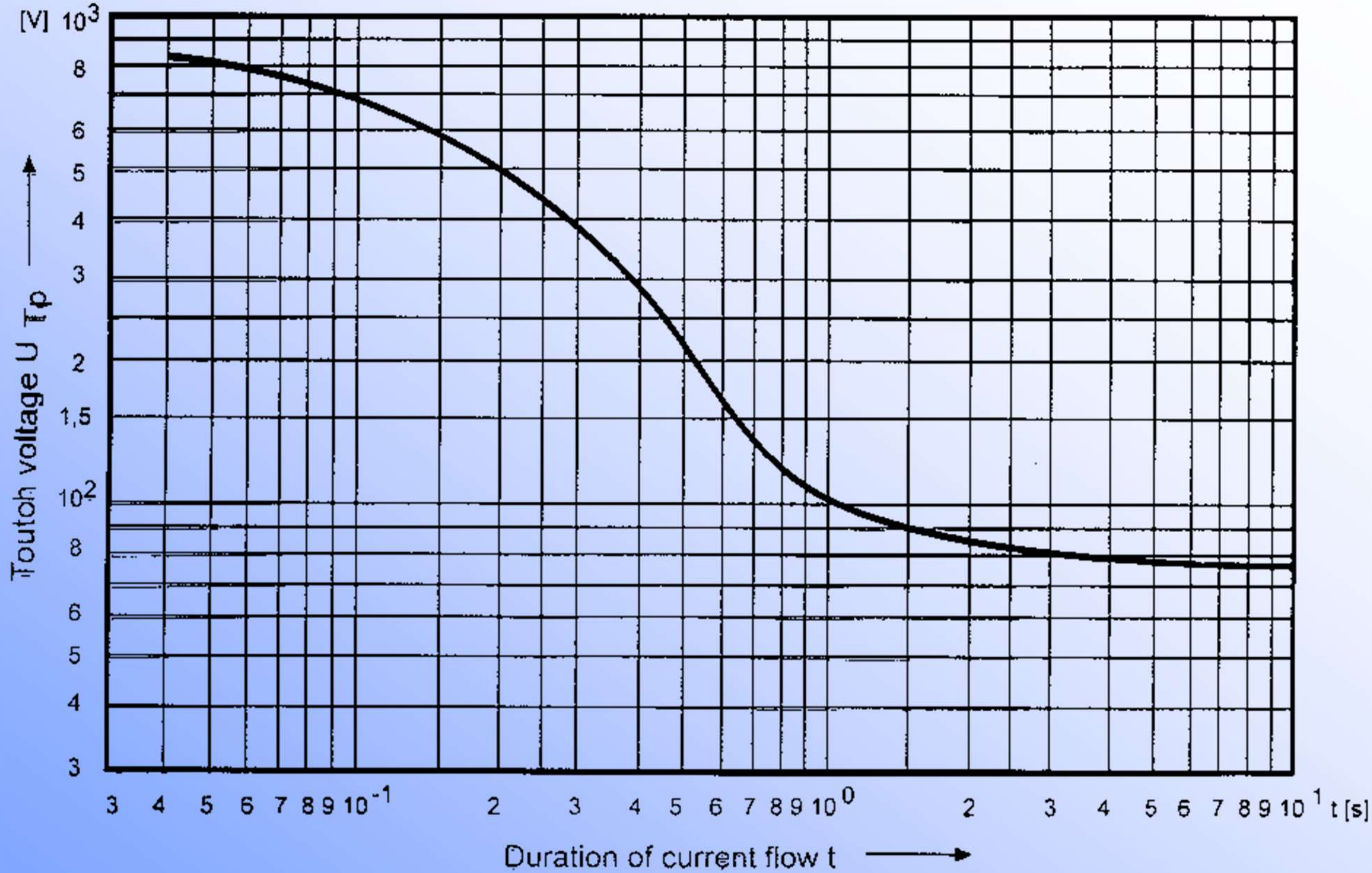
Voltages corresponding to 10% heart fibrillation probability

Earthing Voltages vs. Hazard Voltages

- Touch voltage
- Step voltage
- Only a part of earthing voltage appears as hazard voltage



Touch voltage caused by an earth fault U_t, step voltage U_s, earthing voltage U_e
And potential at earth surface V.



Allowed touch voltages by CENELEC:n

EARTHING IS ACCEPTABLE IF

1) Global earth
   - in city core areas where groundings are connected
2) Earthing voltage < 2 x permitted touch voltage
3) Earthing voltage < 4 x permitted touch voltage & potential grading
4) Proved by calculations or measurements that limits are not exceeded

Example: Touch voltage at the secondary substation

The earthing resistance is 20 Ω and earth fault current 30 A.
In which time the protection has to trip?

Earth fault voltage Um = Rm*Ie = 20Ω*30A = 600V

Touch voltage in base case 50% of this = 300V

From the previous slide figure: 300 V ⇔ 0.37 seconds

The protection must operate in 0.37 seconds

EARTH FAULT PROTECTION

Earthing voltage, Touch voltage

While flowing to earth the current meets a resistance R_e. As a result, the potential of the location rises to the value U_e

$$U_e = I_e R_e$$

The maximum values voltage according to standard SFS 6001 are

$$U_{e\max} \leq k * U_{tp}$$

where k is a factor 2,4 or 5 and U_{tp} is the maximum touch voltage allowed

EARTH FAULT PROTECTION

Maadoitusjännite, kosketusjännite

Earthing voltage, Touch voltage

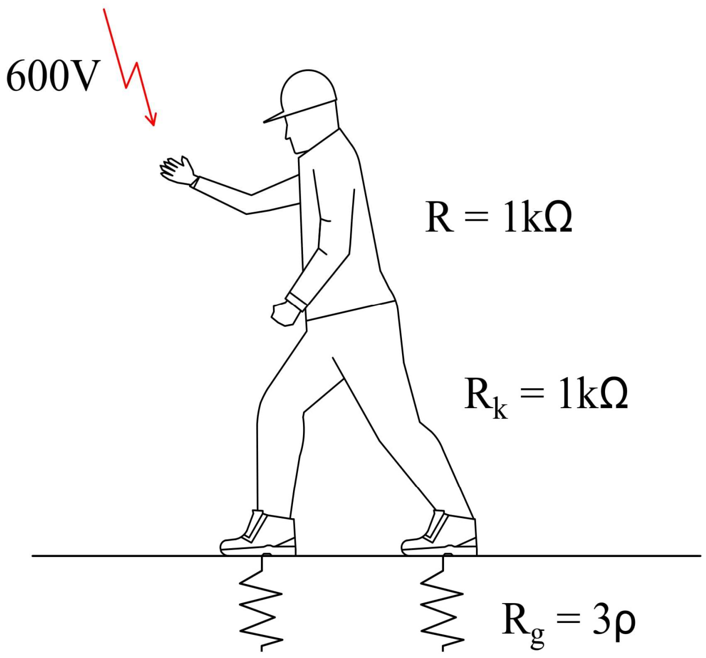
Time [s]	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
U_{TP} [V]	390	280	215	160	132	120	110	110

- Basic case k=2
- In difficult earthing cases, a potential grading must be used. This is a circular electrode buried 1 in 1 meter distance from the protected object. Now k=4 may be used.
- In extremely difficult grounding conditions k=5 is possible, but now all the houses must have local groundings connected in the potential grading system of the house.

Example – transferred hazard voltage

In construction site the temporary power supply is connected to the substation by a cable having PEN wire, but the grounding is made only in the sending end. At the substation happens an earth fault with 600 V earth voltage and 0.4 s time. As a consequence, a hand tool frame will have a 600 V voltage. What is the consequence to the worker?

Soil resistivity ρ=100 Ωm, body resistance 1000 Ω, shoe resistance 1000Ω/foot. Foot-soil contact resistance Rg≈3ρ.



Total resistance=R+0.5(Rk+Rg)
= R+0.5(Rk+3ρ) = 1650 Ω

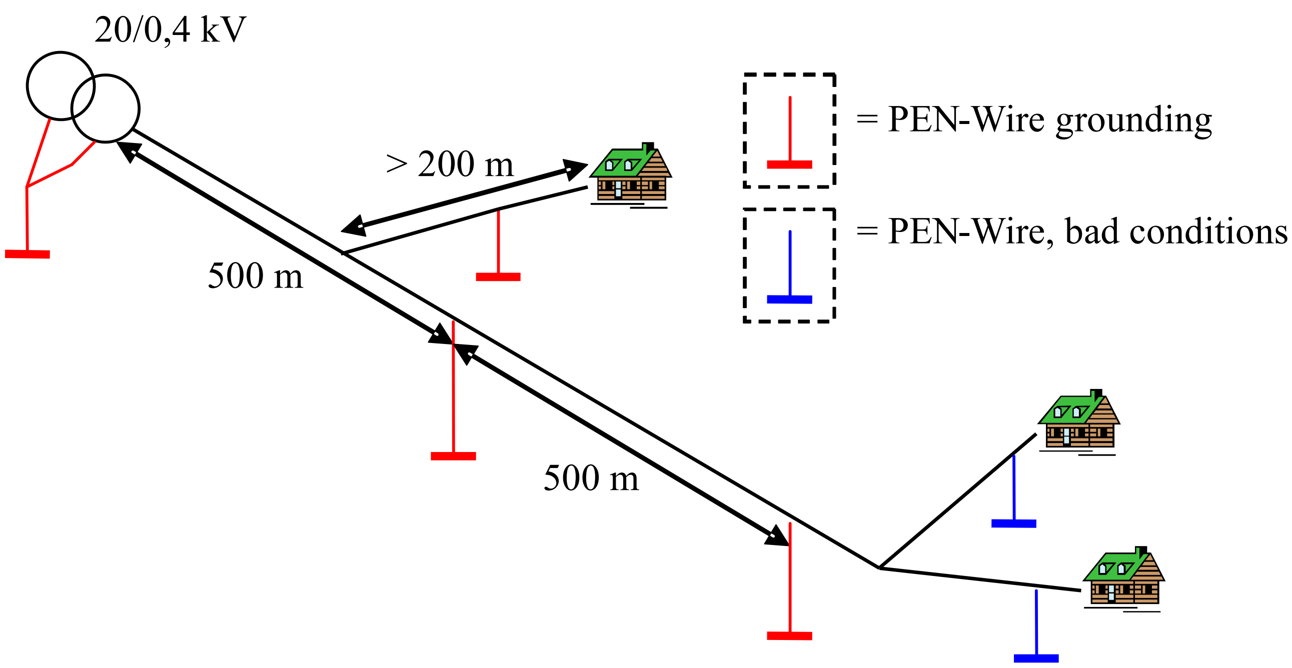
Current = 600V/1650Ω = 360 mA

⇔

Heart fibrillation probability > 1%

GROUNDINGS

Groundings in Low Voltage networks

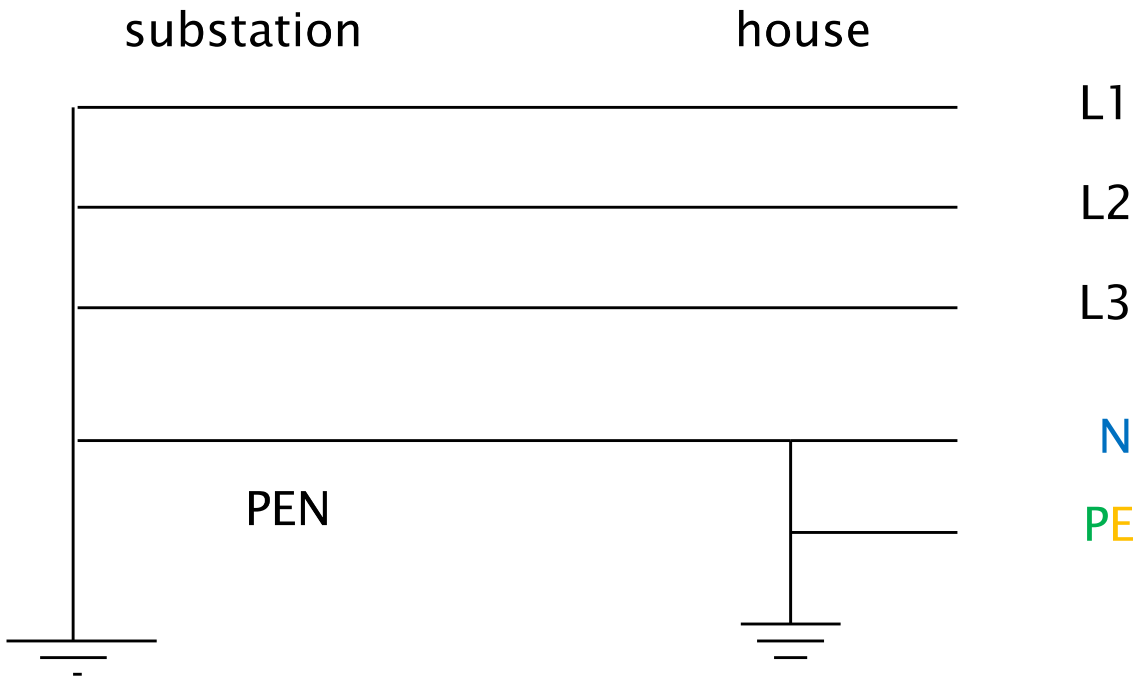


LV groundings in difficult grounding conditions

LV network earthing system

In TN-C-S-system:

- In LV network a common PEN conductor, which is split N and PE at the house connecting point
- N conductor typically blue
- PE conductor green & yellow

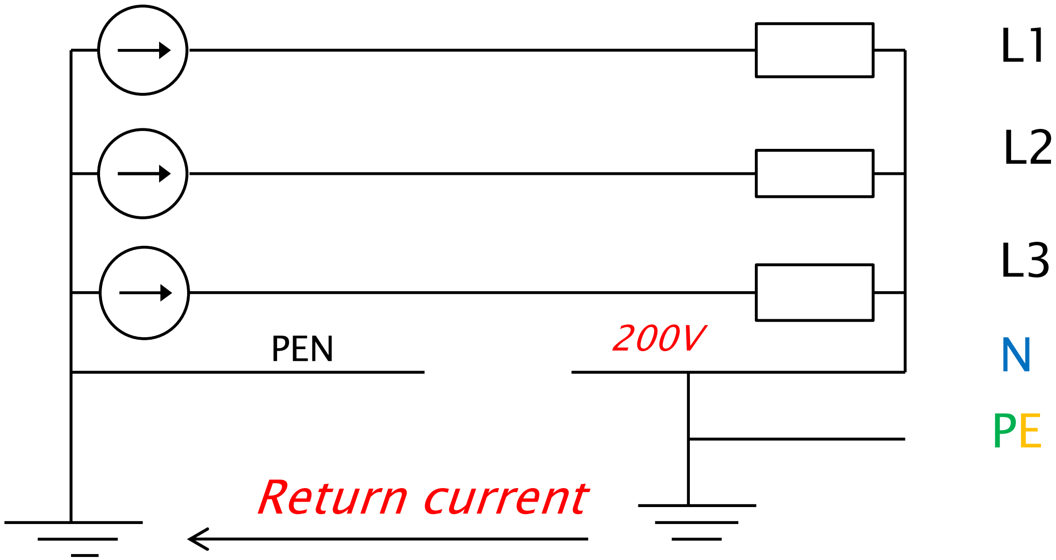


30 mA fault current switch

- Compulsory since 2012 in sockets and from 2017 also in illumination feeders.
- The 30 mA switch measured difference between phase and neutral (return) current and if this is over mA, disconnects in 300 ms.
- This is usually enough to protect from heart fibrillation.

Broken neutral

If PEN conductor is discontinued, a part of load current returns via groundings, which leads to neutral displacement and touch voltages in grounded equipment



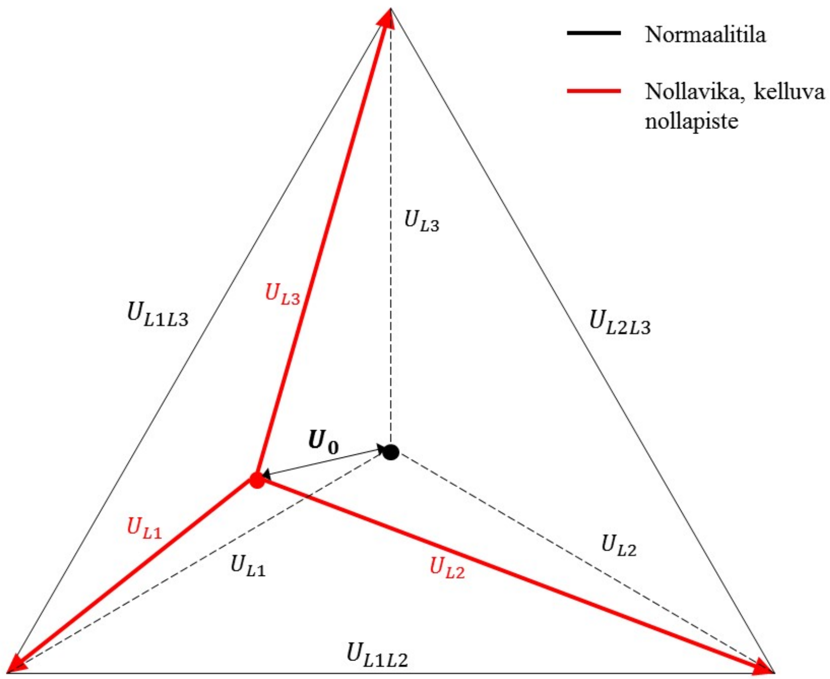
In LV system some load is allways Unsymmetrical => neutral current

If PEN is broken, this current returns via ground

Eg 10 A current and 20 ohms resistance
⇔ 200 V in house neutral

PE delivers this 200 V to all connected Equipment frames. Protection does not notice this situation!

Neutral displacement and phase voltages



During neutral displacement
Neutral voltage > 0 and
Phase voltages are changed.

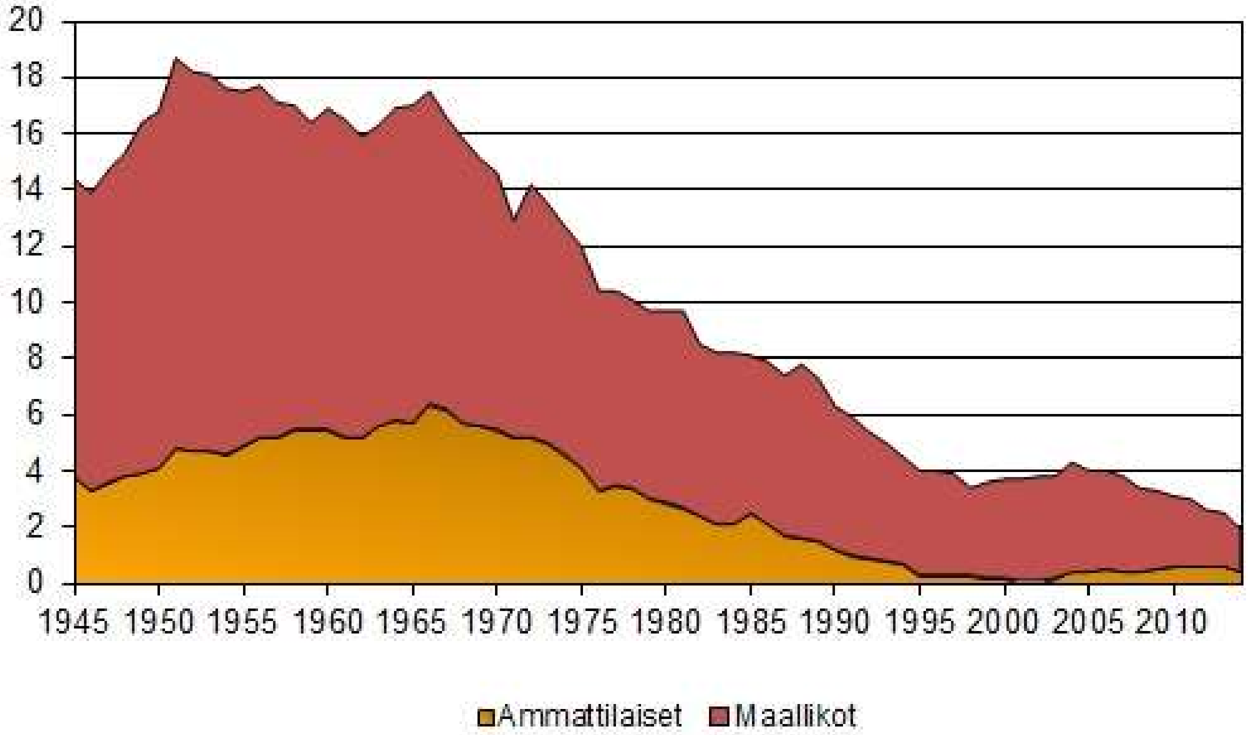
In one phase there is higher
Voltage, even close to 400 V.

The overvoltage varies with
Load current unsymmetry.

In the figure, the red phasors
Illustrate the phase voltages
During neutral displacement.

STATISTICS

Lethal accidents in 1945–2014



Professionals Common people

ELECTRICAL SAFETY

- Every year about 3-4 people die due to electrical accidents.
- Most common reasons
  - Carelessnes
  - Illegal installations
  - Stupidity
  - Bad luck
  - Most cases happen to common people
  - Most accidents happen at 230 V

EXAMPLES OF ELECTRICAL DEATHS

- A construction worker was unloading a truck. The crane made contact to a bare conductor overhead power line.
- A person climbed on a train carriage and touched the power line.
- A plumber got electrical shock from chassis of the elecrical tool. The PE contact of the socket was by mistake connected to phase wire.
- A fisherman touched 20 kV line by the fishing rod made of carbon fibre.
- A farm worker touched light switch the cover of which was broken.
- A child touched a faulty illumination equipment where the frame was in voltage, and at the same time was in contact to the radiator.
- A person got electrical shock from the frame of a washing machine. The frame was in voltage since the plug was broken.
- A person got electrical shock from a water tap. The water heater resistor had broken insulation, which made the water tube having voltage. There was no PE conductor and the water tube was not grounded.

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Electrical shock consequences 2012-2016 (Tukes)

	2012	2013	2014	2015	2016
Professionals					
Temporary pain	22	21	18	27	24
Unable to work ≤ 30 vrk	25	12	11	18	12
Unable to work > 30 vrk	5	3	3	2	1
Death	-	1	1	-	-
Not known	2	-	-	1	-
Professionals altogether	**54**	**37**	**33**	**48**	**37**
Common people					
Temporary pain	20	29	30	38	34
Unable to work ≤ 30 vrk	21	20	18	22	12
Unable to work > 30 vrk	1	3	1	8	1
Death	1	2	2	3	-
Not known	3	6	1	4	4
Common people altogether	**46**	**60**	**52**	**75**	**51**

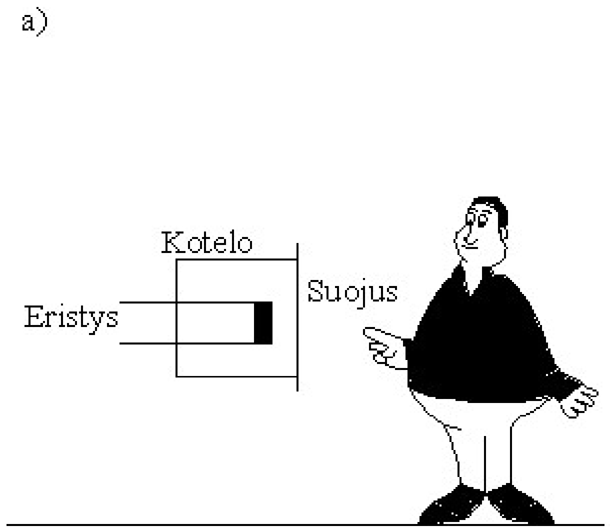
Electrical injuries - mechanisms

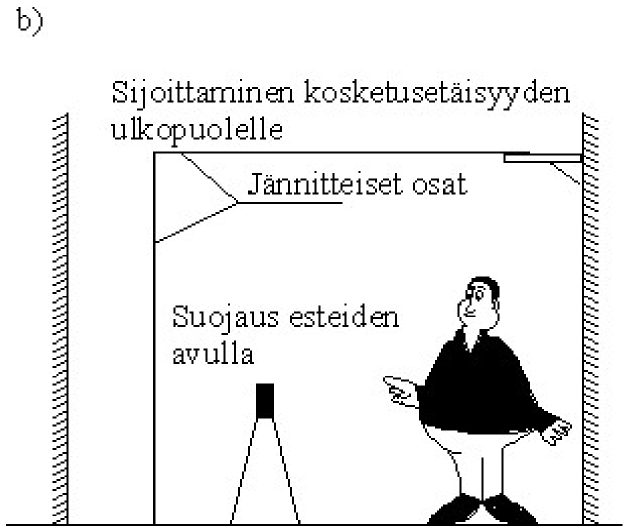
- Current can affect directly or as a power arc
- Most common injuries are combustion of skin
- Biggest injuries when current goes thru heart of brains
- The injuries can be directly visible, or may develop later, even in months or years.
- Current causes injuries by heating and depolarizarion of cells.
- In heart the current may cause arrythmia.
- In muscles the current may cause spasms, which may further cause other injuries and problems.
- In nerve systems, the injuries are very diverse – memory problems, changes in the conciousness, problems of somatic nerve system, psychiatric diseases.

Electrical Safety

- Touch protection: Preventing the live parts from being touched (insulation, equipment chassis, distance to the live parts)
- Touch voltage protection: Minimizing the magnitude and duration of hazard voltages

Electrical Safety



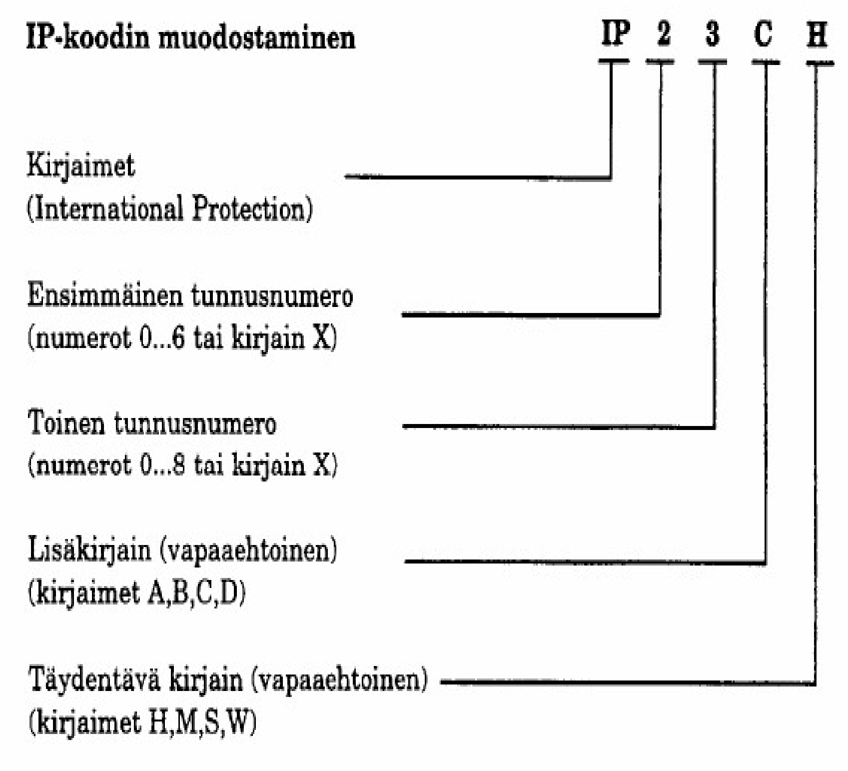


a) Protection for all touching

b) Protection for unintended touching

Methods for touch protetion:
— insulation
— chassis
— barriers
— locating live parts beyond reach

IP-classes of equipment



First number
- Protection of live parts
- Dust and particles

Second number
- Water protection

First letter
- For improved level over number 1

Second letter
- Unexceptional protection

IP-code - first digit

Level / sized	Against	Description
0	-	No protection agains contact or objects
1	>50mm	Back or hand, but not against deliberate contact
2	>12.5mm	Fingers
3	>2.5mm	Tools, thick wires
4	>1mm	Most wires, slender screws, large ants etc.
5	Dust protected	Dust not fully prevented, but must not interfere with the operation of the equipment
6	Dust tight	No ingress of dust. Tested in vacuum

IP-code - second digit

Level / sized	Against	Description
0	-	No protection against water
1	Dripping water	Test duration 10 minutes
3	Spraying water	10 liters/min 50150 kPa 1 min/m2
4	Splash of water	10 minutes as above
5	Water jets	12.5 liters/min 30 kPa 1 min/m2
6	Strong water jets	100 liters/min 100 kPa 1 min/m2
7	Immersion to 1 m depth	Test duration 30 minutes

Typical IP-classes

Tavallisimpia laitteiden kotelointiluokkia

	Selitys	IP-tunnus	Pisara-tunnus
droplets	Tippuvedenpitävä	IP 21	
rain	Sateenpitävä	IP 23 tai IP 43	
Water splash	Roiskevedenpitävä	IP 34 tai IP 44	
Water tight	Vedenpitävä	IP 67