Course code : BTEE-802

High Voltage Engineering

<u>Topics</u>

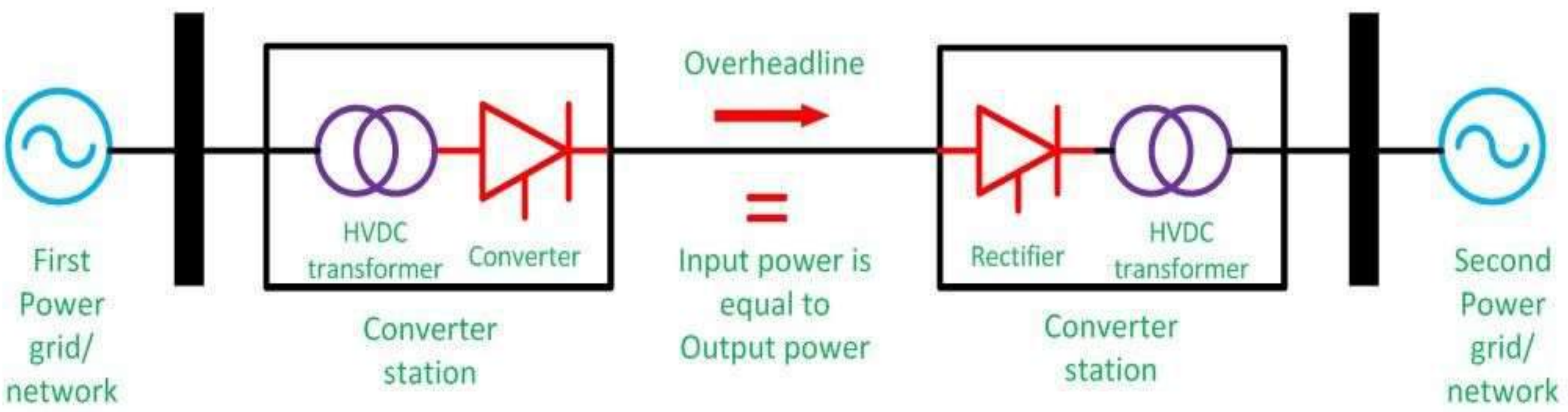
Insulation: High Voltage Direct current (HVDC)

HVDC Transmission System

High voltage direct current (HVDC) power systems uses D.C. for transmission of bulk power over long distances. For long distance power transmission, HVDC lines are less expensive, and losses are less as compared to AC transmission. It interconnects the networks that have different frequencies and characteristics.

AC is better for generation and utilization

DC is better for transmission



HVDC Substation Layout

Classification of HVDC transmission system

The classification of HVDC systems depends upon the arrangement of the pole and the earth return.

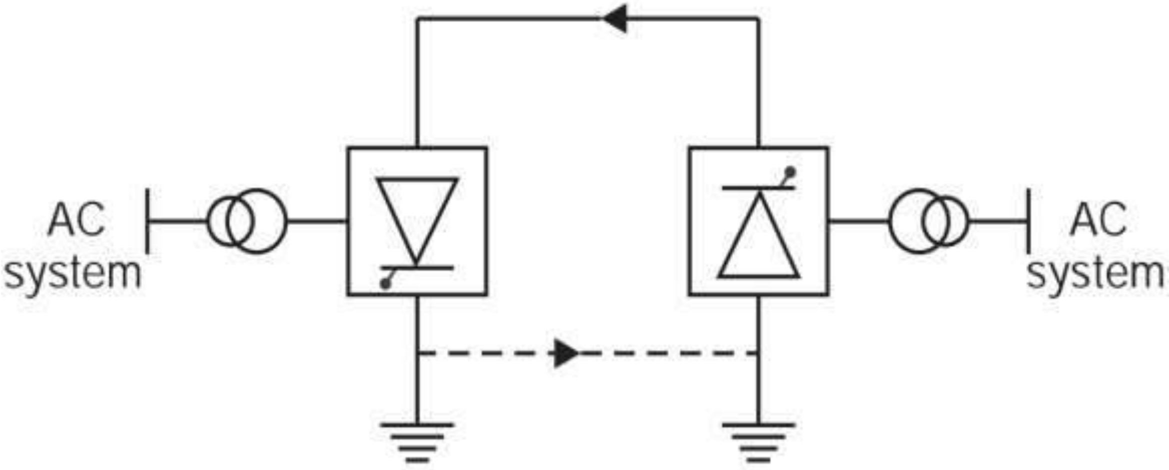
They are as follows:

(i) Monopolar link
(ii) Bipolar link
(iii) Homopolar link

(i)Monipolar Link : A monopolar link has only one conductor, with ground or sea as a return path. Generally, the conductor has a negative polarity with respect to the earth

ADVANTAGES:

- The corona effect in a DC line is less because of the negative
- Less conductor material is required as ground is used as the return path.
- Less insulation cost.



Classification of HVDC transmission system

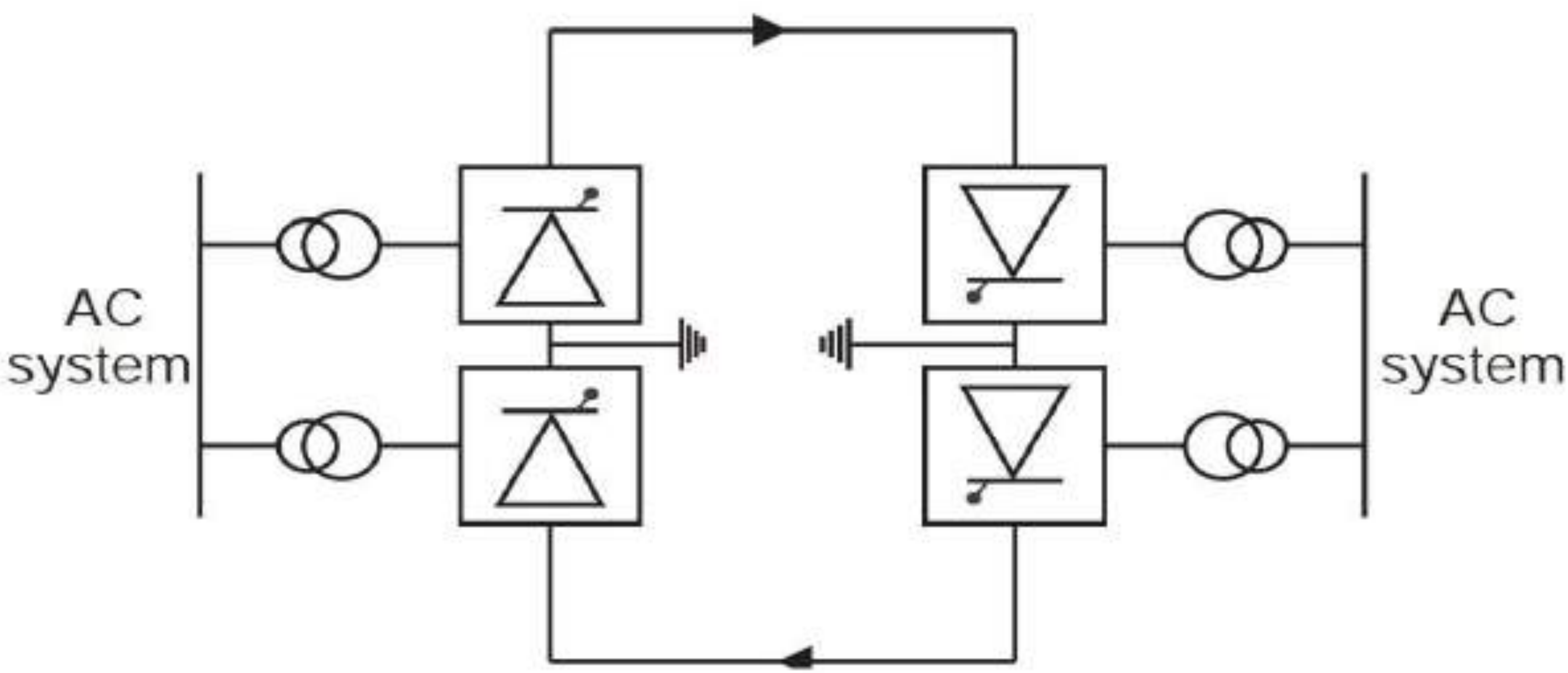
(ii) Bipolar links: have two conductors, one at the positive potential and the other at the negative (same magnitude) with respect to the ground. At each terminal, two identical sets of converters are connected in series, on the DC side.

Advantages:

- Power transmitting capacity is doubled when compared to monopolar link.
- If a fault occurs in one conductor, half power can be transmitted through other

DISADVANTAGES:

- Terminal equipment cost is high.
- More conductor material is required.
- Corona loss is high.



Classification of HVDC transmission system

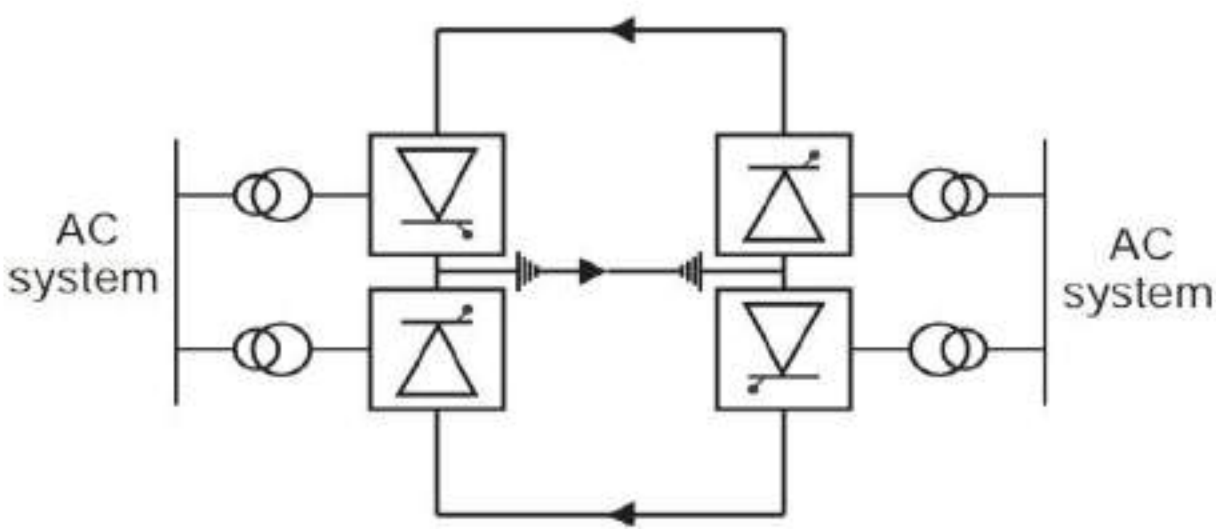
Homopolar link: has two or more conductors, all having the same polarity, and ground is used as the return path.

ADVANTAGES:

- Corona effect is less in negative polarity conductors.
- Less conductor material is required because ground is used as the return path.
- We can avoid power interruption due to faults by transmitting power through other conductors.
- Reliability is high.
- Insulation costs are low.

DISADVANTAGES:

- Ground return path causes corrosion of buried metallic structures.
- Causes disturbance in underground communication cables.



Between AC and DC transmission which one will we use?

We will decide based on:

(i) Technical Performance and

(ii) Economic consideration.

Technical Performance

1. Interconnection:

AC interconnection: Two AC systems are connected by an AC link. Frequency of these two system should be very close. It is also known as synchronous tie

Disadvantages of AC interconnection:

→ Frequency disturbance in one system is transferred to other system

→ Power swing in one system may affect the other system. Major fault in one system may lead to the complete failure of the system.

→ Increase in fault level.

Technical Performance

Advantages of DC interconnection:

A DC interconnection provides loose tie between two AC system.

→ Can interconnect two AC system of different frequency.

→ Fast and reliable control of magnitude and direction of power flow by controlling firing angle.

02. Stability limit: In AC system

→ Reactance of the line increases with the length of the line

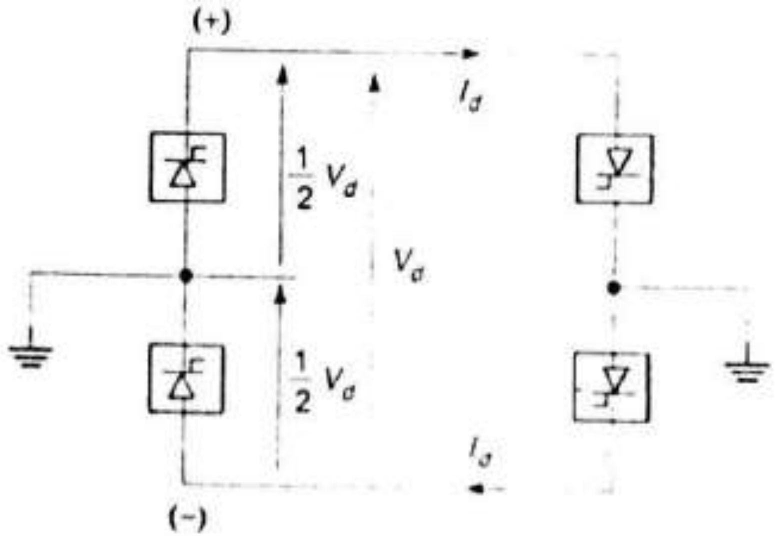
→ It leads the reactive power drop

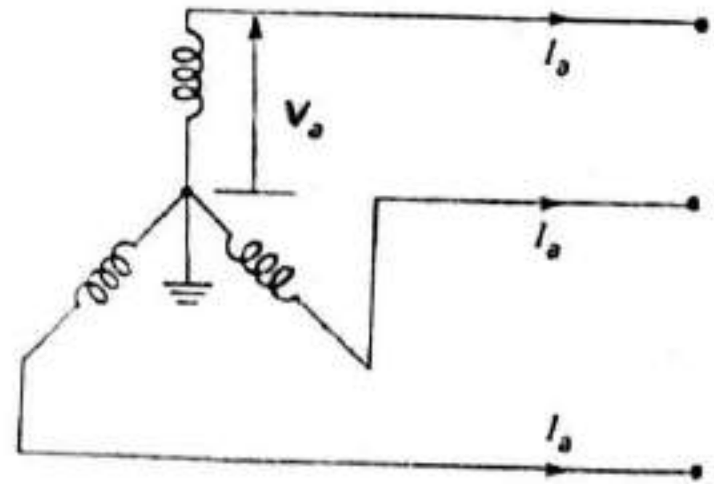
→ So reactive power to be injected at regular interval to stabilize the AC system

But DC system is free of this limitation due to absence of reactance. Thus power transfer capability is unaffected by the distance.

Economic Comparison

01. A new DC line is to be provided instead of 3 phase AC line:





1. same power transmitted;
2. same power losses; and
3. same conductor size.

Since two losses are equal:

$$2{I_d}^2R = 3{I_a}^2R$$

$$\frac{I_a}{I_d} = \sqrt{\frac{2}{3}}$$

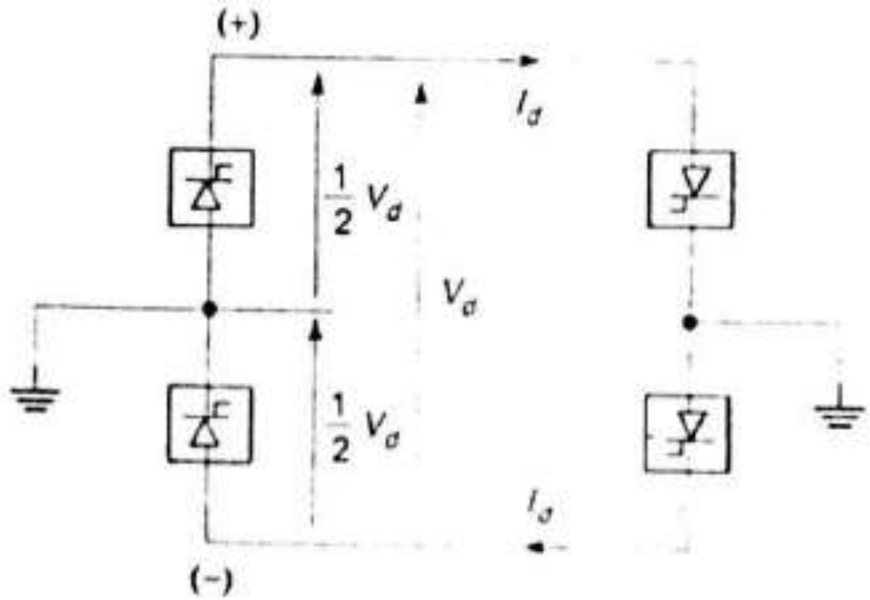
Power transmitted by DC = V_dI_d

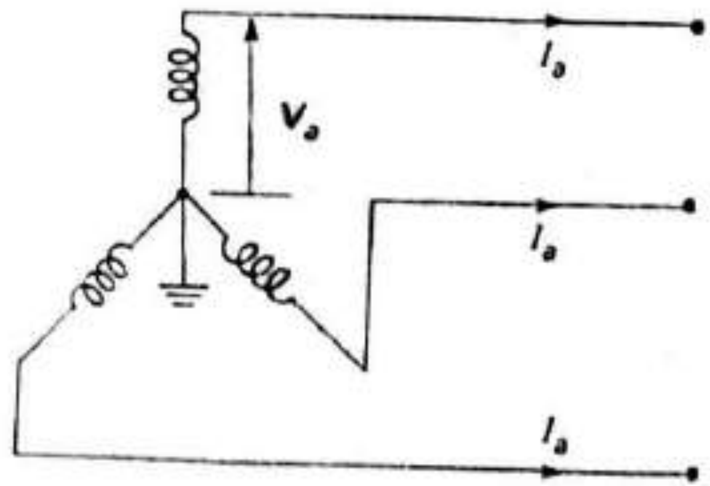
Power transmitted by AC =$3V_aI_a \cos\theta$

Power loss in DC =$2{I_d}^2R$

Power transmitted by AC =$3{I_a}^2R$

Economic Comparison





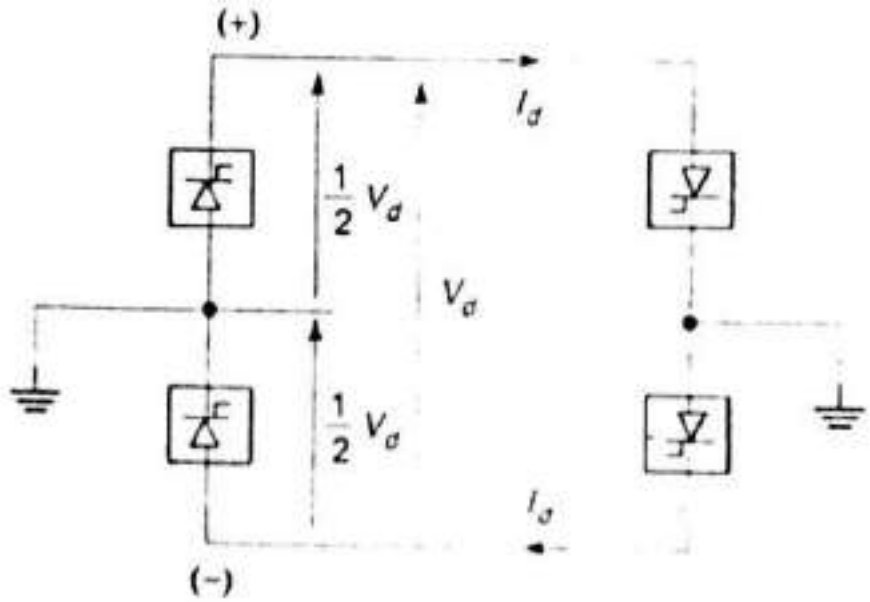
$$\frac{I_a}{I_d} = \sqrt{\frac{2}{3}}$$

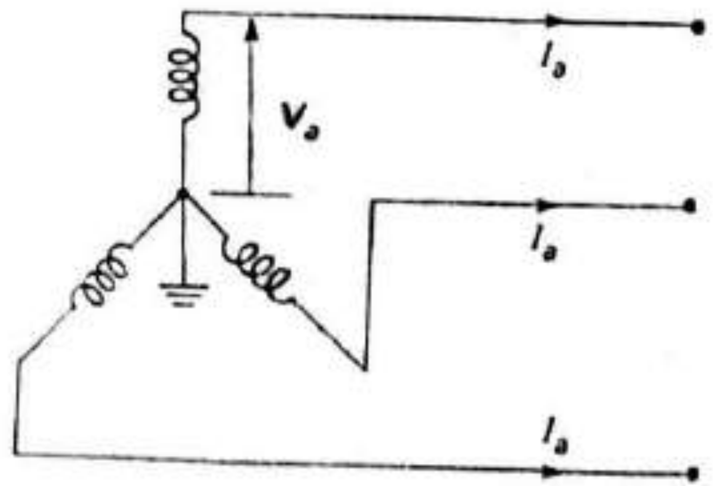
For same power to be transmitted on both side

$$3V_aI_a = V_dI_d$$

$$\frac{V_d}{V_a} = 3\left(\frac{I_a}{I_d}\right) = 3\sqrt{\frac{2}{3}} = \sqrt{6}$$

Economic Comparison





$$\frac{V_d}{V_a} = 3\left(\frac{I_a}{I_d}\right) = 3\sqrt{\frac{2}{3}} = \sqrt{6}$$

$$\frac{\text{DC insulation level}}{\text{AC insulation level}} = \frac{V_d}{2\sqrt{2}\ V_a} = \frac{\sqrt{6}}{2\sqrt{2}} = 0.867$$

Economic Comparison

02. Converting a three phase double circuit line to a three circuit DC line

(a) Consider the first case when the current and insulation levels are assumed to be the same in both the systems. For current to be the same, $I_a = I_d$.

For equality of the insulation levels, $\sqrt{2}\ V_a = \frac{1}{2} V_d$

Power transfer in 3 phase double circuit AC line = $2 \times (3V_a I_a \cos\varphi) = 6V_a I_a$

Power transfer in 3 circuit DC line = $3V_d I_d$

$$\frac{\text{power transmitted by DC}}{\text{power transmitted by AC}} = \frac{3V_d I_d}{6V_a I_a} = \frac{3\,(2\sqrt{2}\ V_a)\,I_a}{6V_a I_a} = \sqrt{2} = 1.414$$

$$\text{power transmitted by DC} = 1.414 \times \text{power transmitted by AC}$$

Economic Comparison

(b) We shall now compare the two systems if percentage losses and insulation level remain the same in both of them. For the same insulation level

$$\sqrt{2}\, V_a = \frac{1}{2} V_d$$

if the same percentage losses are assumed

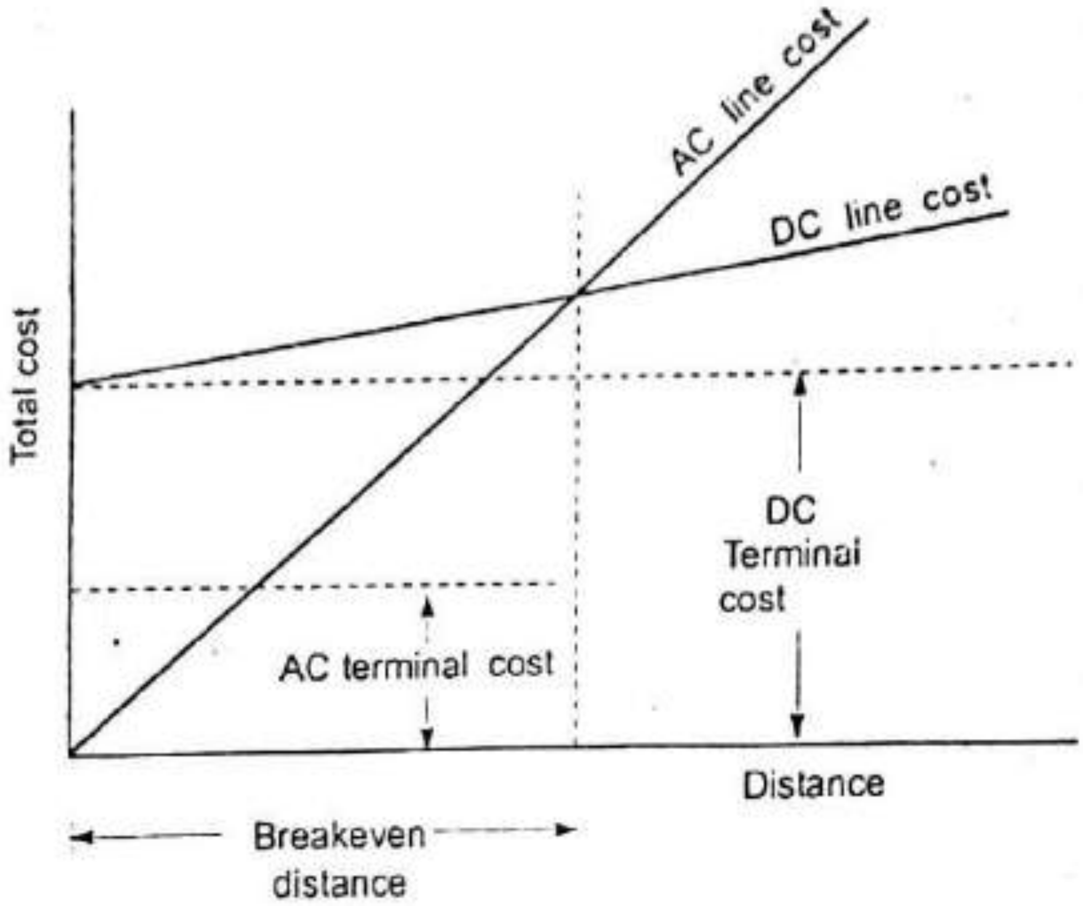
$$\frac{\text{AC loss}}{\text{AC power}} \times 100 = \frac{\text{DC loss}}{\text{DC power}} \times 100$$

$$\frac{6 I_a^2 R}{2 \times 3 V_a I_a} = \frac{6 I_d^2 R}{3 V_d I_d} = \frac{6 I_d^2 R}{3\,(2\sqrt{2}\, V_a)\, I_d}$$

$$I_d = \sqrt{2}\, I_a$$

$$\frac{\text{power transmitted by DC}}{\text{power transmitted by AC}} = \frac{3 V_d I_d}{2 \times 3 V_a I_a} = \frac{3\,(2\sqrt{2}\, V_a)\,\sqrt{2}\, I_a}{6 V_a I_a} = 2$$

Economic Distance for HVDC transmission system



Advantages of HVDC transmission system:

See page no 616-617 from

Electrical Power system By Ashfaq husain

Course code : BTEE-802

High Voltage Engineering

<u>Topics</u>

Insulation: High Voltage Direct current (HVDC)

Objectives

In this course you will learn the following:

→What is high voltage?

→ Why needed

→Levels of voltages

→ Application of High Voltage

→Electrical Insulation and Dielectrics

What is high voltage

- A mobile phone is operated from a 4V battery. It may be destroyed if anyone attempts to operate it from a 12V car battery.

  Therefore 12V is quite a high voltage for a mobile phone.

What is high voltage

230kV

S... transformer is used to reduce the voltage to 33kV

...ltage is s...

230kV

...refer...

...al pow... system.

Long transmission line used to carry the power to Dhaka

230kV

S... transformer is used to rise the voltage to 132kV or 230kV

33kV

...transformer is used to reduce the voltage to 11kV

At Kaptai we gen... ...kV or 2...

11kV

11kV

Another Step down transforme... is used to reduce the voltage further to 400V suitable for end user.

400V

230V

Domestic users get ... 230Volt.

What is high voltage

- Below 11kV : Low voltage
- 11kV – 100kV : HV (high Voltage)
- 100kV – 400kV : VHV (Very high voltage)
- 400kV and above : EHV (Extra high voltage)
- UHV : Ultra high voltage

Levels of high voltage:

World over the levels are classified as:

→LOW VOLTAGE
→HIGH VOLTAGE
→ VERY HIGH VOLTAGE
→EXTRA VOLTAGE
→ULTRA HIGH Voltages

However , the exact magnitude of these levels vary from country to country. Hence this system of technical terms for the voltage levels is inappropriate .

In most part of the world even 440 V is considered to be high voltage since it is dangerous for the living being.

Hence it would be more appropriate to always mention the level of voltage being referred without any set nomenclature .

Why hi

New Loss in transmission line

$(2I)^2R=4I^2R$

Basically it is requ ... es to be

able ... mor ... ame line.

Kaptai

Dhaka

2I

Therefore we conclude that it is not wise to increase the line current to transmit more power over a line, keeping the voltage same.

Why hi e

Basically it is requ lines to be abl mor e same line.

Loss in transmission line = I^2R,
R is the resistance of the line.

Kaptai

Dhaka

I

I

2V

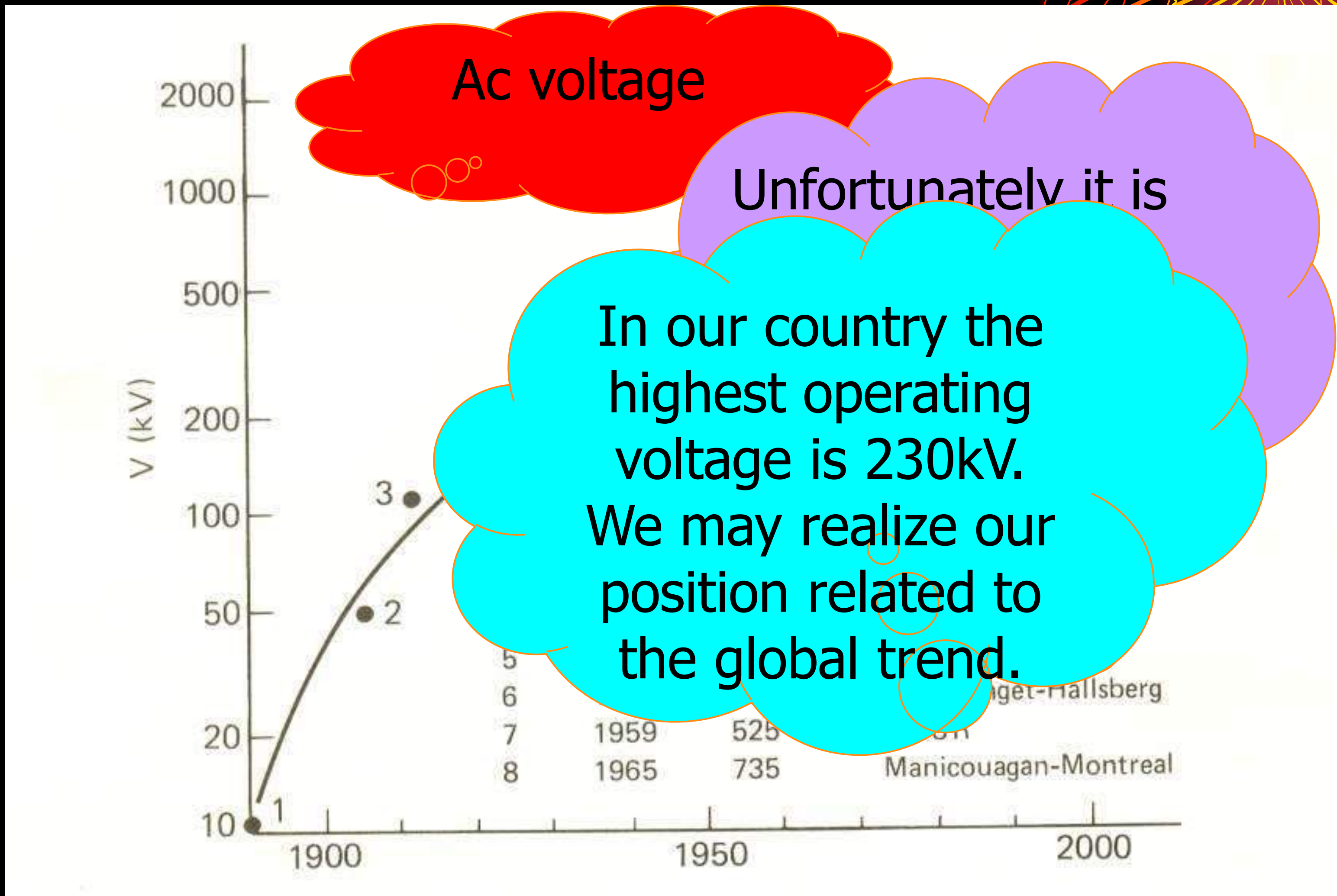
Therefore we see that if the transmission line voltage is increased it is capable of transmitting more power without increasing the power loss in the line.

I

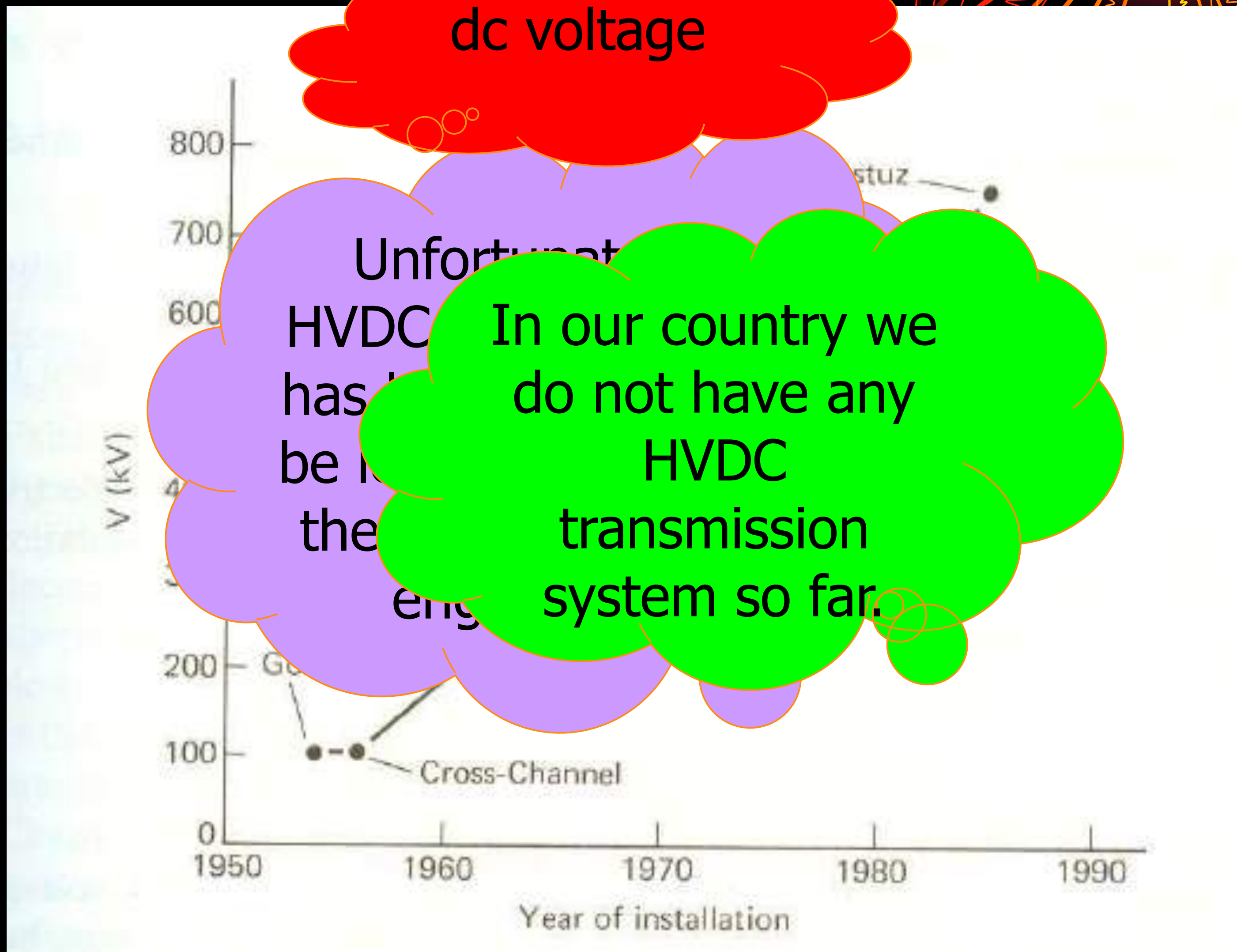
I

Generator

Trends in voltage growth



Trends in voltage growth



dc voltage

Unfortunat
HVDC
has
be
the
eng

In our country we do not have any HVDC transmission system so far.

Fields of applications of HV

- Power system engineering
- Researc
- Ind
- Nu
- E
- A
- Med X-ray machin

Interested students may find new areas of application of HV

What we learn in High Voltage Engineering

- Testing of HV equipments like power transformers, bushings, CB, insulators, cables etc.
- Usually tests are done at a voltage much higher than the operating voltage.
- Generation, measurement and control of different types of HV.

What we learn in High Voltage Engineering

- **Failure mechanism of HV equipments caused by HV stress.**
- **Breakdown mechanism of different types of insulating materials (solid, liquid, gas, vacuum) under different types of voltages (ac, dc, li, si).**

Few future prospects of HV

- For co ... ad distri ... d any mor ... co
- Co ... type GIS ... near futu
- HV has ... al and industrial applications like water treatment plant, insect killer/repeller, exhaust air purifier etc.

Interested students may add new names to this list.

ac High Volt

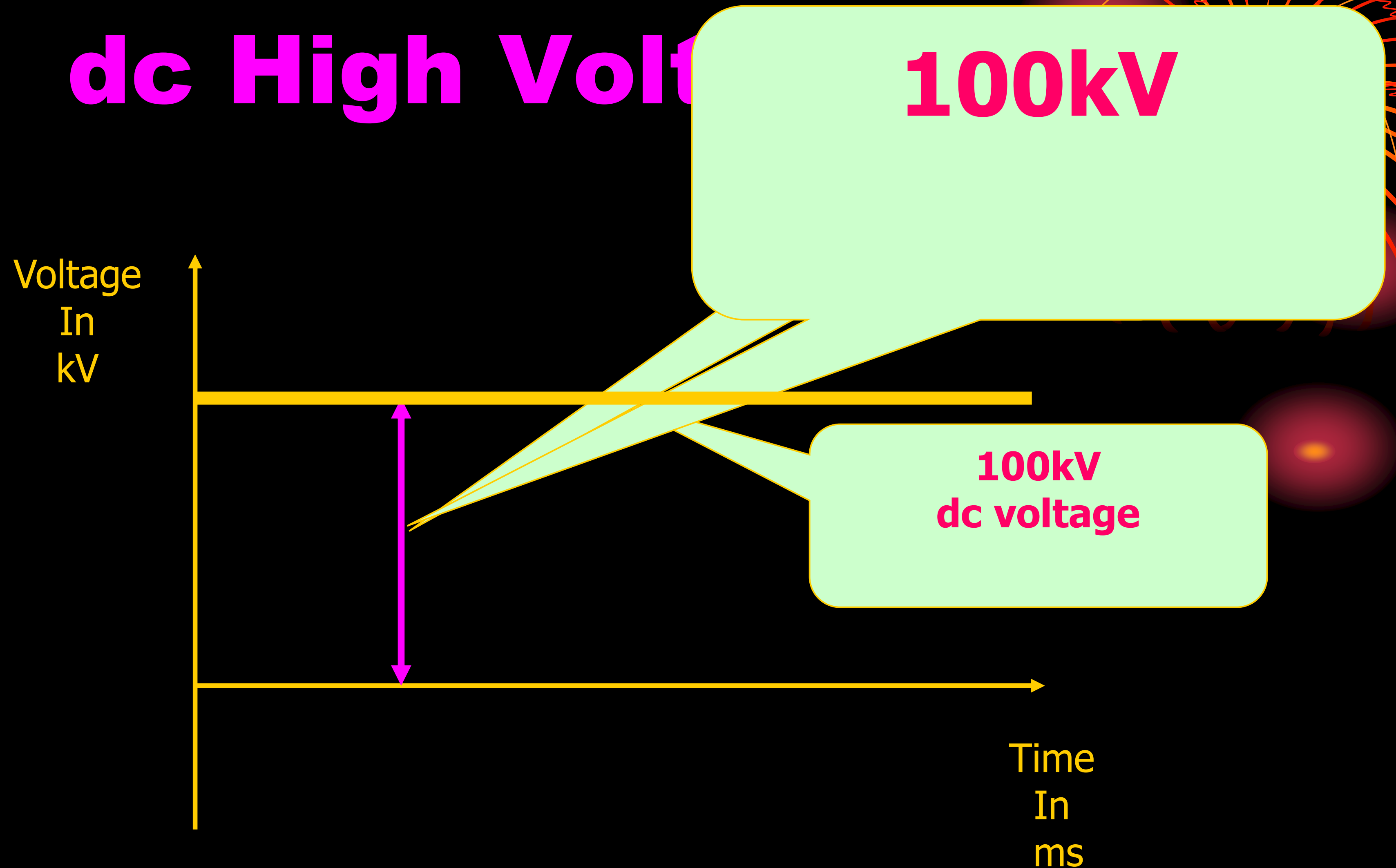
Suppose it is said that the voltage is 100kV.
Then this peak value is

Voltage
In
kV

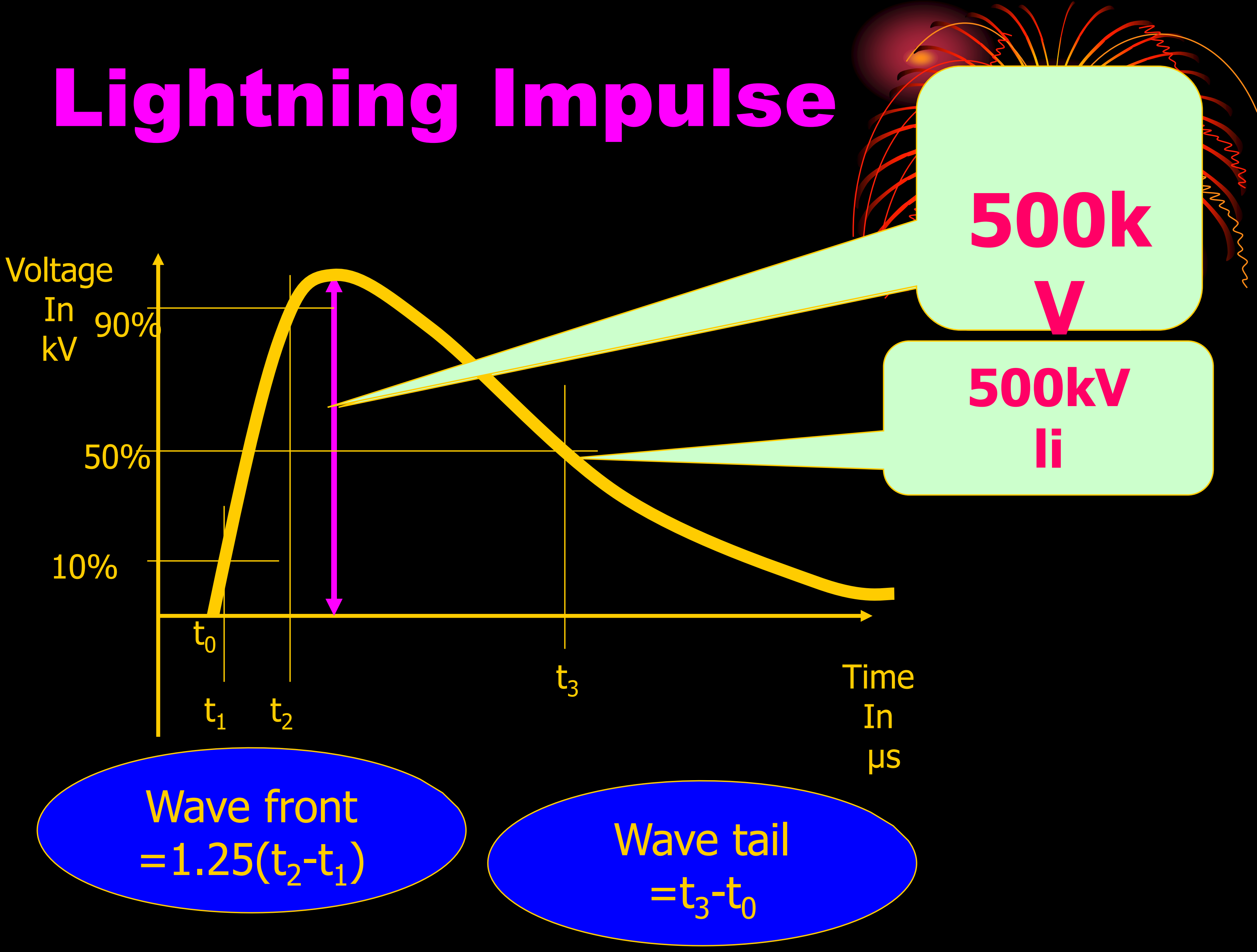
In high voltage engineering, we should always be careful about the peak value of the ac voltage, because this is the maximum voltage in the system and may be responsible for initiating breakdown or failure.

10 ms

dc High Volt



Lightning Impulse



Course outline

Course No. EEE 4309

Course Title : High Voltage Engineering

High Voltage dc : Rectifier circuits, Voltage multipliers, Van-de-graff generator.

High Voltage ac : Cascaded transformers and Tesla coils.

Impulse Voltage : Shapes, mathematical analysis, codes and standards, single and multistage impulse generators, tripping and control of impulse generators.

Breakdown in gas, liquid and solid dielectric materials.

Corona.

High Voltage measurement and testing.

Over voltage phenomena and insulation co-ordination.

Lightning and switching surges, basic insulation level, surge diverters and arresters.

VOLTAGE LEVELS

Consumer

ac power frequency :

110 V, 220 V- single phase

440 V, 3.3 kV ,6.6 kV, 11 kV-three phase (3.3 & 6.6 kV are being phased out)

Besides these levels ,the Railway Traction at 25 kV , single phase is one of the biggest consumer of power spread at any particular stretch to 40 km of track length

Generation : Three phase synchronous generators

440 V, 3.3 kV, 6.6 kV (small generators) , 11 kV (110 & 220 MW)

21.5 kV (500 MW), 33 kV (1000 MW)

[limitation due to machine insulation requirement]

Distribution :

Three phase

440 V, 3.3 kV, 6.6 kV, 11 kV, 33 kV, 66 kV

With the increase in power consumption density, the power distribution voltage levels are at rise because the power handling capacity is proportional to the square of the voltage level.

(In Germany 440 V , 3.0 kV 6.0 kV, 10 kV, 30 kV, 60 kV)

ac Transmission :

110 kV, 132 kV, 220 kV, 380 - 400 kV, 500 kV, 765 - 800 kV, 1000 kV and 1150 kV exist.

Work on 1500 kV is complete.

In three phase power system, the rated voltage is always given as line to line, rms voltage .

d.c. transmission :

dc single pole and bipolar lines : ± 100 kV to ± 500 kV

Advance countries like US, Canada and Japan have their single phase ac power consumption level at 110 V .Rest of the whole world consumes single phase ac power at 220 V .

The only advantage of 110 V single phase consumer voltage is that it is safer over 220 V. However, the disadvantages are many.

Disadvantages :

→It requires double the magnitude of current to deliver the same amount of power as at 220 V

→Hence for the same magnitude of I2R losses to limit the conductor or the insulation temperature to 70° C (for PVC) , the resistance of the distribution cable should be 4 times lower. Therefore, the cable cross-section area has to be increased four folds.

→Four times more copper requirement, dumped in the building walls is an expensive venture.

→Due to higher magnitude of current, higher magnetic field in the buildings . Not good for health.

→With the installation of modern inexpensive protective devices (earth fault relays), 220 V is equally safe as 110 V

Rated maximum temperature of cables:

→ It is important to understand the current and voltage carrying capacities of a conductor separately. While the current carrying capability is determined by the conductivity of the conductors, directly proportional to the area of conductor cross-section, the voltage bearing capacity depends upon the level of insulation provided to the conductor .

→The current carrying capability in turn is determined by maximum permissible temperature of the insulation or that of the conductor.

→ The real power loss, I2R and the rate of cooling determine the temperature rise of the conductor which should not be more than the maximum permissible temperature of the type of insulation provided on the conductor .

Hence, not only electrical but thermal and mechanical properties of insulation are important in power system .

Electrical Insulation and Dielectrics

Gaseous Dielectrics:

Atmospheric air is the cheapest and most widely used dielectric . Other gaseous dielectrics, used as compressed gas at higher pressures than atmospheric in power system, are Nitrogen , Sulphurhexafluoride SF6(an electro-negative gas) and it's mixtures with CO2 and N2 . SF6 is very widely applied for Gas Insulated Systems (GIS), Circuit Breakers and gas filled installations i.e. sub-stations and cables. It is being now applied for power transformers also.

Vacuum as Dielectric :

Vacuum of the order of 10-5 Torr and lower provides an excellent electrical insulation. Vacuum technology developed and applied for circuit breakers in the last three decades is phenomenon .

Liquid Dielectrics:

Organic liquids, the mineral insulating oils and impregnating compounds, natural and synthetic, of required physical, chemical and electrical properties are used very widely in transformers, capacitors, cables and circuit breakers.

Ex: Polychlorinated biphenyls (PCBs)

Solid Dielectrics:

→Very large in number .

→Most widely used are : XLPE, PVC, ceramics, glass, rubber, resins, reinforced plastics, polypropylene, impregnated paper, wood, cotton, mica, pressboards, Bakelite, Perspex, Ebonite, Teflon, etc.

→ Introduction of nano materials are in offing.

Recap

In this lecture you have learnt the following:

Levels of voltages for power consumption, distribution and transmission.

Electrical Insulation and Dielectrics in the power system.

Congratulations, you have finished Lecture 1.

Books

This one we will follow in the class