EE6508 - Power Quality

Transient Overvoltages

presented by

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Lecture outline

- Transient Overvoltage
  - Introduction to transient overvoltages
  - Surge propagation: Traveling waves
  - Reflection and transmission of traveling waves
  - Switching overvoltages
  - Lightning phenomenon
  - Impulse voltage wave

- Protection against Transient Overvoltages
  - Basics of protection against transient overvoltage
  - Surge arresters
  - Metal oxide varistor (MOV)

References

Texts:

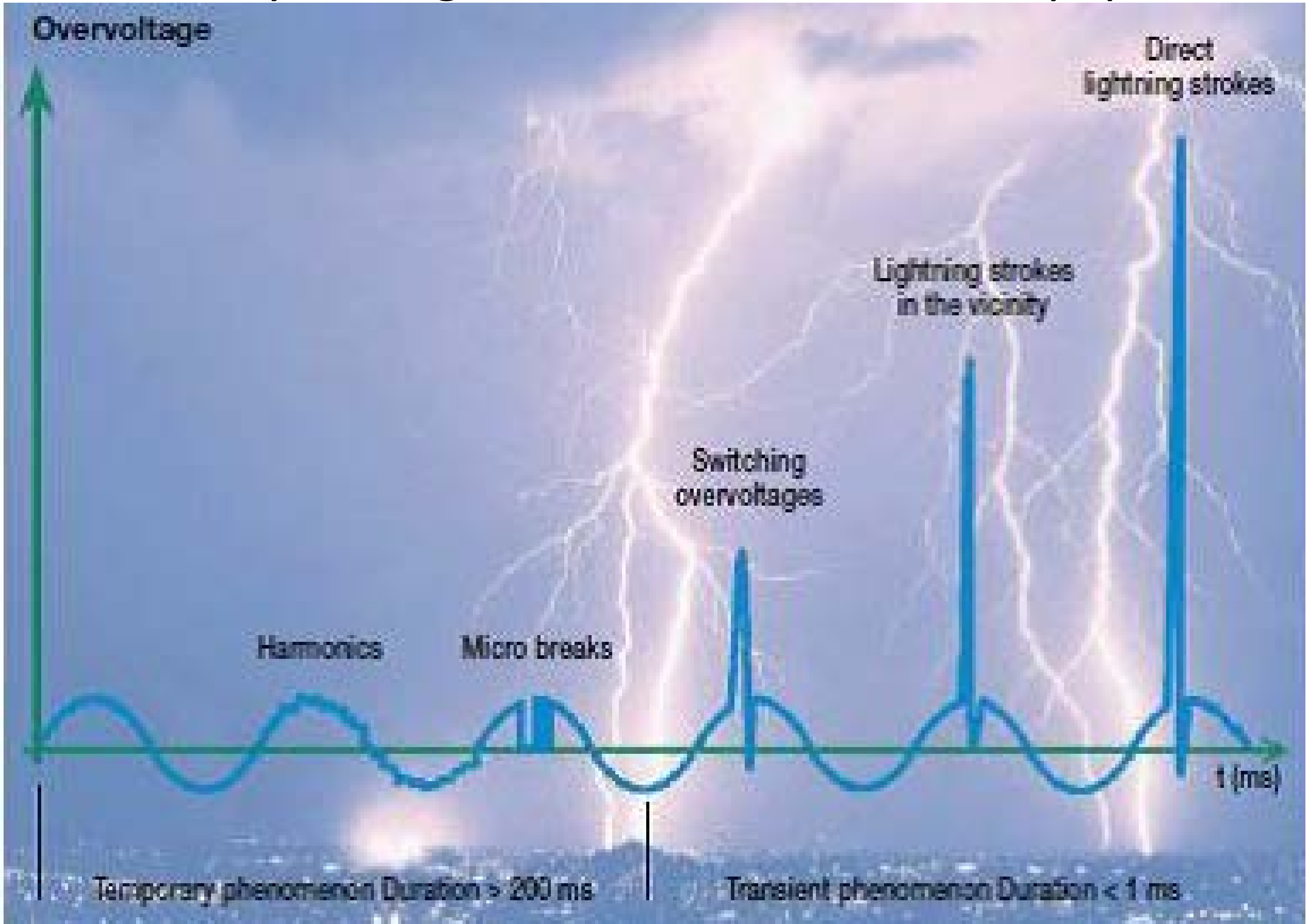
1. Dugan R C, McGranaghan M F, Santoso S, and Beaty H W, Electrical Power Systems Quality, Second Edition, McGraw-Hill, 2002. 2.
2. Kennedy B W, Power Quality Primer, First Edition, McGraw-Hill, 2000.

Reference:

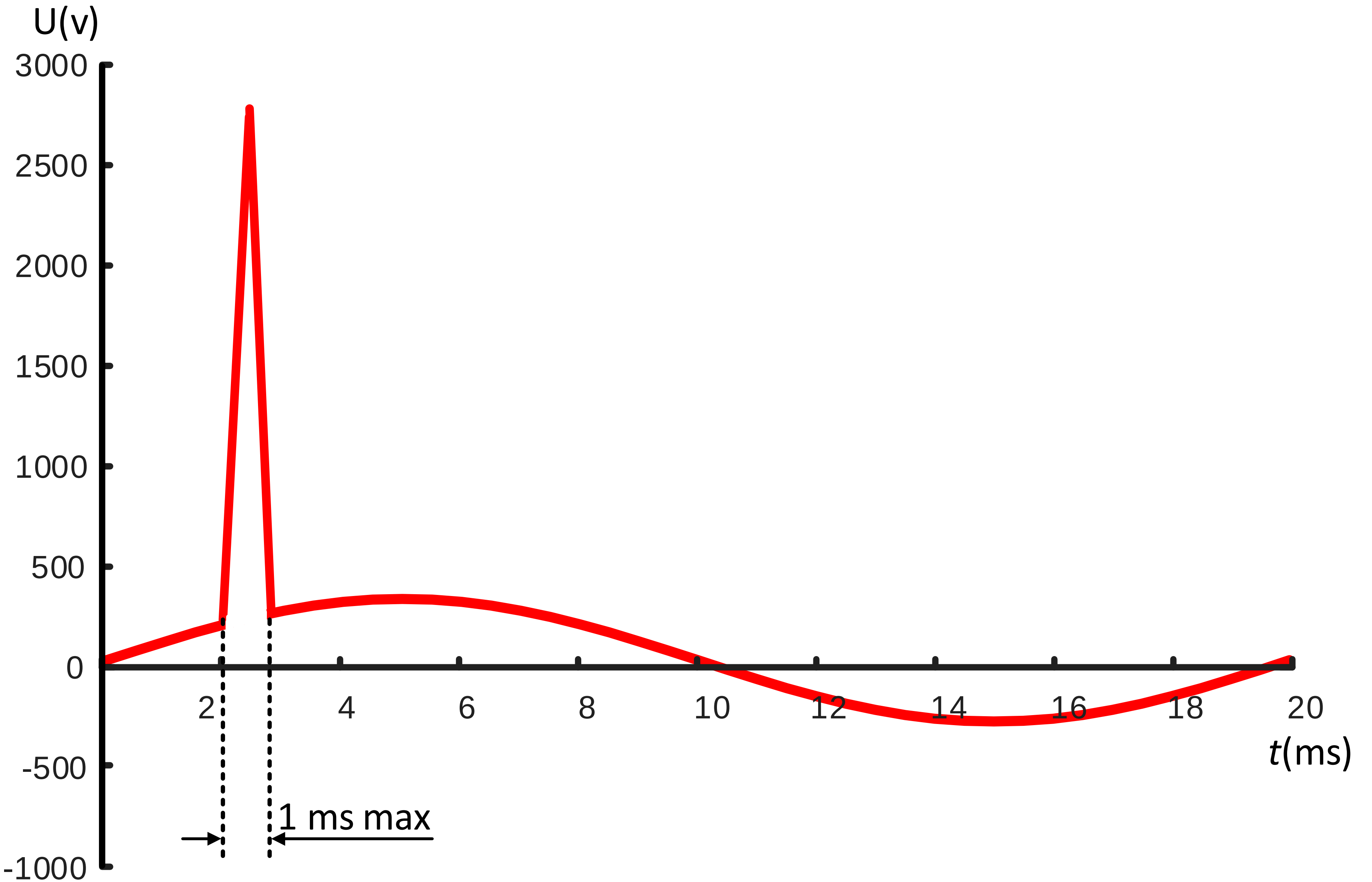
3. Allan Greenwood, "Electrical Transients in Power Systems", 2nd Edition, John Wiley & Sons Inc., 1991.

Transient Over-voltages

- A sudden (shorter than a millisecond) rise in the flow of power
- Voltage peak can reach 12x's the nominal voltage
- It can cause costly damage to electric/electronic equipment



Transient Over-voltages

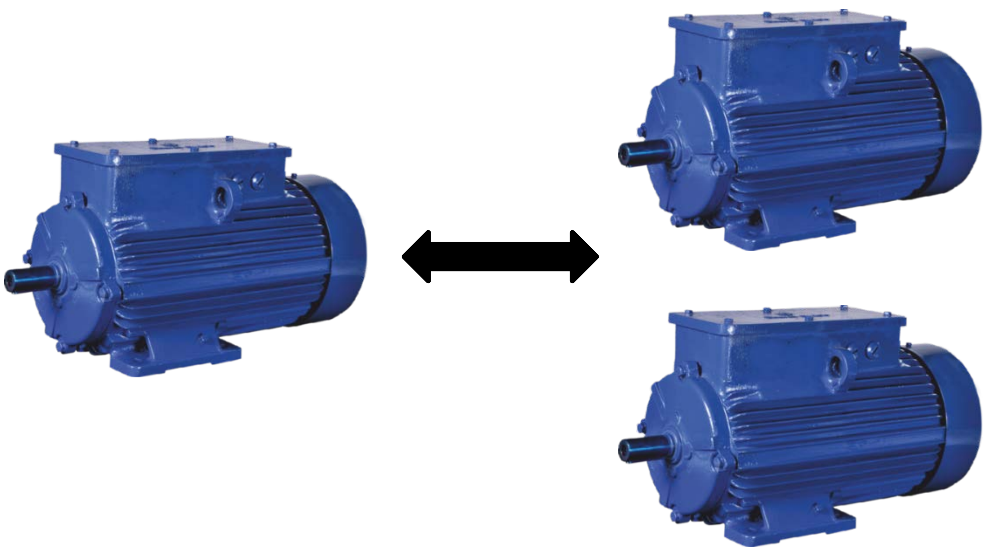


Transient Over-voltages

- Two common sources of transient overvoltages (also called surges) in transmission lines, or power systems in general, are:
  - ✓ Switching events, and
  - ✓ Lightening
- The concept and methodology of travelling waves are very useful to analyse both these processes.
- At least <u>20%</u> of transients are generated from <u>external sources (i.e. lightning, power company grid switching)</u>. As a result:
  - ✓ Catastrophic equipment failure,
  - ✓ Immediate operation shutdown,
  - ✓ Long term disruption of business, and
  - ✓ Expensive equipment repair and replacement.

Transient Over-voltages

- At least 80% of transients are generated from internal sources (i.e. load switching, normal equipment operations). As a results:
  - ✓ Cumulative damage,
  - ✓ Premature equipment failure,
  - ✓ Data losses, system resets, and down time.



Transient Overvoltage Coupling

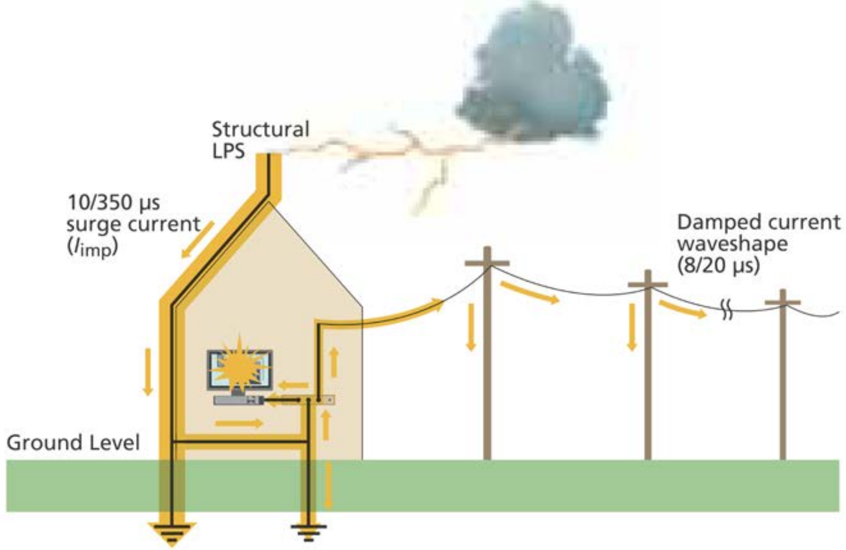


Illustration of lightning current flow from a direct strike to a structure

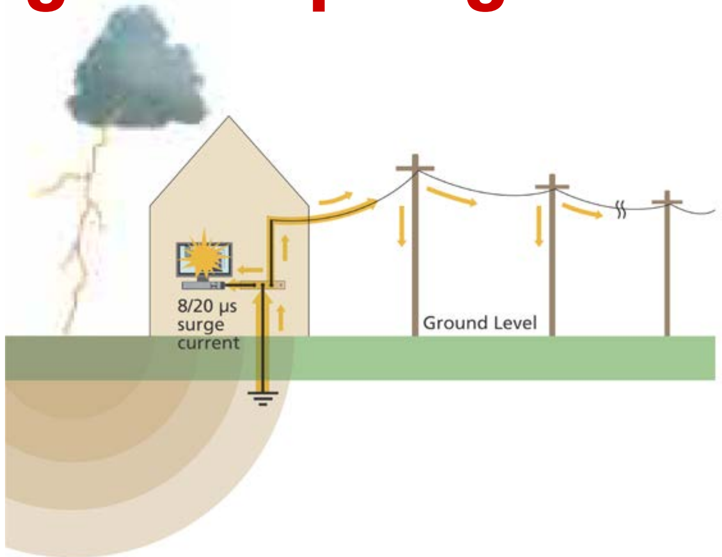


Illustration of lightning current flow from a direct strike near the structure

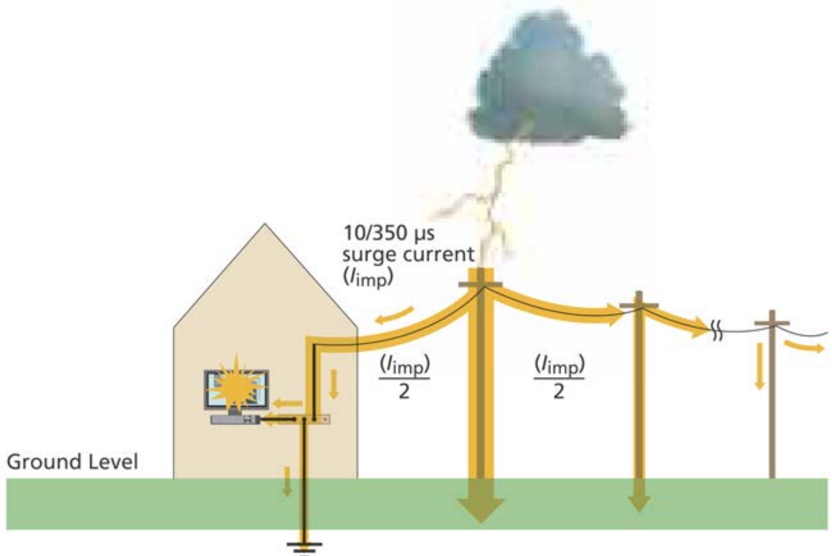


Illustration of lightning current flow from a direct strike to a nearby service

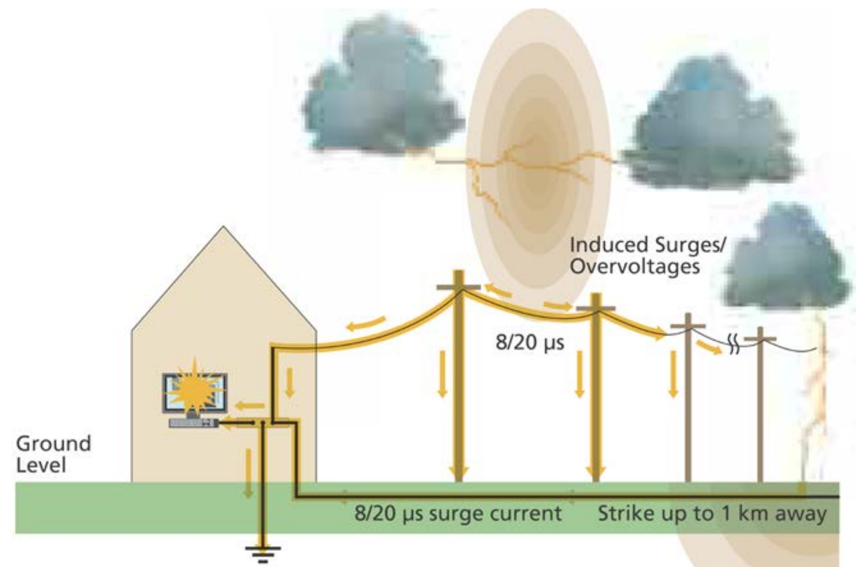
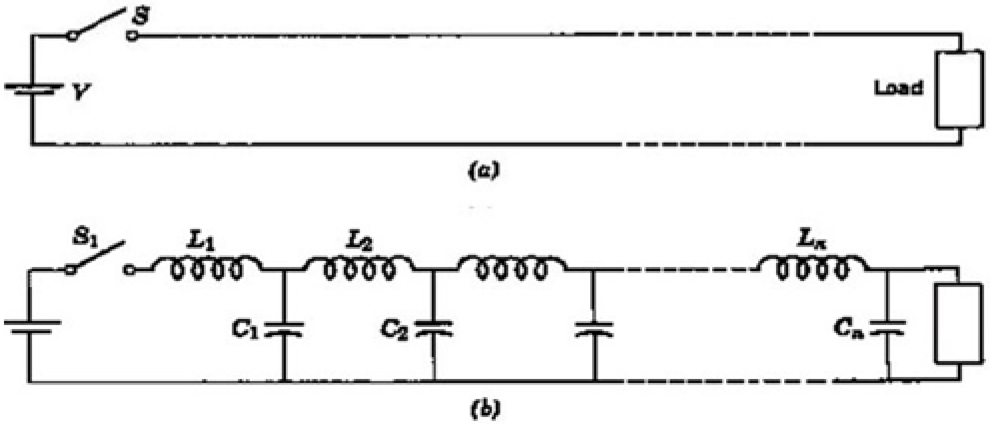


Illustration of lightning current flow from lightning flashes near connected services

http://www-public.tnb.com/eel/docs/furse/ESP_-_Introduction.pdf

Surge Propagation: Traveling Waves

- Consider closing the source to a transmission line as shown:
  - ✓ In the lumpy representation V and I will appear through out the system instantly.
  - ✓ In the distributed systems, V and I develop through successive propagation of the disturbance.



(a) Two-wire transmission line, (b) "Lumpy" Representation [3]

- Let the distributed line parameters be:
  L: Inductance/m of the line.
  C: Capacitance/m of the line.
  R: Negligible

- The differential equation describing the propagation of the voltage and current waves as a function of both space and time are:

$$\frac{\partial^2 V}{\partial x^2} = LC\,\frac{\partial^2 V}{\partial t^2}, \text{ and } \frac{\partial^2 I}{\partial x^2} = LC\,\frac{\partial^2 I}{\partial t^2}$$

Surge Propagation: Traveling Waves

- The solutions for V and I can be obtained as:

$$V = f_1(x - vt) + f_2(x + vt)$$

$$I = \frac{1}{Z_o} f_1(x - vt) - f_2(x + vt)$$

Where,

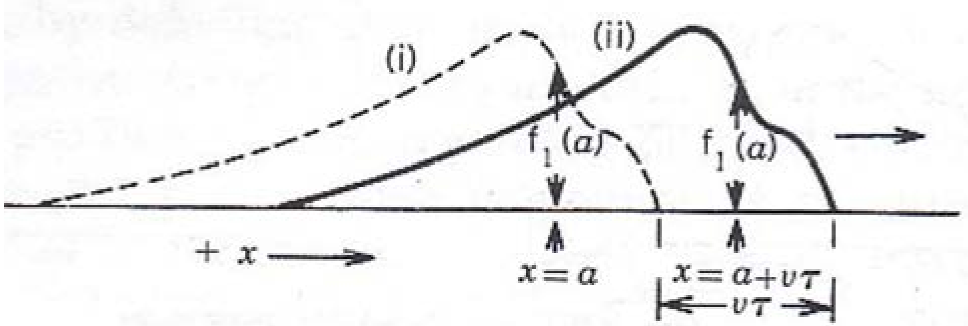
$Z_o = \sqrt{L/C}$ is the characteristic impedance of the line, and

$v = 1/\sqrt{LC}$ is the velocity of propagation of the disturbance

- Each part of the voltage and current can be interpreted as a travelling wave, moving with a velocity v.

Note that:

$$f(x - vt)\big|_{x=a}^{t=0} = f(x - vt)\big|_{x=a+\tau v}^{t=\tau} = f(a)$$



The function $(x\text{-}vt)$ at (i) $t = 0$ and (ii) $t = \tau$ [3].

Surge Propagation: Traveling Waves

- After switching the voltage and current do not reach the entire circuit instantly. It rather travels, as a wave, at a velocity ($v = 1/\sqrt{LC}$), which depend on *L* and *C*.
- It may be shown that:
  - ✓ For <u>overhead</u> transmission lines:

    $v = 1/\sqrt{LC} \approx 1/\sqrt{\mu\varepsilon}$

    $v \approx \frac{1}{\sqrt{\mu_o \varepsilon_o}} = c \approx 3 \times 10^8$ m/s or 300 m/µs

    $\mu_0 = 4\pi \times 10^{-7}$ H/m
    $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

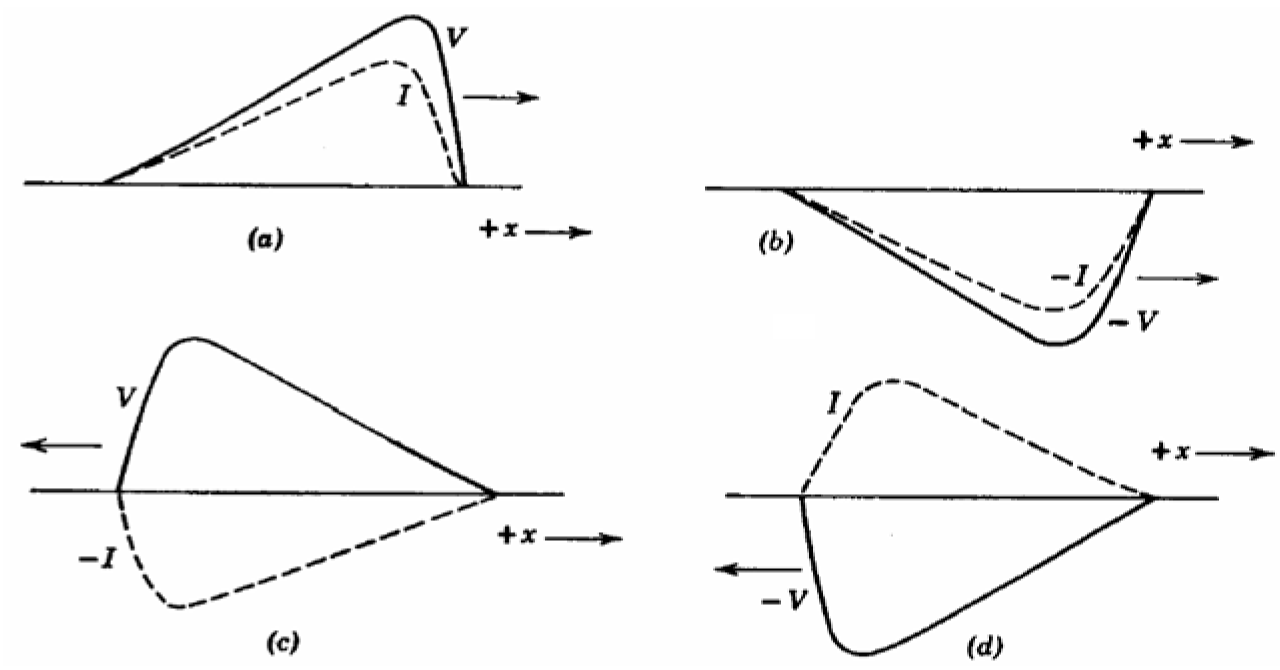
    In reality, the actual velocity will be lower than the speed of light.
  - ✓ For <u>cables</u>: $v \approx \frac{1}{\sqrt{\mu_o \varepsilon_o \varepsilon_r}} = \frac{c}{\sqrt{\varepsilon_r}}$ m/s

    ε_r = is the relative permittivity of the insulation.
- The magnitudes of the voltage and current waves are related by the surge impedance. That is, $I = V/Z_o$
  where, $Z_o = \sqrt{L/C}$, which also depends on *L* and *C*.

Surge Propagation: Traveling Waves

- Note that $I = \frac{1}{Z_o} f_1(x - vt)$-$f_2(x + vt)$

  The current wave in -x direction has a negative - sign, so that the magnitudes of V and I will be negative of each other for this wave



Various combinations of voltage and current waves [3].

Discontinuities

- Since traveling waves are affected by the characteristic impedance (Z_o), it undergoes major changes when it reaches junctions of components or regions having different characteristics impedances.
- Discontinuities are when the characteristics of the circuit changes. Example of discontinuities are when the wave moves from:
  - ✓ Line to cable
  - ✓ Line to unloaded transformer
  - ✓ Line with a Fault
  - ✓ Line to a bus with many feeders, etc
- The characteristics impedance of the circuit changes at the junction or a discontinuity.
- The effect of such changes can have significant impact on the transient behaviour of the circuits and circuit conditions.
- These changes are analysed using reflection and transmission (refraction) of waves at such junctions.

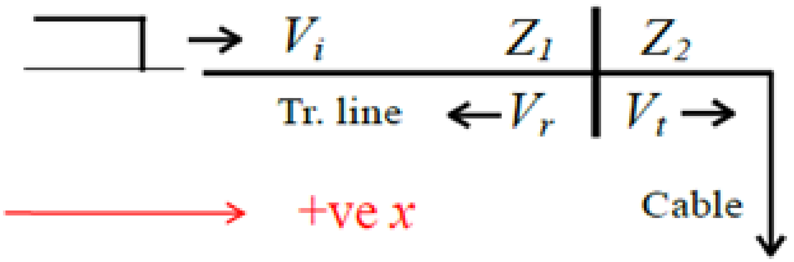
Reflection and Transmission of Traveling Waves

- Consider an incident wave V_i traveling down a transmission line with characteristic impedance Z_1 reaching the bus bar connected to a cable of characteristics impedance Z_2.

- A part of V_i will be transmitted to the cable (V_t) and a part (V_r) will be reflected back to the transmission line.

- The relationship at various sections are:

$$I_i = \frac{V_i}{Z_1}, I_r = -\frac{V_r}{Z_1}, \text{and } I_t = \frac{V_t}{Z_2}$$



- Equating voltages and currents at the two sides of the junctions:

$$V_i + V_r = V_t, \text{and } I_i + I_r = I_t \Rightarrow \frac{V_i}{Z_1} - \frac{V_r}{Z_1} = \frac{V_t}{Z_2}$$

Reflection and Transmission of Traveling Waves

- Solving these equations:

$$V_r = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right] V_i = \alpha V_i \qquad \text{and,} \qquad V_t = \left[\frac{2Z_2}{Z_2 + Z_1}\right] V_i = \beta V_i$$

$\alpha = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]$ is called the reflection coefficient of the junction, and

$\beta = \left[\frac{2Z_2}{Z_2 + Z_1}\right]$ is called the transmission coefficient of the junction.

- These coefficients can be used to determine what portions of the traveling waves enter the terminal equipment, the cables in this case. It should be noted that for certain combination of Z_1 and Z_2 the surge at the terminal can be larger than the actual incident wave V_i.

Example

- A transmission line with L=1.6mH/km and C=0.01μF/km is terminated at a cable having a surge impedance of 50 Ω and a capacitance of 0.2 μF/km.

Calculate:

a) Surge impedance of the transmission line

b) Velocity of the wave propagation in the transmission line and in the cable

If a steep fronted wave of 300 kV reaches the junction from the transmission line, compute the reflected and the transmitted voltage.

a) Surge impedance of tr. line: $Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{1.6\times10^{-3}}{0.01\times10^{-6}}} = 400\Omega$

b) Velocity of propagation in the line:

$$v = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{1.6\times10^{-3}\times10^{-3}\times0.01\times10^{-6}\times10^{-3}}} = 2.5\times10^{8}\,\frac{m}{s}$$

Example

b). Velocity of propagation in the cable:

$$Z_0 = \sqrt{\frac{L}{C}} \Rightarrow L = C\, Z_0^{\,2} = \frac{0.2\times10^{-6}}{1000}\times 50^2 = 0.5\times10^{-6} \text{ H/m}$$

$$v = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.5\times10^{-6}\times\dfrac{0.2\times10^{-6}}{1000}}} = 1.0\times10^{8}\text{m/s} = 100 \text{ m/}\mu\text{s}$$

c) Reflection co-efficient: $\alpha = \left[\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right] = \left[\dfrac{50-400}{50+400}\right] = -0.78$

Transmission co-efficient: $\beta = \left[\dfrac{2Z_2}{Z_2 + Z_1}\right] = \left[\dfrac{2\times 50}{50+400}\right] = 0.22$

Reflected voltage = - 0.78×300 = -234 kV

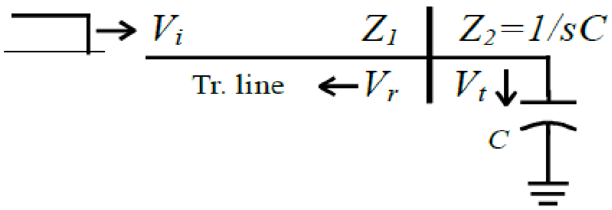
Transmitted voltage = 0.22×300 = 66 kV

- Note that the voltage wave entering the cable is much less than the wave arriving the junction.

Traveling wave at a General (Capacitor) Termination

- Consider a step incident wave V_i traveling down a transmission line with characteristic impedance Z_1 reaching the bus terminated at a capacitance C (say, shunt compensation).
- In the previous example, both the characteristics impedances were real numbers. ($Z_1 = \sqrt{L_1 / C_1}$, and $Z_2 = \sqrt{L_2 / C_2}$)
- s-domain analysis is convenient to investigate the reflected (V_r) and transmitted voltages (V_t) at general junctions.
- For the capacitor termination,

$$Z_2 = \frac{1}{sC}, \quad \text{and}$$



step surge: $$V_i = \frac{V_i}{s}$$

- Therefore, the reflected surge,

$$V_r(s) = \frac{Z_2 - Z_1}{Z_2 + Z_1} V_i = \frac{\frac{1}{sC} - Z_1}{\frac{1}{sC} + Z_1} \frac{V_i}{s} = \frac{V_i}{s} \frac{(1/CZ_1) - s}{(1/CZ_1) + s}$$

Traveling wave at a Capacitor Termination (cont'd)

- Denoting $(1/CZ_1)$ by α, it can be written as: $V_r(s) = V_i\left[\frac{1}{s} - \frac{2}{s+\alpha}\right]$

  so that, $V_r(t) = V_i\ [1 - 2e^{-\alpha t}]\ = V_i\ [1 - 2e^{-(1/CZ_1)t}]$

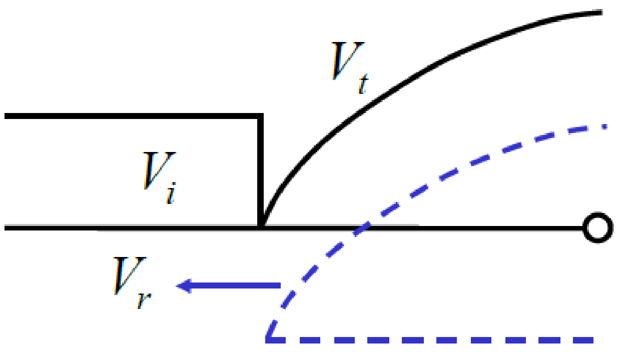
- Similarly, the transmitted surge,

$$V_t(s) = \frac{2Z_2}{Z_2 + Z_1}\ V_i\ = \frac{\frac{2}{sC}}{\frac{1}{sC} + Z_1}\ \frac{V_i}{s}\ = \frac{V_i}{s}\ \frac{(2/CZ_1)}{(1/CZ_1) + s} = 2V_i\left[\frac{1}{s} - \frac{1}{s+\alpha}\right]$$

  and, $V_t(t) = 2V_i\ [1 - e^{-\alpha t}]\ = 2V_i\ [1 - e^{-(1/CZ_1)t}]$

- The propagation of V_i, V_r and V_t are shown in the following diagrams. It should be noted that the transmitted voltage reaches a magnitude, which is double the incident voltage surge.

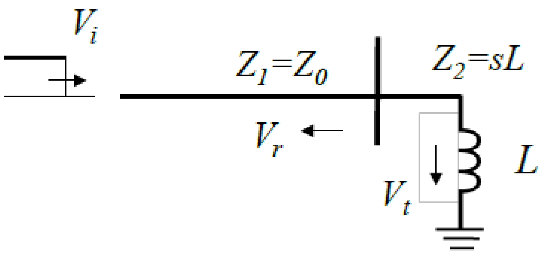
- However, this voltage is no longer a step voltage with steep front, but rises with a rise time constant of CZ_1.



Traveling wave at an Inductor Termination

- Consider a step incident wave V_i traveling down a transmission line with characteristic impedance Z_1 reaching the bus terminated at an Inductance L (say, a transformer).
- s-domain analysis is convenient to investigate the reflected (V_r) and transmitted voltages (V_t) at general junctions.
- For the inductorr termination,

$$Z_2 = sL, \quad \text{and step surge: } V_i = \frac{V_i}{s}$$

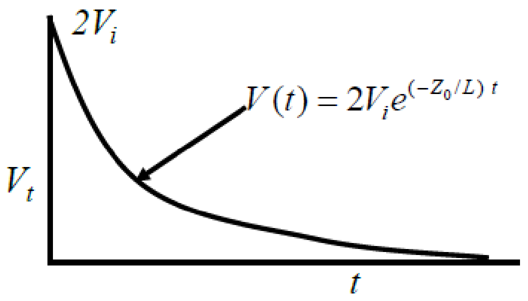


- Therefore, the transmitted surge,

$$V_t(s) = \frac{2Z_2}{Z_2 + Z_1} V_t = \frac{2sL}{sL + Z_0} \frac{V_i}{s} = 2V_i \frac{1}{s + (Z_0 / L)}$$

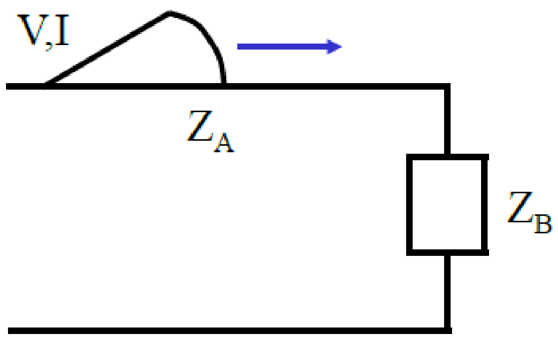
$$V_t(t) = 2V_i \, e^{-(Z_0/L)t}$$

- The shape of the voltage is as shown, and the maximum value is $2V_i$ at t=0.

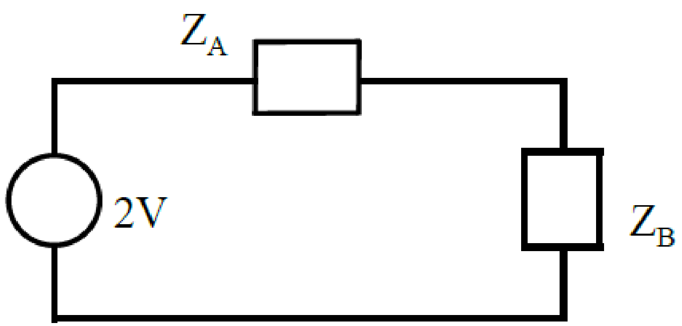


Equivalent Circuits for Refracted Waves

- For a wave (V, I) approaching a junction from Z_A to Z_B,
  - the refracted voltage is: $$V_B = \left[\frac{2Z_B}{Z_B + Z_A}\right] V = \beta V$$ $$= I_B \times Z_B$$
  - the refracted current is: $$I_B = V_B / Z_B = \left[\frac{2V}{Z_B + Z_A}\right]$$
- Therefore, the actual circuit on the left can be represented by the equivalent shown on the right.



Circuit



Equivalent

- When the line is terminated at high impedance equipment or open terminal, V_B**= 2 V**. This observation will be used in many occasions.

Switching Over-voltages

- Two common sources of over-voltages in transmission lines are:
  - Switching events,
  - Lightening

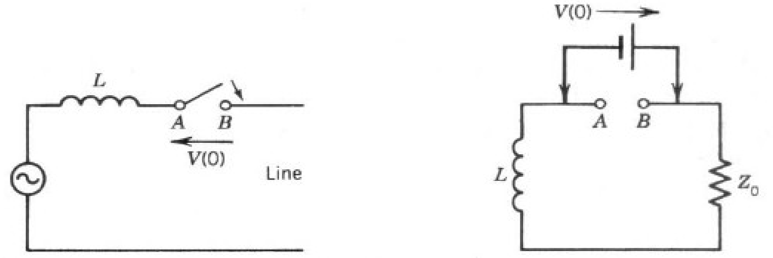
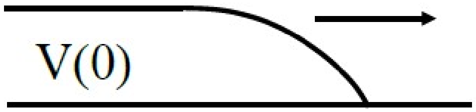


Fig. 9.19. Connecting a transmission line to an inductive source: (*a*) one line diagram, (*b*) equivalent circuit.

- Consider the switching operation shown in the following figure: The voltage across the switch before switching V(0), will be divided between the source and the transmission line. Therefore, the voltage impressed on the line will be:

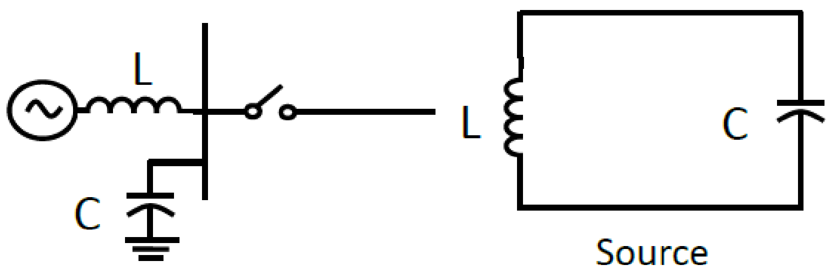
$$v(s) = \frac{V(0)}{s} \frac{Z_0}{Z_0 + sL} \quad \Rightarrow \quad v(t) = V(0)[1 - e^{-(Z_0/L)t}]$$



- The switching surge starts at 0, but will rise exponentially to the max value *V(0)* with time constant L/Z_0.
- The value of *V(0)* depends on the instant of switching, and the maximum value of *V(0)* in a three phase system can be $\pm\sqrt{2}(V_L/\sqrt{3})$.

Switching Over-voltages

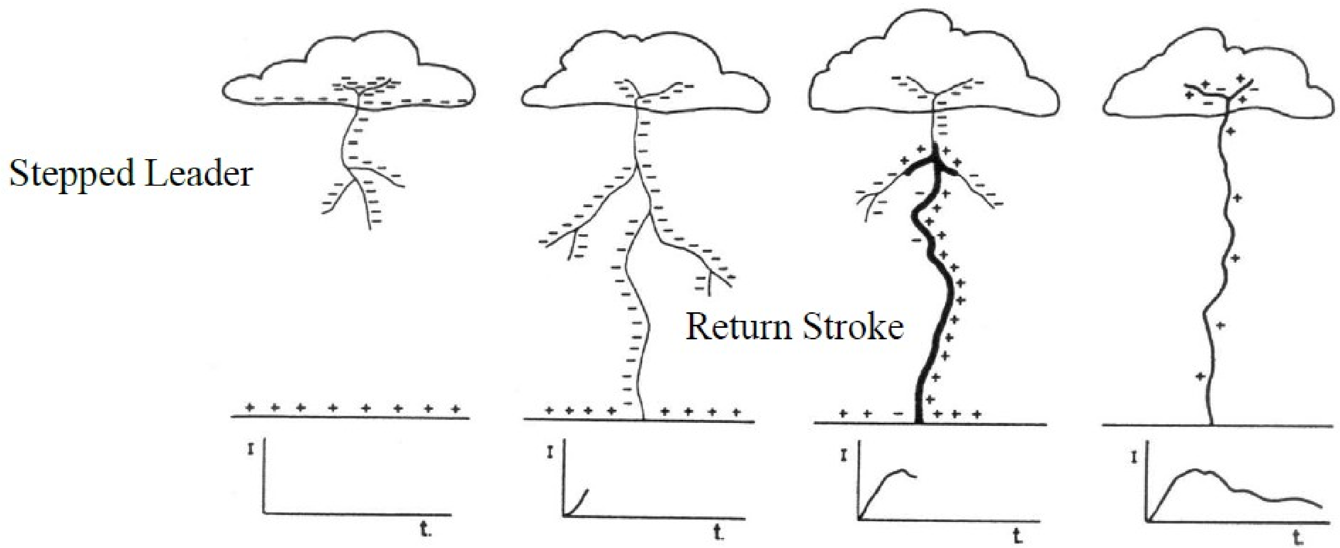
- If the transmission line is open ended, the maximum voltage at the open end can rise to $2 \times \sqrt{2}(V_L/\sqrt{3})$ after reflection. $\beta = 2$
- In the worst case situation, if the transmission line happens to have trapped charges the maximum trapped voltage would be $\pm \sqrt{2}(V_L/\sqrt{3})$. Then,
  - In this situation, the maximum value of $V(0)$ is $\pm\, 2\times\sqrt{2}(V_L/\sqrt{3})$, which happens when the source voltage and the trapped voltage are of opposite polarities.
  - If the transmission line is open ended, then the voltage at the open end can rise to $3\times\sqrt{2}(V_L/\sqrt{3})$.
- In a more general configuration, the source impedance may consist of many components. A simple example will be:



$$Z(s) = \frac{Ls \cdot \dfrac{1}{Cs}}{Ls + \dfrac{1}{Cs}} = \frac{Ls}{LCs^2 + 1}$$

Lightning Phenomenon

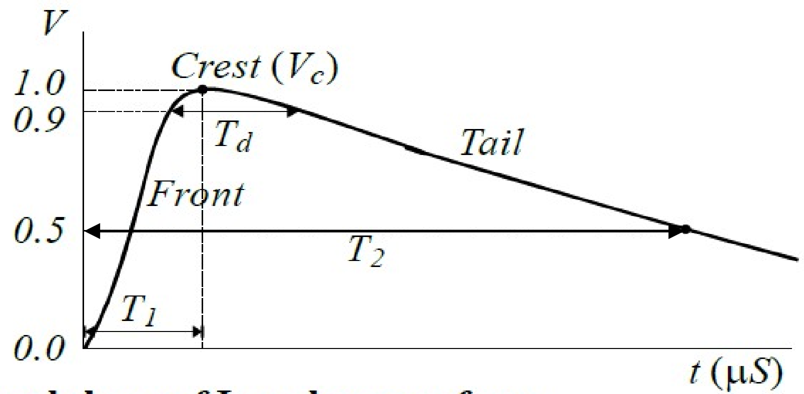
- Lightning is the discharge of the electric charge accumulated in the clouds. The general discharge process is indicated in the following diagrams.



- Lightening strokes from cloud to ground account only for about 10% of all lightning discharges, the majority take place between clouds.
- The general shape of current surge resulting from lightning discharge at various stages is shown in the diagram.
- The lightning current is commonly modeled as an impulse wave.

Impulse Voltage Wave

- The important features of an impulse wave are shown in the following figure.
- The impulse wave is specified as: T_1/T_2 μS V_c kV, where
  - T_1: Time to crest (rise time)
  - T_2: Time to half-value (half time)
  - T_d : Time above 90%



General shape of Impulse wave form

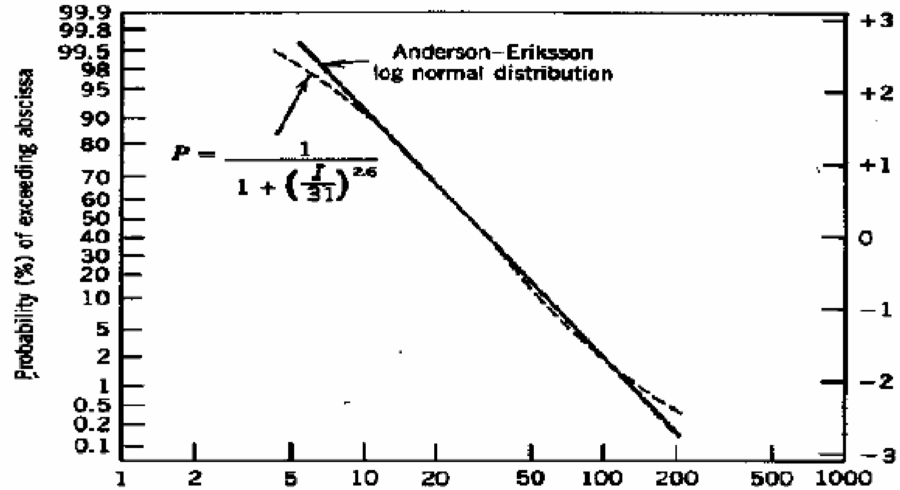
- The lightning surges are represented by currents with impulse shape. The parameters of a typical lightning wave lie in the following ranges:
  - The rise time range between 1-10 μs
  - The half time range between 50-1000 μs
  - A typical lightning current impulse may be: 1/50μs, 10 kA

Lightning Surges

- The cumulative distribution shown relates to the magnitude in negative lightning flashes.

- The lightning stroke current is almost always more than 10 kA.

- The high lightning current is characterized by a sharp rise to crest (1-10μs) followed by a longer decay time (50-1000μs) to half time.

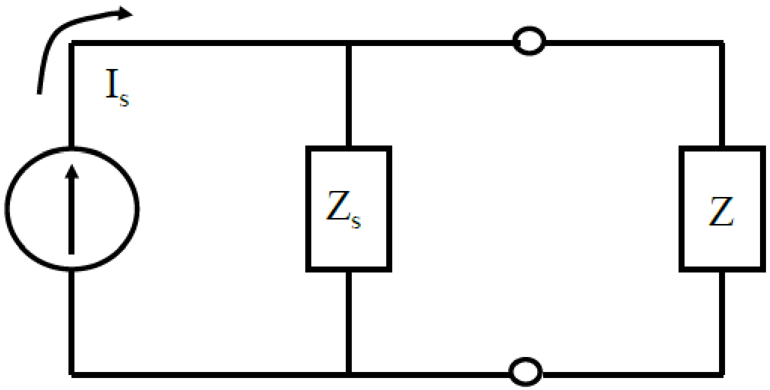


Cumulative probability distribution of stroke current magnitude

  - 50% of currents have a rate of rise exceeding 20kA/μs and 10% exceed 50kA/μs.
  - The mean duration of currents above half value is 30μs and 18% have longer half-times than 50μs.

Modeling Lightning Surge

- Lightning strokes are commonly analyzed by modeling it as a current source: where,
  I_s - the stroke current
  Z_s-lightning channel impedance
  Z-impedance of the stricken object



- Then the voltage developed across the stricken object:

$$V_s = I_s \frac{Z_s Z}{Z_s + Z} = I_s \frac{Z}{1 + Z / Z_s}$$

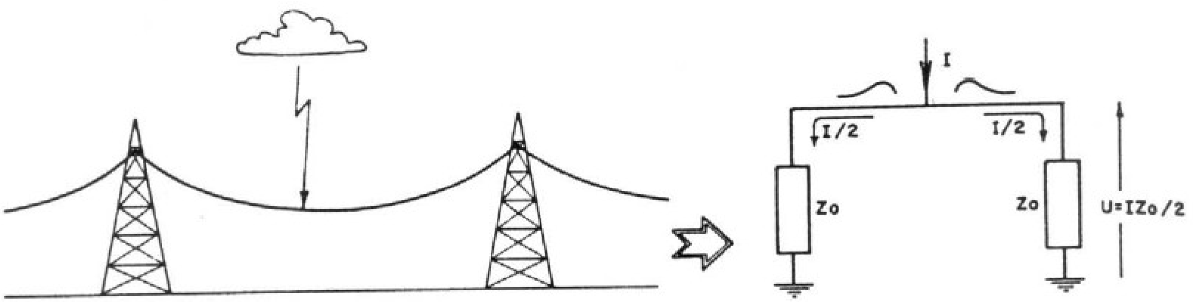
- Z_s is usually quite high ('000 Ω) compared to Z, (Z_0 ~ '00 Ω), and therefore,
  Surge voltage developed: $V_s \approx I_s Z$
- It can be seen that lightning surges are independent of the system voltage.

Mid Span Strike

- Lightning strikes transmission lines (usually earth wire) in the middle of the line. The schematic and the corresponding circuit are shown below.

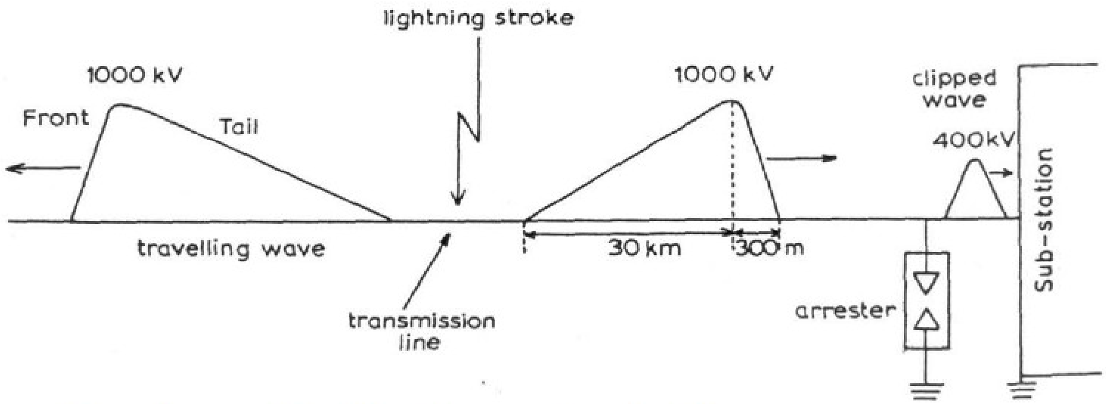
- The voltage wave due to the strike in a line with a surge-impedance Z_0 will be:

$$V_s = I_s Z_0 / 2$$



- For a stroke current of 5 kA, a trans. line of surge impedance of 400 Ω, the lightning voltage surge is:

$$V = 5\times10^3\times400/2$$
$$= 1000\ \text{kV}$$



- The propagation of the surge is schematically shown in the figure.

Protection against Over-voltages / Lightning

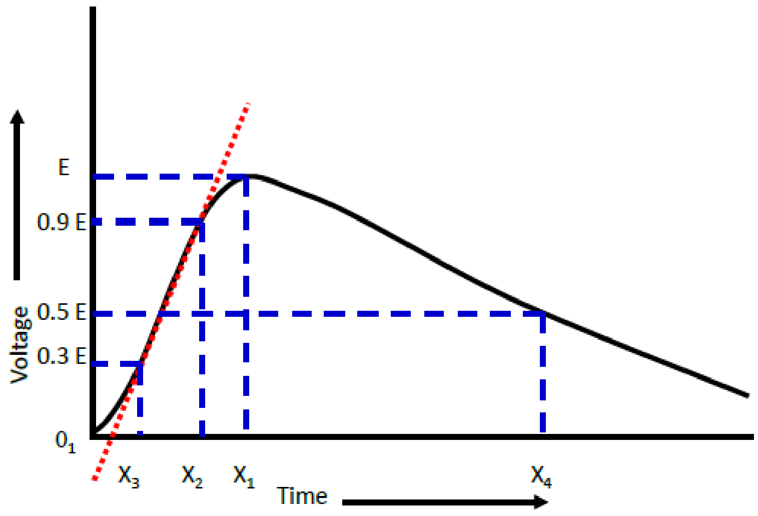
- Surges can enter the substation on the phase conductors. Protective devices must be connected between the phase conductors and to “absorb” or “divert” the energy of surges to ground.
- The information required are:

1. **Stress** - likely magnitude and frequency of over-voltages 50 or 60 Hz temporary over-voltages, lightening & switching surges, etc. This has been discussed.
2. **Strength** - withstand capability of various insulation components, solid, liquid, gas (air mainly, sometimes SF6).
3. **Protection** - devices & arrangements that will eliminate or reduce the effects of surges.
4. **Economics** - cost of different approaches: 1, 2 & 3 must be coordinated to be effective yet economical.

Strength: Withstand Voltage

- Voltage an equipment/component can withstand depends upon:
  - The Magnitude of the stress
  - Rate at which it is applied
  - Duration of stress (equipment can withstand a higher voltage for a shorter period of time)
- The characteristics is statistical: does not always fail at a particular value.
  - Scatter tends to be greater for more non-uniform geometry
- Insulation ages: the strength deteriorates with age.
- Withstand voltage is expressed in terms of Volt-Time Characteristics, which are generally measured with a standard impulse voltage input.
  - Peak value
  - Rise time (Front)
  - Decay time (Tail)

Example: 20 kV, 1.2/40 µs

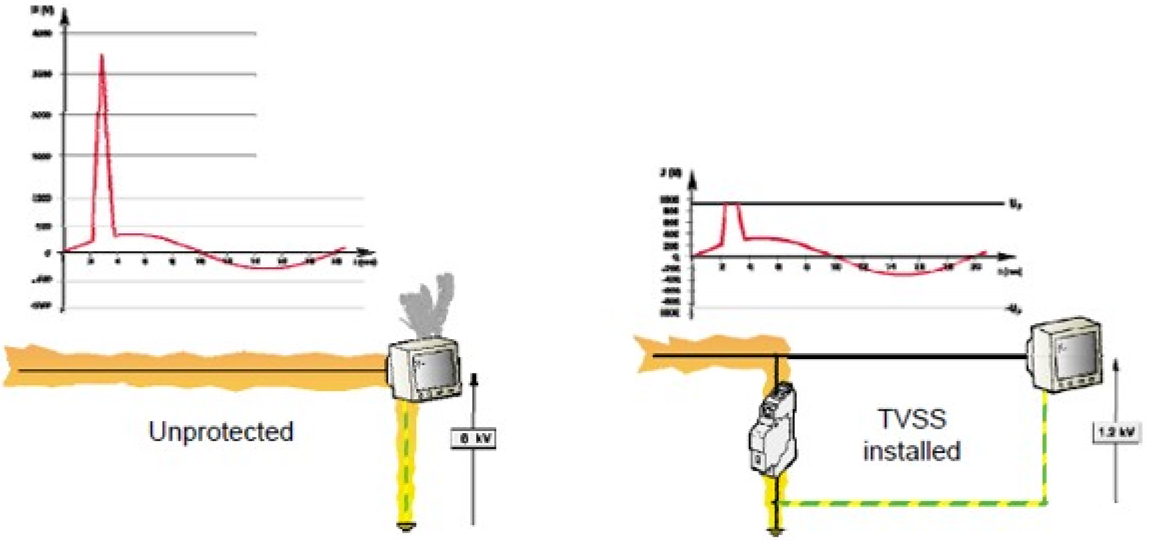


Basics of Protection against Over-voltages

- Transients are a fact of life, which may be due to:
  - Switching (can control some what)
  - Lightning
  - Equipment failures, etc.
- Must accept surges as matter of economics: strive to minimize the overall cost.
- Fundamental principles of over-voltage protection:
  - Limit the voltage across sensitive insulation/equipment
  - Divert the surge current away from the load
  - Block the surge current from entering the load
  - Bond grounds together at the equipment
  - Reduce, or prevent, surge current from flowing between grounds
  - Create low pass filter using limiting and blocking principles

Overvoltage Protection

- Devices intended to limit transient voltages and divert surge currents to the ground



- Surge duration is between 20 – 350µs (millionths of a second)
- Breaker response time: 10 – 60ms (thousandth of a second)
- **SPD** response time: **3-100ns** (**billionths** of a second)
- **Even at a surge duration of 350µs, the breaker is too slow to respond to the surge**
- **The SPD is much faster, ensuring protection**

Protection against Overvoltages

- The figure illustrates the basic principles. Commonly used devices/equipment are:
  - Arresters / Diverters
    - Metal Oxide Varistors (MOVs)
  - Transient voltage surge suppressors (TVSS)
  - Isolation transformers
  - Low pass filters
  - Low impedance power conditioners

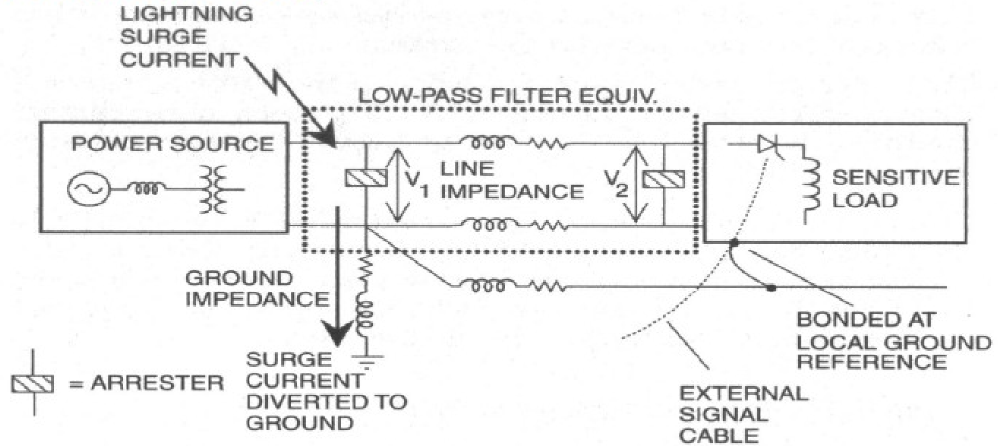


Figure 4.16 Demonstrating the principles of overvoltage protection.

- The devices should be located close to the equipment to protect.
- Local ground may not be at zero potential.
- Impedance of the ground paths may be significant.
- Bonding to have common ground (*eg*., lv signal cable).

Protection against Overvoltages (2)

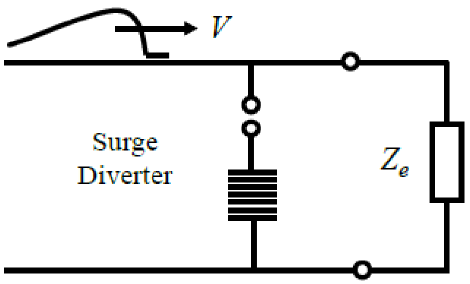
- Power system equipment are often protected against over voltages by various means and devices.
  - Overhead earth wire(s) may protect the phase conductors from direct lightning stroke.
  - Surge Diverters are devices connected in parallel with an equipment to protect against over voltages.
    - They do not pass any current flow during normal conditions
    - They break down (ie, flashes over) when the abnormal voltage arrives.
    - Examples are: Rod Gap (Arcing rings), Expulsion tubes, etc.
- Lightning arresters with non linear resistance are commonly used.
  - A lightning arrester behaves like a switch which closes momentarily (~10mS) on an over voltage. Their basic characteristics are that:
    - They should pass no current at normal voltage,
    - They should break down as quickly as possibly after the abnormal voltage appears, and
    - They should interrupt the power frequency follow-on current after a flash over.

Surge Diverters / Arc Gaps

Use of the traditional diverter to protect an equipment is shown below.

- Before the gap sparks over, voltage across Z_e is the refracted voltage.

$$V_{th} = \frac{2Z_e}{Z_0 + Z_e} V, \qquad Z_{th} = \frac{Z_0 Z_e}{Z_0 + Z_e}$$

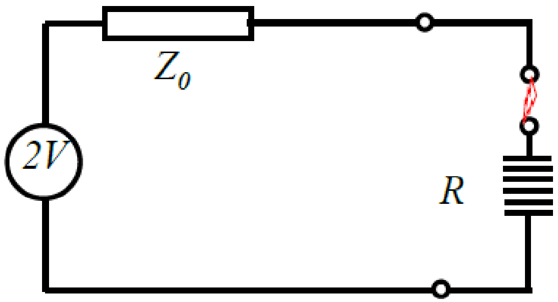


- When the gap sparks over,

Voltage across R, $V_R = V_e = \frac{R}{R + Z_{th}} V_{th}$

- Normally, $Z_e >> Z_0$, then, $V_{th} \approx 2V$, and $Z_{th} = Z_0$.

- The equivalent circuit will be as shown.

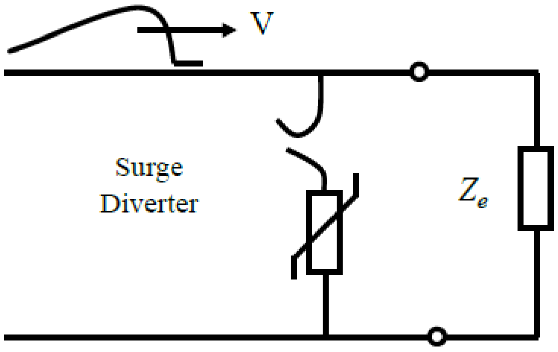


so that $$V_e \approx \frac{R}{R + Z_0} 2V$$

- Selecting the value of $R << Z_0 << Z_e$, the voltage V_e is attempted to maintain within the withstand voltage of the equipment.
- However, it possible for V_e to exceed the withstand voltage of the equipment if V gets sufficiently high.

Use on Nonlinear Resistors in Arresters

- Use of non linear resistor in an arrester to protect an equipment is shown below.
- As shown earlier, befor the spark over,



$$V_{th} = \frac{2Z_e}{Z_0 + Z_e} V \approx 2V$$

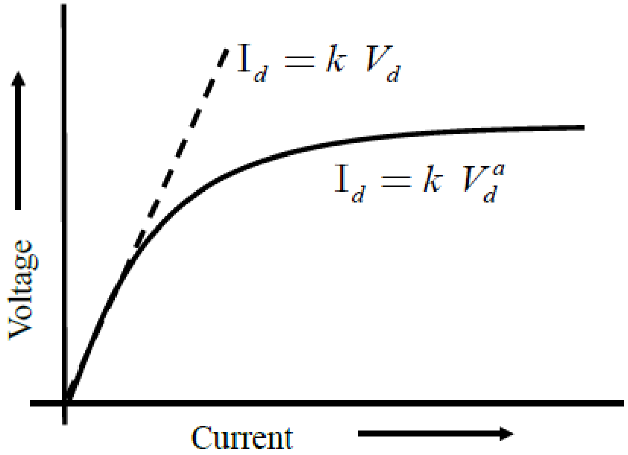
$$Z_{th} = \frac{Z_0 Z_e}{Z_0 + Z_e} = Z_0$$

- When the spark over occurs, the simple voltage divider is not valid for the non linear resistor. The *v-i* characteristics of the non-linear resistor is of the form shown in the figure and described by:

$I = k\, V^{\alpha}$, (α = 4~6 for SiC3),

(usually, *I* in A and, *V* in kV).

- Therefore, the value of the voltage V_e has to be found from simultaneous solution of the circuit equation and the resistor characteristics.

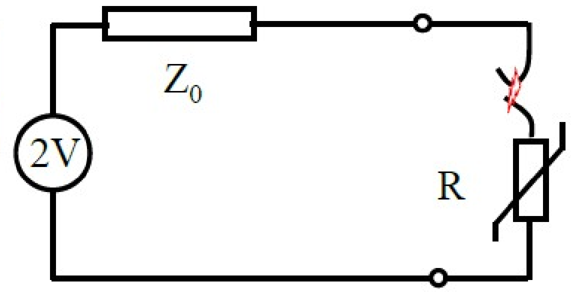


Analysis: Graphical Analysis

- With, $Z_e >> Z_0$, the equivalent circuit after spark over becomes:

  since, $V_{th} = \dfrac{2Z_e}{Z_0 + Z_e} V \approx 2V$, $Z_{th} = \dfrac{Z_0 Z_e}{Z_0 + Z_e} = Z_0$

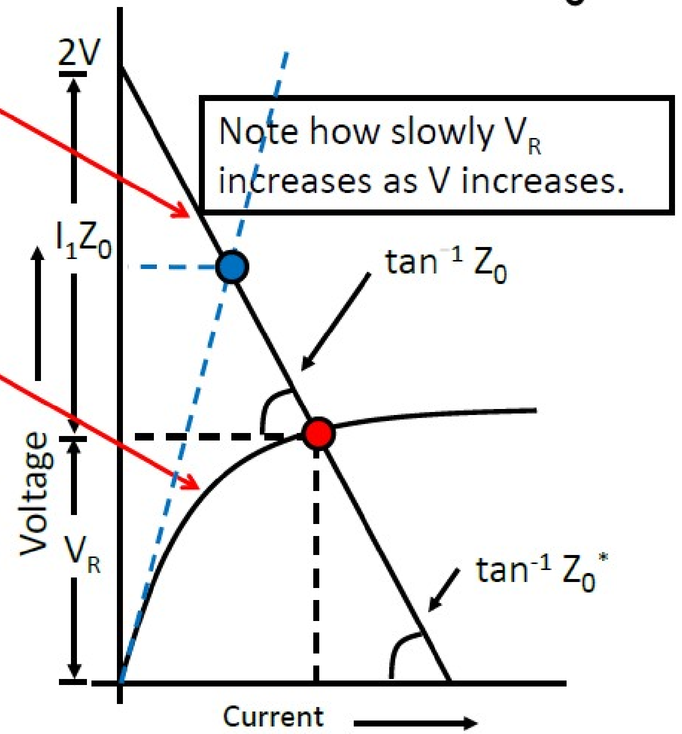
  Hence, $V_R = 2V - IZ_0$ (1)



- This equation need to be solved along with the non-linear characteristics of the resistor,

  $$I = k\, V_R^{\alpha}, \qquad (2)$$

- The graphical solution methodology is as shown. It should be noted that,
  - V_R can be kept within limits, and
  - V_R rises very slowly even when V gets significantly high.
- Usually, V is expressed in kV
  I is expressed in A, and
  Therefore, R is expressed in kΩ.



Metal Oxide Varistor (MOV) Arresters

The purpose of using a surge arrester is to limit the overvoltages that may occur across electrical apparatus due to either lightning or switching surges. By doing so, both power apparatus and its insulation are protected against failure.

Some arresters are composed of an external porcelain tube containing an ingenious arrangement of stacked discs, air gaps, ionizers, and coils. The discs (or valve blocks) are composed of a silicon carbide material. The resistance of this material decreases dramatically with increasing voltage.

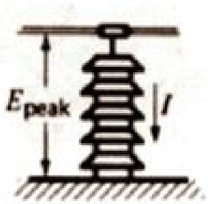
A more modern type of arrester has valve blocks made of stacked zinc-oxide discs without using any air gaps or other auxiliary devices. Its E-I characteristic is similar to that of a silicon carbide arrester, except that it is much flatter and therefore more effective in diverting surge currents. These metal-oxide varistor (MOV) arresters are largely used today.

Under normal voltage conditions, spark gaps prevent any current from flowing through the tubular column. Consequently, the resistance of the arrester is infinite. However, if a serious overvoltage occurs, the spark gaps break down and the surge discharges to ground. The 50Hz following-through current is limited by the resistance of the valve blocks and the arc is simultaneously stretched and cooled in a series of arc chambers. The arc is quickly snuffed out and the arrester is then ready to protect the line against the next voltage surge. The discharge period is very short, rarely lasting more than a fraction of a millisecond.

Metal Oxide Varistor (MOV) Arresters

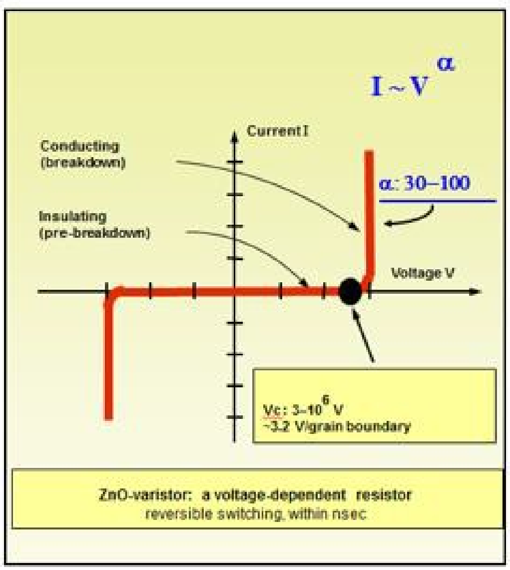
The upper end of the arrester is connected to the line or terminal that has to be protected, while the lower end is solidly connected to ground.

Ideally, a surge arrester clips any voltage in excess of a specified maximum, by permitting a large current to be diverted to ground. In this way the arrester absorbs energy from the incoming surge.



The V-I characteristic of an ideal surge arrester is, therefore, a horizontal line whose level corresponds to the maximum permissible surge voltage.

In practice, the V-I characteristic slopes upward but is still considered to be reasonably flat.



Example:
Voltage-current characteristic of a surge arrester having a nominal rating of 30kV (42.4 kV peak), used on a 34.5 kV line (28.5 kV peak, line-to-neutral)

34.5 kV : Rated L-L voltage of the line

$$28.5\text{ kV} = \left(34.5\text{ kV}/\sqrt{3}\right)\times\sqrt{2} < 42.4\text{ kV} = 30\times\sqrt{2}$$

Commercial Surge Arresters

LV < 1 kV	MV < 35 kV	HV > 35 kV






Image source: www.abb.com