Effects of surge voltage on electrical machines

Day 24

ILOs – Day24

- Introduce surge phenomena in power system
- Classify different types of surges in power system
- Explain the causes for generation of surges
- Define certain parameters related to surges

Surges in power system

- The sudden rise in voltage for a very short duration on power system is known as voltage surge or transient voltage
- Voltage surges are generally a phenomenon of high voltage (HV) power systems
- Transients can reach amplitudes of tens of thousands of volts
- Surges are considered as the most damaging to the insulation of the power system and the terminal equipment such as transformers, generators, and motors
- Surges or transients can also damage, degrade, or destroy electronic equipment within any home, commercial building, industrial, or manufacturing facility

Types of surges

Types of surges

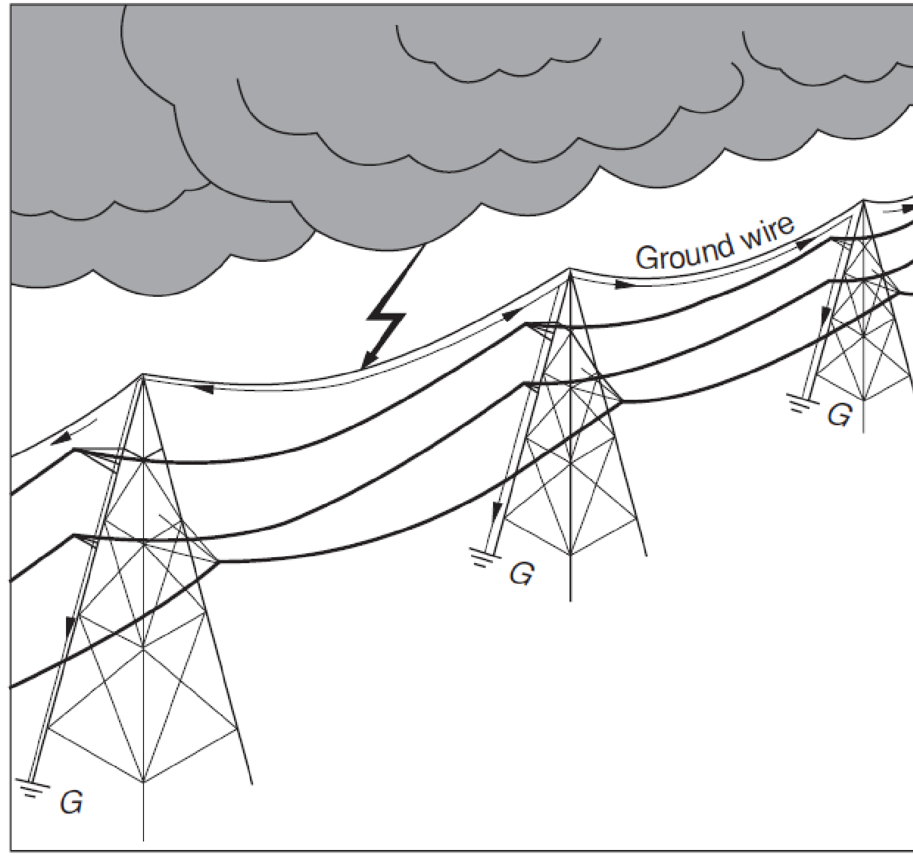
- The type of a surge is identified by its shape, and its severity is measured by its amplitude (V_t) and time (t_1) to reach this amplitude
  - **Temporary over-voltages**
  - **Voltage surge or a transient**

Types of surges - **Temporary over-voltages**

- These are of a relatively longer duration, and may have several successive peaks, lasting from one-half of a cycle to a few cycles at the power frequency, depending upon the time constant ($\propto R/L$) of the circuit that gives rise to such over-voltages
- The likely causes of such temporary over-voltages are:
  - Ground fault
  - Sudden change of load
  - Resonance and ferro-resonance effects

Types of surges - Voltage surge or a transient

- The occurrence of a surge or a transient is not intentional, and may appear on an MV, HV and EHV system as a result of system disturbances, such as during:
  - A lightning strike
  - A switching operation
  - Contact bouncing
  - Because of a surge transference from higher voltage to the lower voltage side of a power transformer
  - Arcing insulators and arcing grounds



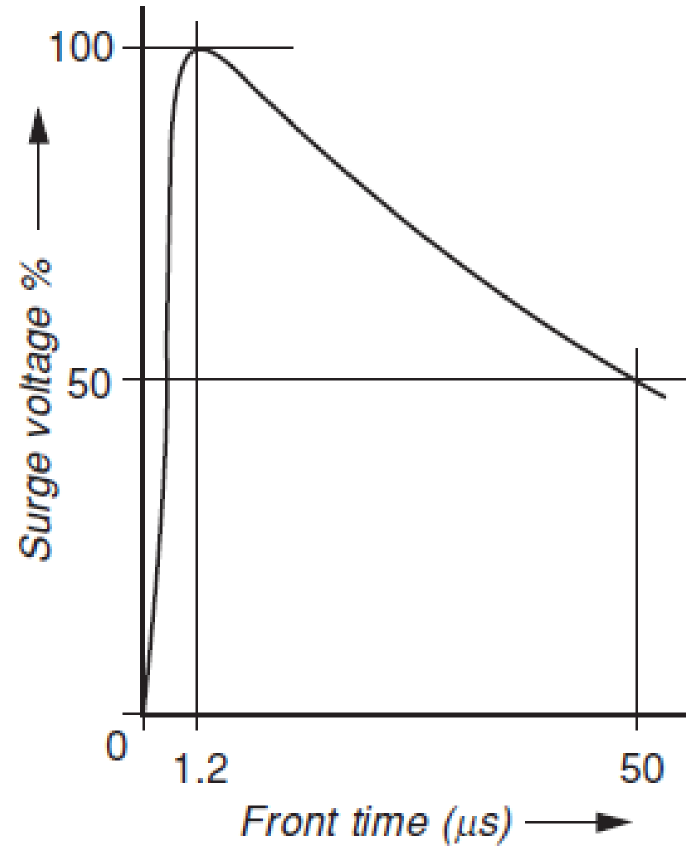
Atmospheric lightning surge

Types of surges - Voltage surge or a transient

- These surges are of very short duration and may be defined by the following two parameters:
  - The first highest peak amplitude, V_t
  - Time of rise, t_1
- *Depending upon the time of rise, a* surge may be classified into three groups:
  - Lightning surges
  - Switching surges
  - Very steep or front of wave (FOW) surges

Lightning surges

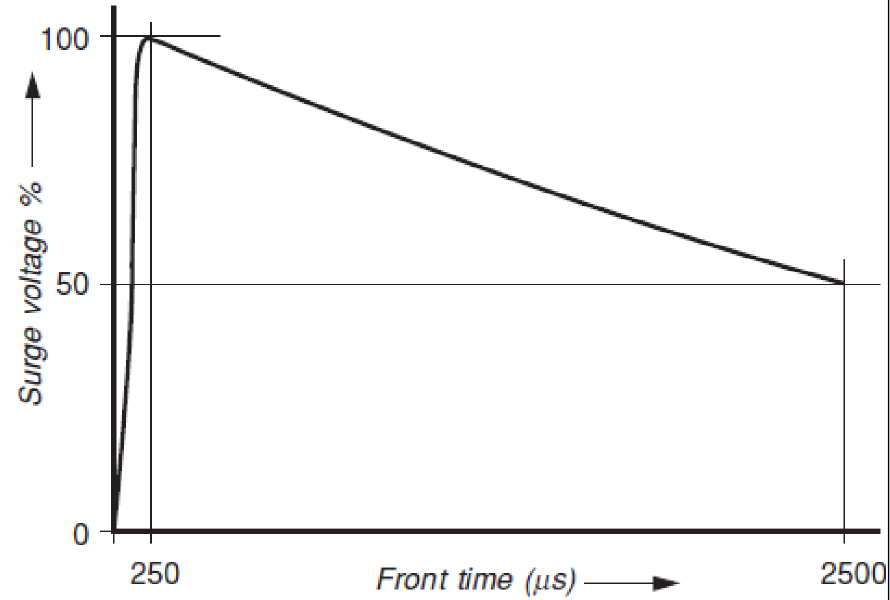
- These are fast rising and may have a front time of almost 1 µs or even less
- They are therefore considered short duration surges



A 1.2/50 µs lightning impulse

Switching surges

- These are slow rising surges and have a front time of more than 10 μ s
- They are considered as long-duration surges due to their high total effective duration
- But they discharge very high energy, even during this short duration, and may deteriorate or damage the insulating properties of the system or the terminal equipment that is subject to such a surge and absorb its severity
- For the purpose of energy discharge by a surge, the amplitude and duration of switching surges alone is considered
- The duration of these surges is much higher than that of the other two types of surges



A 250/2500 μs switching impulse

Very steep or front of wave (FOW) surges

- These are very fast rising and of very short duration and may have a front time as short as 0.1 μ s or less
- As a result, while their energy discharge may be small, their rate of rise is very rapid
- This makes them capable of damaging few line end coils of the terminal equipment
- Sometimes a restrike of the interrupting contacts of a circuit breaker, or a quick re-closing of a power equipment, may also cause such surges
- The situation may become worse:
  - When interrupting small reactive currents, such as during the opening of an unloaded power line, an unloaded transformer or a motor running at no-load. In all such cases it may cause current chopping, leading to extremely steep switching surges or,
  - When the system already had a trapped charge before a reclosure

- All electrical equipment are designed for a specific BIL
- If the actual severity of a prospective surge, is expected to be higher than these BIL levels, the same must be damped to a safe level, with the use of surge arresters, surge capacitors or both

Causes of voltage surges

- External cause
- Internal cause

Causes of voltage surges

- **External causes**
  - These are mainly due to atmospheric disturbances
  - The effect of such surges is totally different from that of switching surges, and the amplitude is independent of the system voltage
- **Internal causes**
  - These are due to sudden changes in circuit parameters inside the power system itself

Causes of voltage surges – External causes

- ***Lightning strike***
  - The most popular theory is the charging of clouds at high voltages, up to 20 million volts and a charging current 5–100 kA or so, due to the movement of hot air upwards and tiny droplets of water downwards
  - This process tends to make the tops of the clouds positive and the bottom negative, which creates a voltage gradient between the clouds and the earth.
  - The voltage gradient may exceed the breakdown value of the air and cause a flashover
  - This flashover is similar to an electrostatic discharge of the atmosphere to the ground, and is termed a lightning strike
  - There may be up to 20 pulses in each lightning strike, each having a duration of about 50 μs

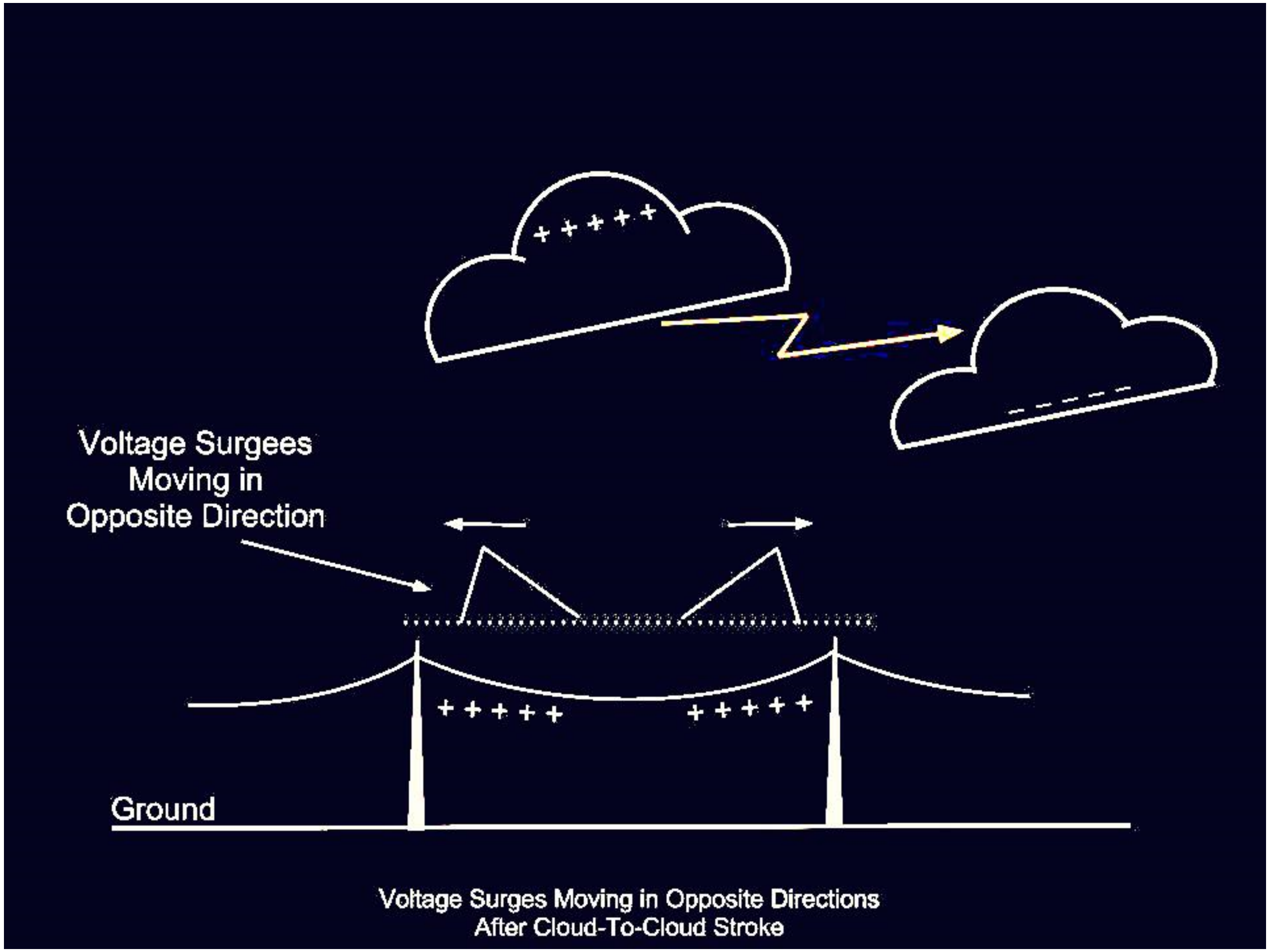
Causes of voltage surges – Lightning strike

Causes of voltage surges – External causes

- ***Electrostatically induced charges***
  - ***Due to the presence of thunder clouds in the vicinity:***
    - A charged cloud above and near the overhead line induces a charge of opposite polarity than its own in the line
    - When this cloud bursts suddenly and discharges, the induced electrostatic charge on transmission line gets free and travels in both directions on the line at a speed nearly equal to the velocity of light
    - The potential at any point along the line thus rises suddenly from its normal value to the amplitude (V_t) *of the travelling wave*
  - Due to the friction of dust or free snow blowing past the conductors

Causes of voltage surges – External causes

- ***Electrostatically induced charges***
  - ***Due to the presence of thunder clouds in the vicinity:***

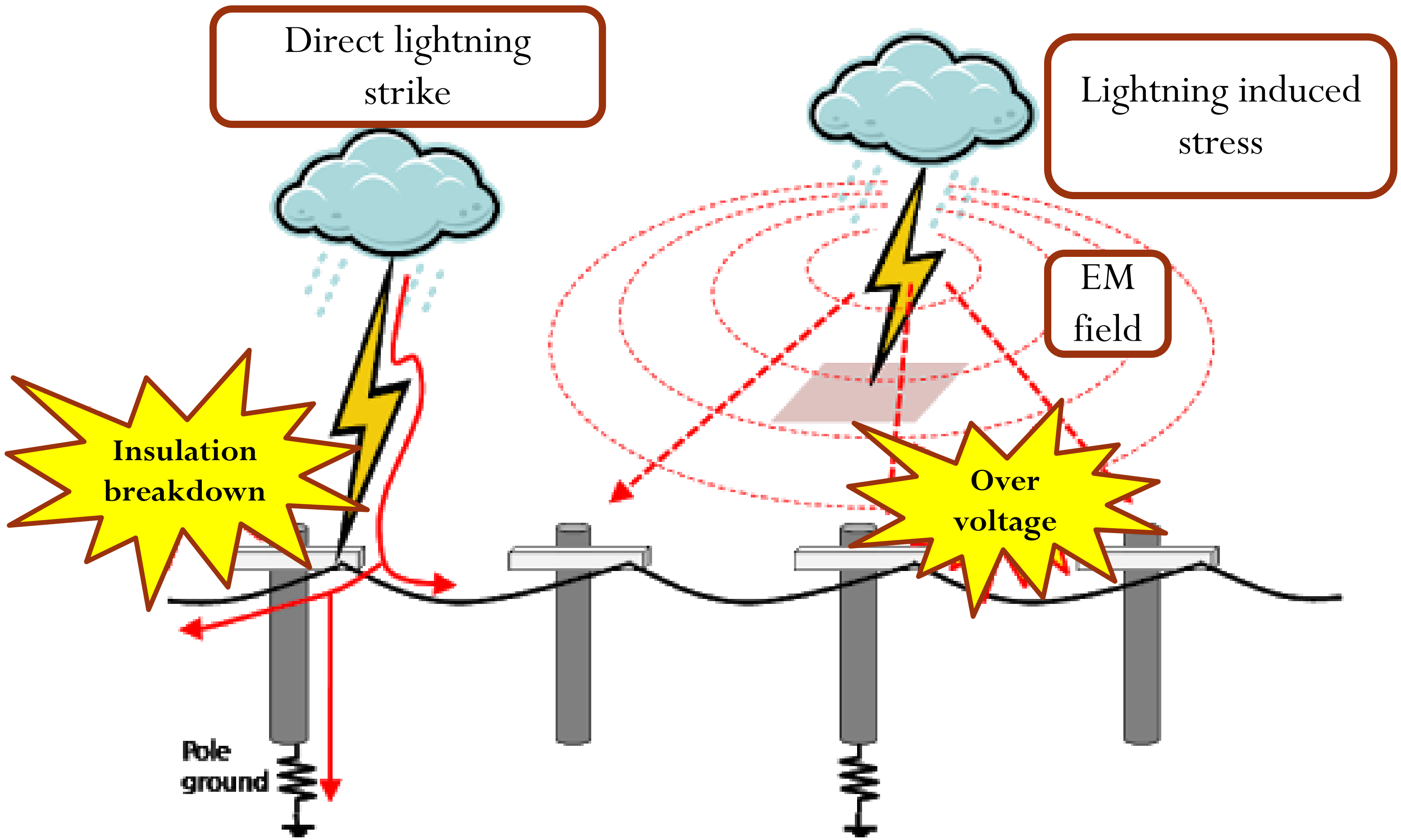


Causes of voltage surges – External causes

- ***Electromagnetically induced voltage***
  - ***Due to lightning in the vicinity of the overhead lines***
    - It is an indirect effect of a lightning strike
    - The lightning surges may impose very severe stresses on the line and cause damage to the line insulators and the terminal equipment without causing a trip by the protective device
    - These surges can be contained at the receiving end with the use of a surge arrester or a diverter

Causes of voltage surges – External causes

- ***Electromagnetically induced currents***
  - ***Due to lightning in the vicinity of the overhead lines***



Causes of voltage surges – **Internal causes**

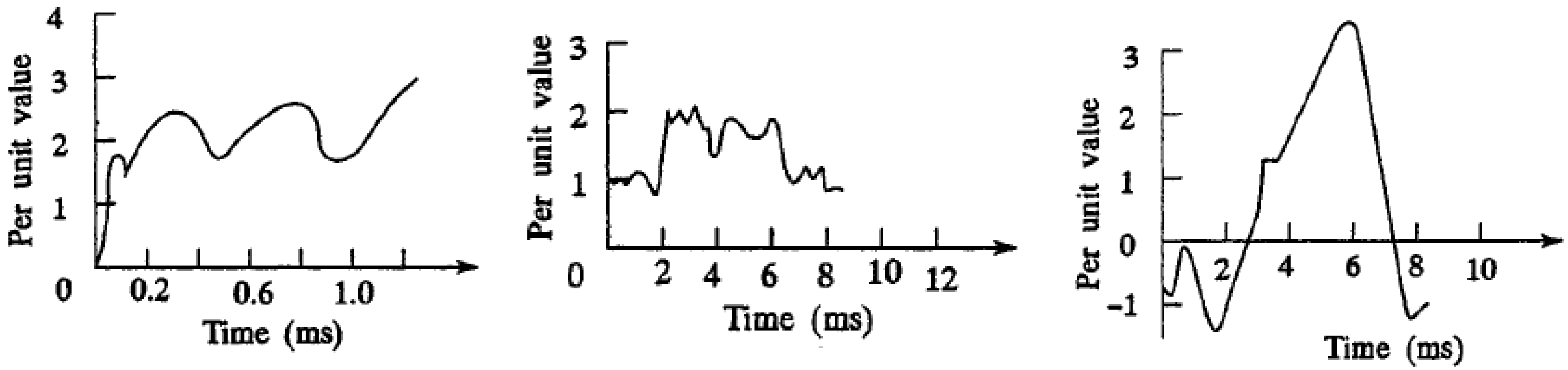
- Making or breaking a power circuit causes a change in the circuit parameters and produces voltage surges
- Those arising out of switching operations are attributed to internal causes

Causes of voltage surges – **Internal causes**

- Switching implies sudden interruption of flow of current (i.e on/off of electrical network)
- The making and breaking of electric circuits with switchgear may result in abnormal over-voltages in power systems having large inductances and capacitances
- Switching operations in HV (> 400 kV) power system can give rise to voltage surges of very high amplitude
- These over-voltages may go as high as six times the normal power frequency voltage
- Common switching operations:
  - De-energizing of transmission lines, cables, shunt capacitor, banks, etc.
  - Disconnection of unloaded transformers, reactors, etc.
  - Energization or reclosing of lines and reactive loads
  - Sudden switching off of loads
  - Short circuits and fault clearances
- During these switching operations, energy storage elements like capacitors and inductors tend to cause disturbance to the network in the form of surges

Causes of voltage surges – Internal causes

- Switching surges are often irregular (oscillatory or uni-polar) in shape and can be of high frequency or power frequency with its harmonics
- The relative magnitudes of switching over-voltages may be about 2.4 p.u.in the case of transformer energizing and 1.4 to 2.0 p.u. in switching transmission lines



Switching impulses

Surge related definitions

- Impulse
- Surge frequency
- Surge impedance

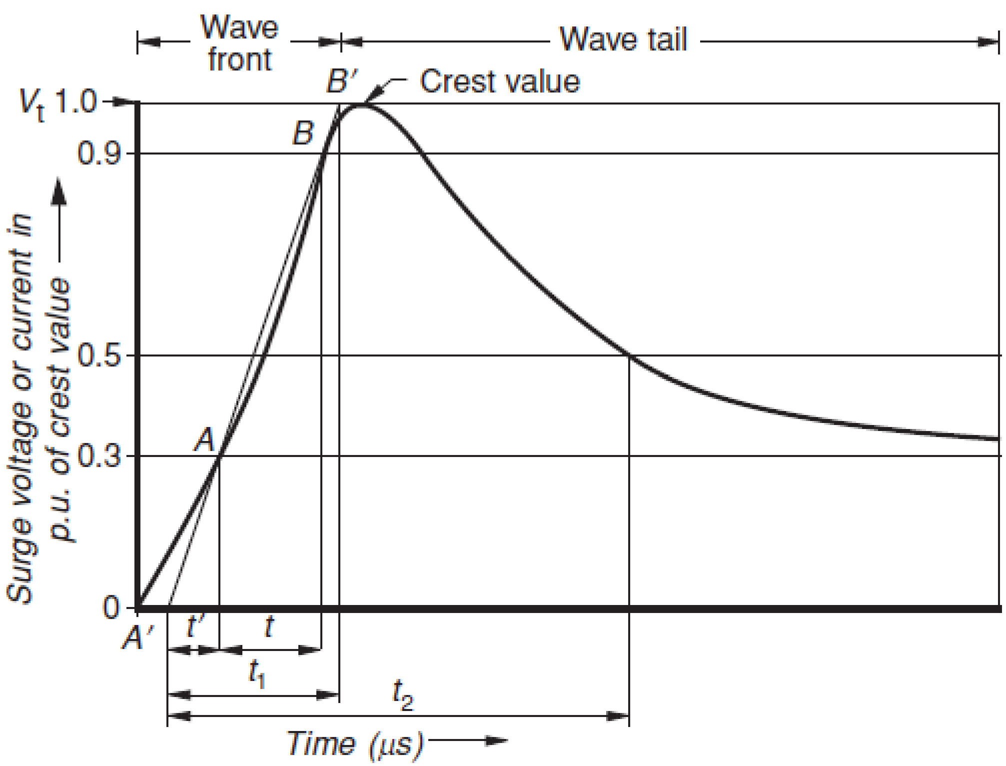
Impulse

- An impulse is an intentionally applied voltage or current in a laboratory
- It is in the form of an aperiodic and unidirectional waveform
- It rises rapidly without appreciable oscillations to a maximum value and then falls, usually less rapidly, to zero
- The parameters which define a voltage or a current impulse are:
  - its polarity
  - peak value
  - rate of rise (front time)
  - time to half its value on the tail
- A transient of an external or internal nature, is then related to one such type of impulse, for laboratory testing a particular equipment or system, to establish its suitability

Impulse generator in Laboratory

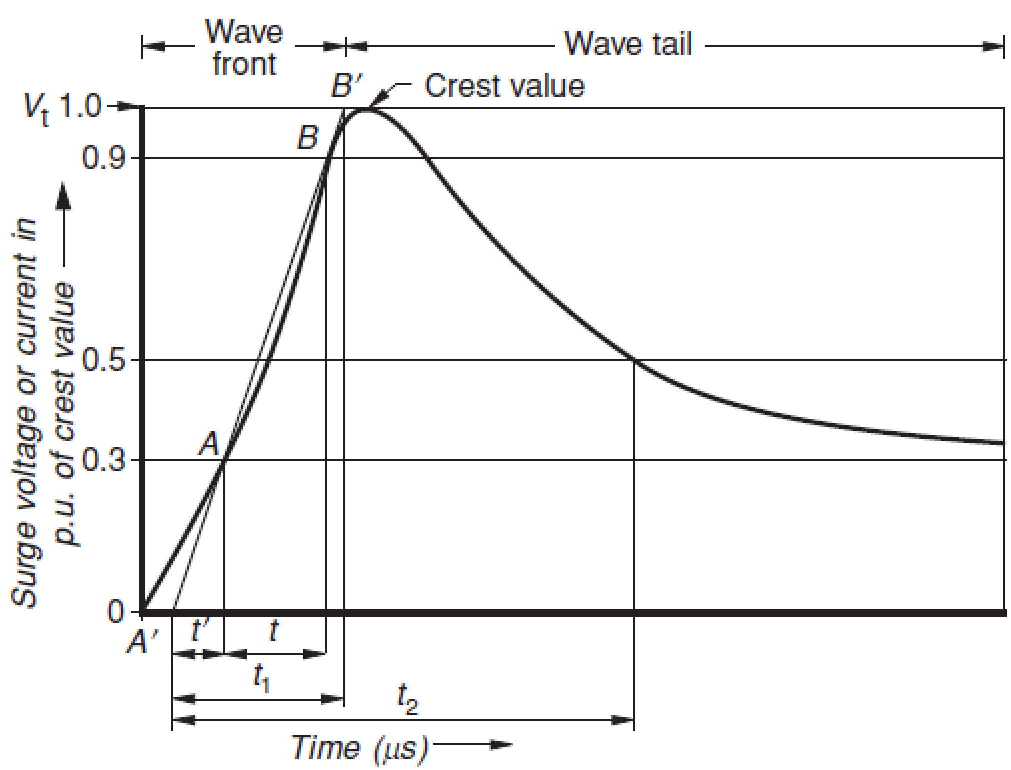
Impulse

- The type of wave is generally designated as t_1/t_2
  - *Virtual origin (A'): Graphically, A' is obtained as the point of intersection of the straight line through the points A and B with the zero line*
  - *Definition of the virtual origin A' is essential since the origin O of the recorded waveform is often not recognizable due to superposed disturbance voltages*



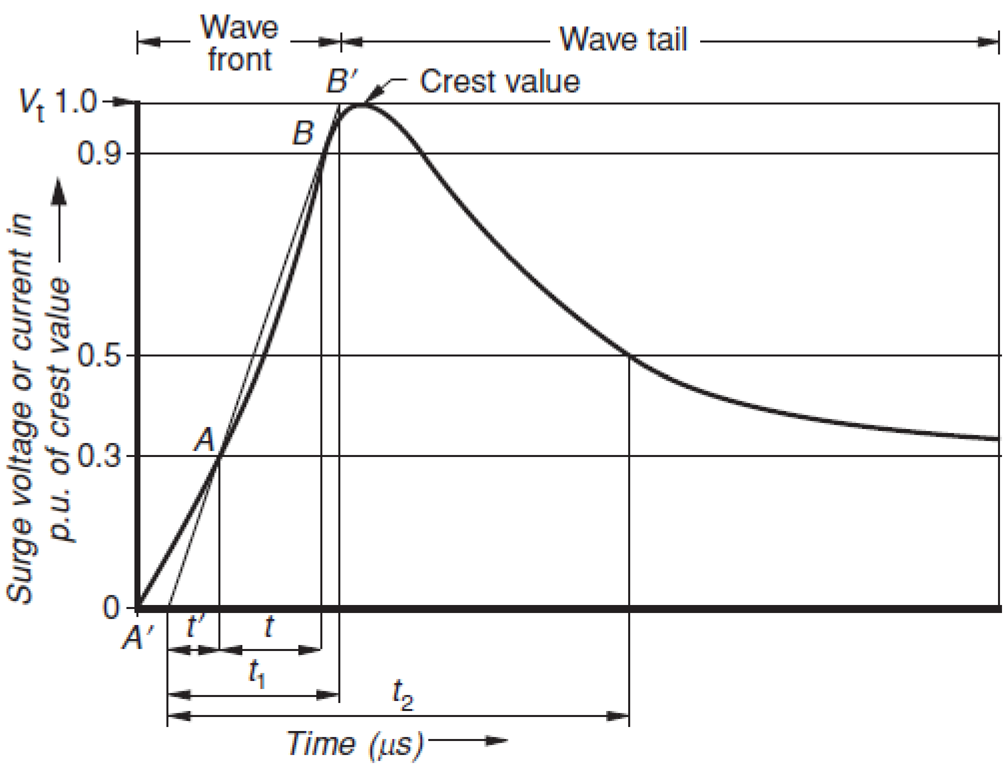
Impulse

- The type of wave is generally designated as t_1/t_2
  - t_1 = *virtual front time of an impulse:*
    - $t_1 = 1.67\times$ *time taken by the impulse to rise from* 30% of its peak value to 90%
    - t_1 = *Graphically, it is the time between the virtual origin A' and the point of intersection of the straight line through A and B with the peak line*



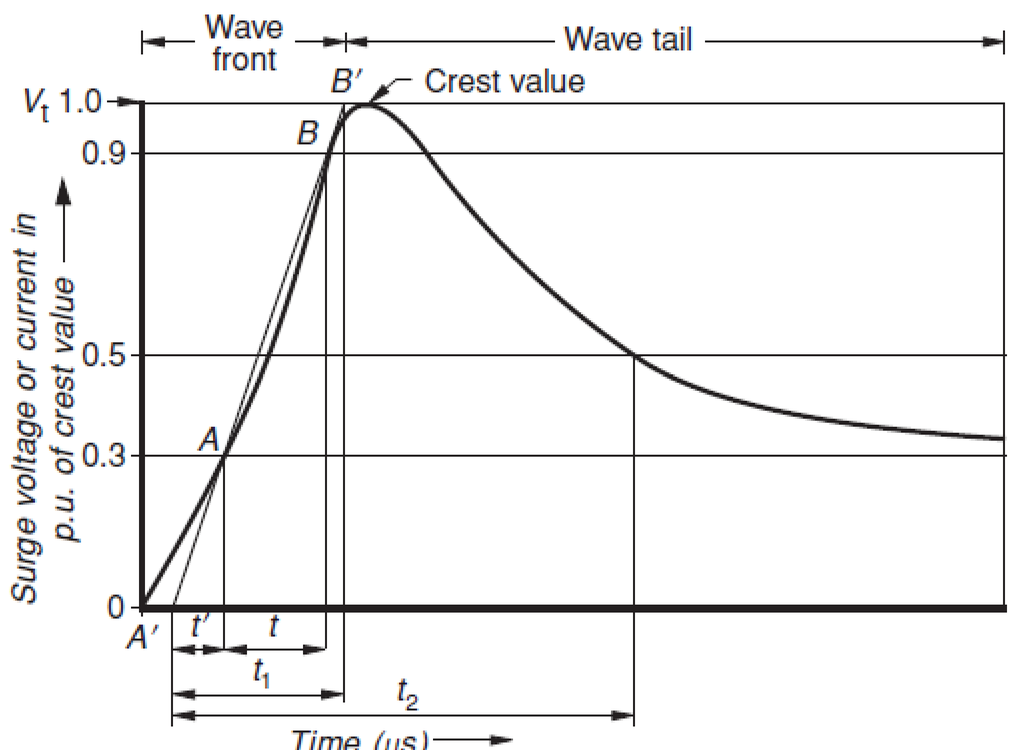
Impulse

- The type of wave is generally designated as t_1/t_2
  - $t_2 = $ *Virtual Time to Half-Value*
    - $t_2 = $ *time interval between the virtual origin and the instant at which the impulse has decreased to half of its peak value*



Impulse

- According to IEC 60060-1 a 1.2/50 μs impulse is called a standard lightning impulse, and a 250/2500 μs impulse a standard switching impulse.



Impulse

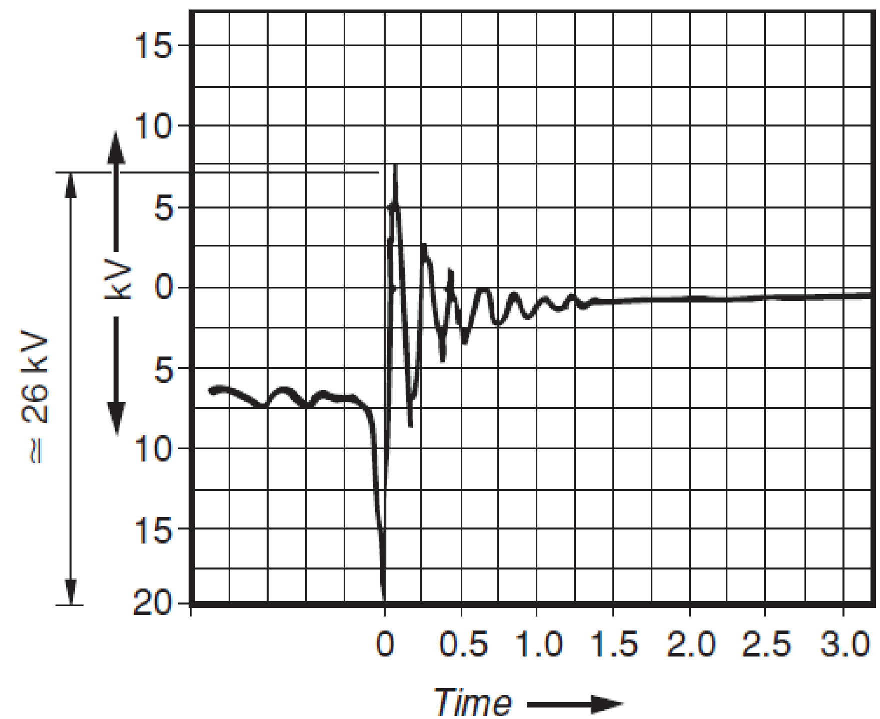
- ***Differentiating a switching impulse waveform from a lightning impulse waveform***
  - The distinction between a lightning transient and a switching transient may be made on the basis of the duration of the wave front (shape), rather than of its origin
  - Accordingly a voltage impulse with a wave front duration of less than 1 μs, up to some tens of μs, is generally considered a lightning impulse whereas an impulse with a front duration of some 10 μs to thousands of μs is considered a switching impulse

Surge frequency

- This is the frequency at which the surge travels
- This frequency can be very high, of the order of 5–100 kHz or more, depending upon the circuit parameters
- The natural frequency of oscillations of the transient voltage in terms of circuit parameters can be expressed as:

$$f_s = \frac{1}{2\pi\sqrt{LC}} \quad Hz$$

- Where, f_s = surge frequency in Hz
- L = leakage inductance of the circuit
- C = lumped leakage capacitance of the circuit



Oscillogram of a typical switching impulse showing high frequency contents

Surge impedance

- The shape and characteristics of a surge wave are influenced by the circuit parameters, i.e. L of the inter-connecting cables and the current carrying components of the equipment through which it travels and the leakage capacitance C of such cables and the motor dielectric lumped capacitance etc.
- Relation between L and C that determines the shape of the travelling wave is known as the surge or natural impedance Z_s of the system and is expressed as:

$$Z_s = \sqrt{\frac{L}{C}} \quad \Omega$$

- Where, L = circuit leakage inductance (H)
- C = circuit lumped leakage capacitance (F)

Velocity of surge propagation

- The velocity of current or voltage waves in any medium is called the velocity of propagation of electricity in that medium
- The velocity of electromagnetic waves (electricity) through a conductor is a measure of line or conductor parameters through which it propagates and is represented by:

$$U = \frac{1}{\sqrt{L_0 C_0}} \quad km/s$$

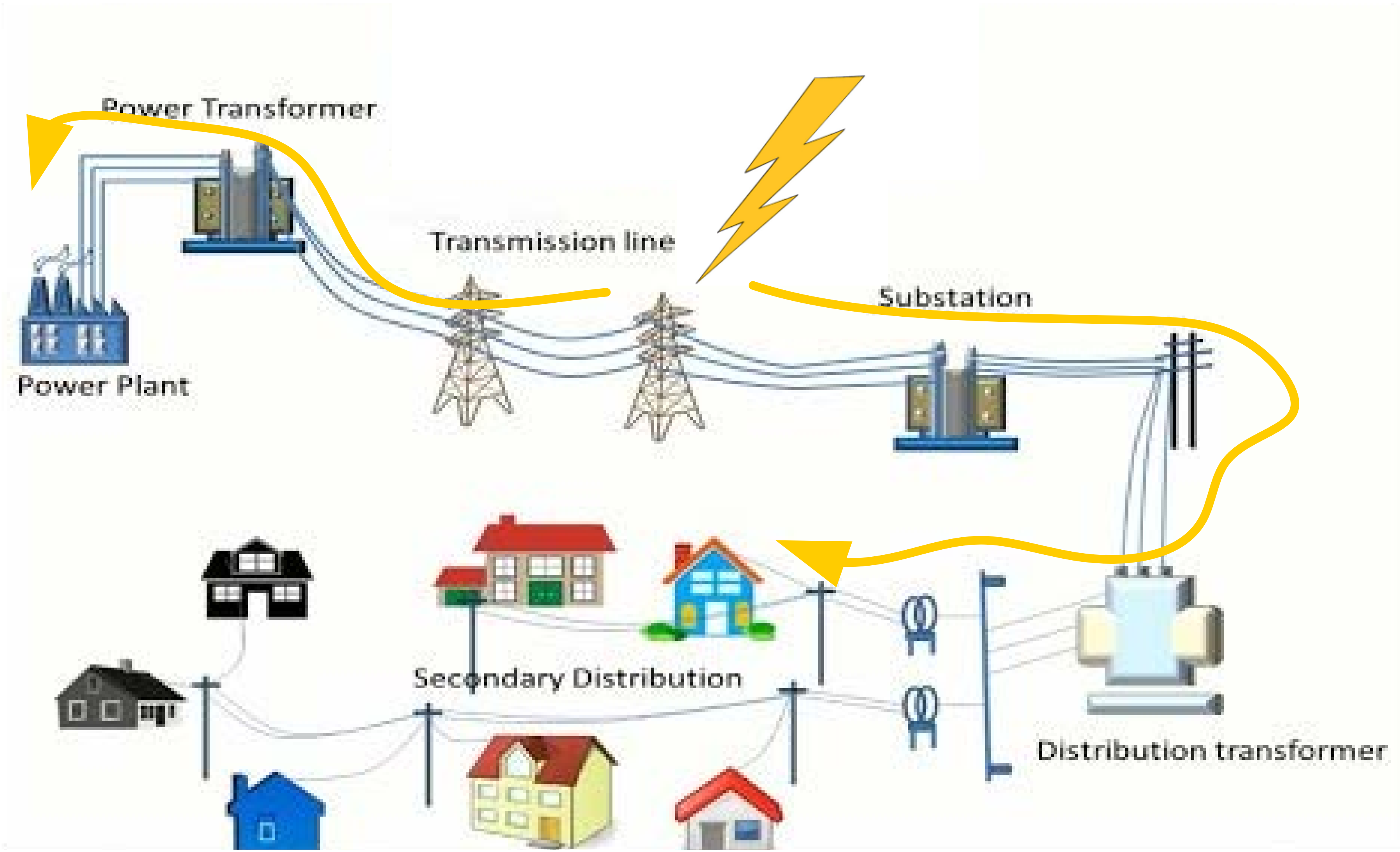
Where,

- L_0 = line or conductor mutual inductance in H/km, through which it travels
  - This will depend upon the skin effect and the mutual induction between two or more adjacent current carrying conductors
  - In overhead lines, it is very low due to wide spacing between conductors
  - In cables also it is very low, although the conductors are placed in close proximity but they are transposed and nullify the effect of proximity.
- C_0 = leakage capacitance in F/km.

Basic Insulation Level - BIL

- Further the equipment if placed from the source of voltage surges, reduced will be the effects of surge
  - For example, a rotating machine, which may be a motor or a generator, would rarely be subject to a direct lightning stroke as it would seldom be connected on a bus exposed to direct lightning surge strikes
  - It is usually connected through a bus or a cable which is fed through a transformer
- All these interconnecting devices would withstand most of the severity of a lightning strike
- The terminal equipment would experience somewhat attenuated and damped surge as the surge loses its strength while travelling the length of the line

Basic Insulation Level - BIL



Basic Insulation Level - BIL

- This diminishing effect of surge voltage enables proper coordination of insulation to be provided to different equipments in a power system
- Different equipment installed at different locations on the same power system may thus have varying degree of basic insulation level (BIL),
  - When lightning impulse over voltage appears in the system, it is discharged through surge protecting devices before the equipments of the system gets damaged
  - Hence, the insulation of such equipment must be designed to withstand a certain minimum voltage before the lightning impulse over voltage gets discharged through surge protecting devices
  - Therefore, operating voltage level of surge protecting devices must be lower than the said minimum voltage withstanding level of the equipment
  - This minimum voltage rating is defined as **BIL** or basic insulation level of electrical equipment