Effects of surge voltage on electrical machines

Day 26

Effect of Surge on Transformers

ILOs – Day26

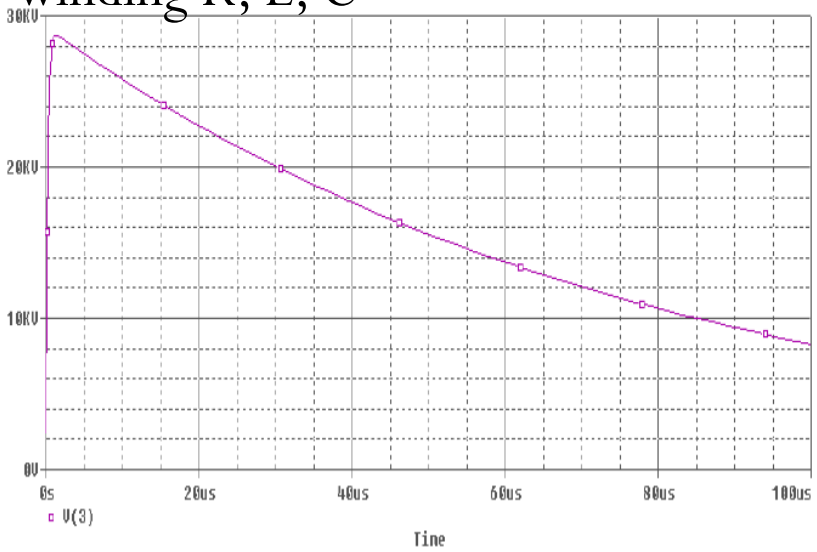
- List the effects of surge on transformers
- Explain the nature of distribution of surge voltage inside transformer winding
- Draw and explain various transformer winding models for surge studies
- Discuss commonly used surge protective devices used in transformers

Effect of surge on Transformers

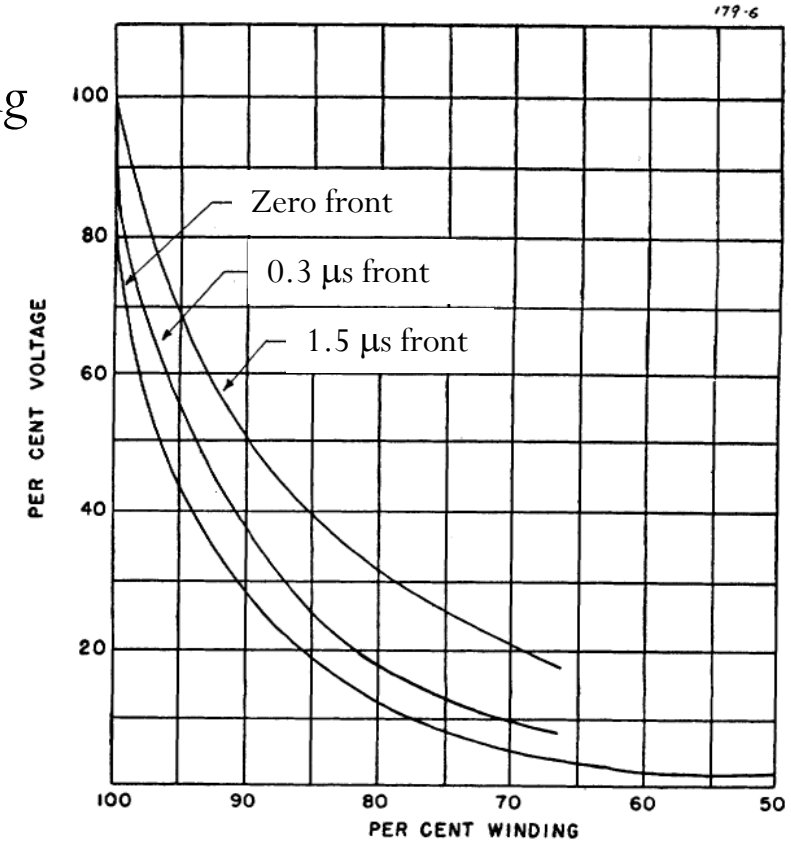
- Power transformer is one of the most important and expensive equipments in electrical power system
- Damage of transformer certainly causes utility to loss revenue from energy supply to its customers
- Moreover, the utility must pay repairing cost
- In addition the system reliability is decreased if contingency plan is not well prepared
- The principal cause of transformer damage is overvoltage due to lightning or switching
- In case of such overvoltage exceeds the basic lightning impulse insulation level (BIL) of transformer insulation, the damage of internal or external insulation could unavoidably occur
- Unlike transmission line with self-restoring insulation, transformer insulation is non-self restoring
- Thus, if insulation level is not well selected and designed, permanent damage could occur and subsequently need to be repaired as soon as possible

Surge distribution inside transformer winding

- As with motors, when an impulse strikes a transformer line terminal, the first few turns (or coils) are mostly affected rather than the bottom end coils
- The voltage stress experienced by different coils progressively reduces as the surge passes through length of the winding
- Transients voltage distribution along the winding length depends upon the impulse voltage parameter i.e. rise time and frequency and winding R, L, C



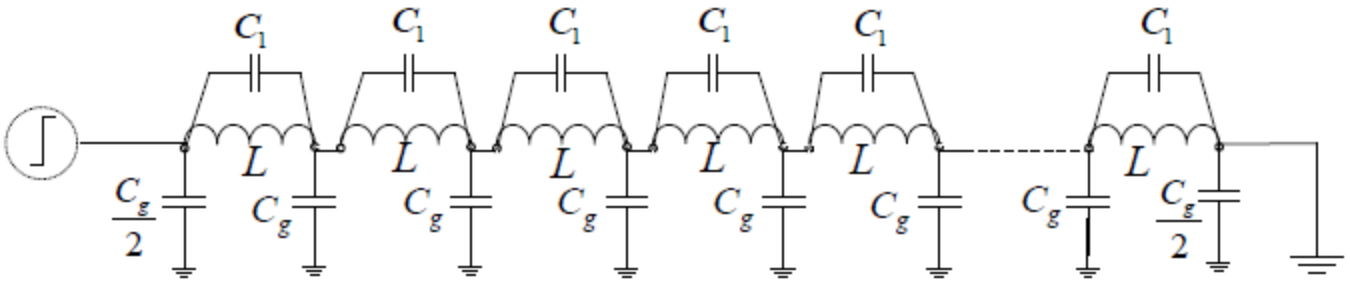
Lightning impulse generated at lab for testing



Initial voltage distribution along length of winding

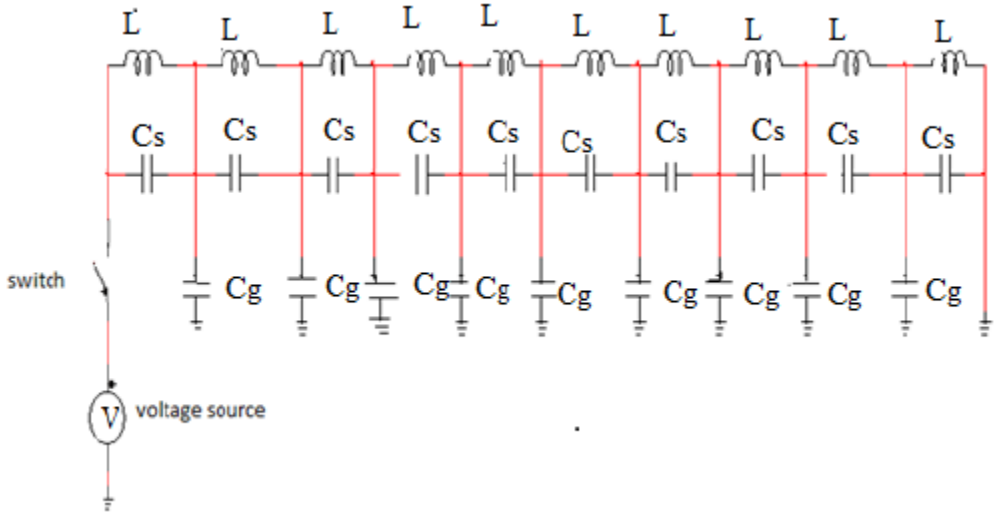
Transformer winding models for surge studies

- Various researchers have proposed different forms of winding models for surge propagation studies in transformers
  - For the study of the transients response of the transformer at high frequencies, the capacitance of transformer winding is important, although it is of no importance at power frequency voltage levels
  - The most detailed model of the transformer is one in which every turn of the winding is represented and all capacitances and inductances are included
  - Such a model may be prohibitive in terms of memory and complexity
  - The details can be reduced, by taking some assumption, to simplify L, C network without losing much accuracy



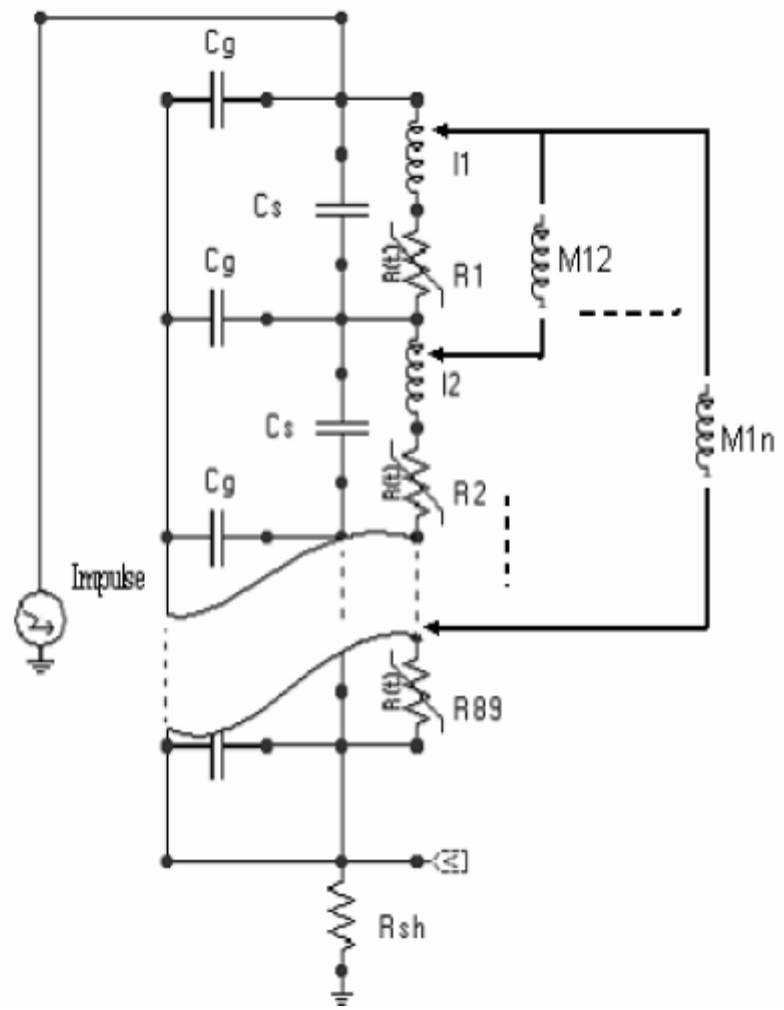
[1] M. Popov, R.P.P. Smeets, L. van der Sluis, H. de Herdt and J. Declercq, "Analysis of Voltage Distribution in Transformer Windings During Circuit Breaker Prestrike", International Conference on Power Systems Transients (IPST2009) in Kyoto, Japan June 3-6, 2009

Transformer winding models for surge studies



[2] **Kanchan Rani1, R. S. Gorayan** , "TRANSIENT VOLTAGE DISTRIBUTION IN TRANSFORMER WINDING (EXPERIMENTAL INVESTIGATION)", **IJRET: International Journal of Research in Engineering and Technology, Volume: 02 Issue: 04 | Apr-2013,**

Transformer winding models for surge studies



- Chiranjib Koley Prithwiraj Purkait, Sivaji Chakravorti , "**SVM Classifier for Impulse Fault Identification in Transformers using Fractal Features",** ***IEEE Transactions on Dielectrics and Electrical Insulation Vol. 14, No. 6, December 2007***

Transformer winding models for surge studies

- PrP – PhD thesis, JU 2002

Protection of transformers from lightning surges

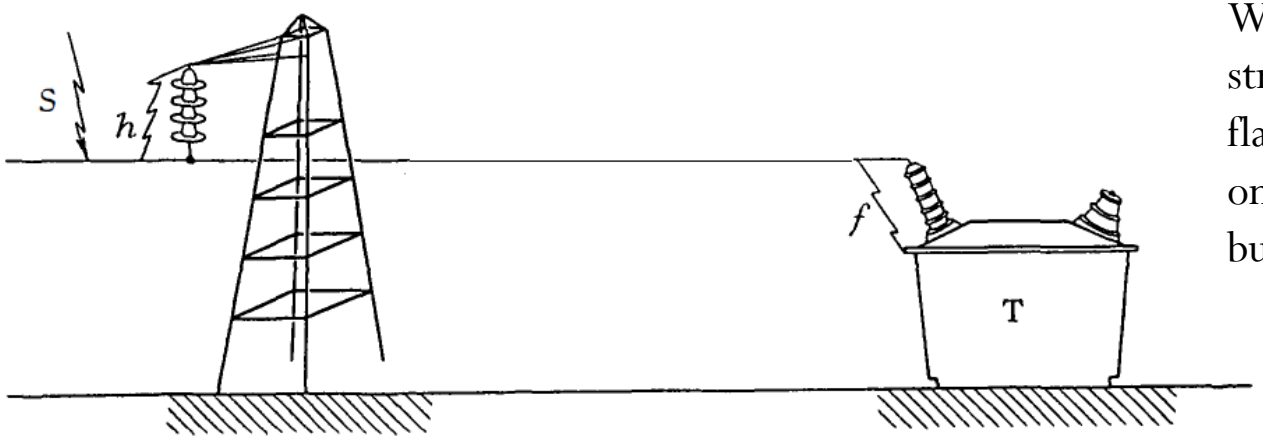
- Numerous auxiliary devices have been deployed to reduce such troubles to minimum
- The important ones may be classified as:
  - earth wires
  - de-ion gaps
  - substation shielding
  - Surge arresters
  - coordinating gaps
  - wave-flatteners
- Each may be employed separately or in conjunction with one or more of the others
- Many of them are not specifically used for the protection of the transformer windings but rather for the purpose of reducing line outages
- Nevertheless, most of them do serve the former purpose to a greater or less extent

Protection of transformers from lightning surges

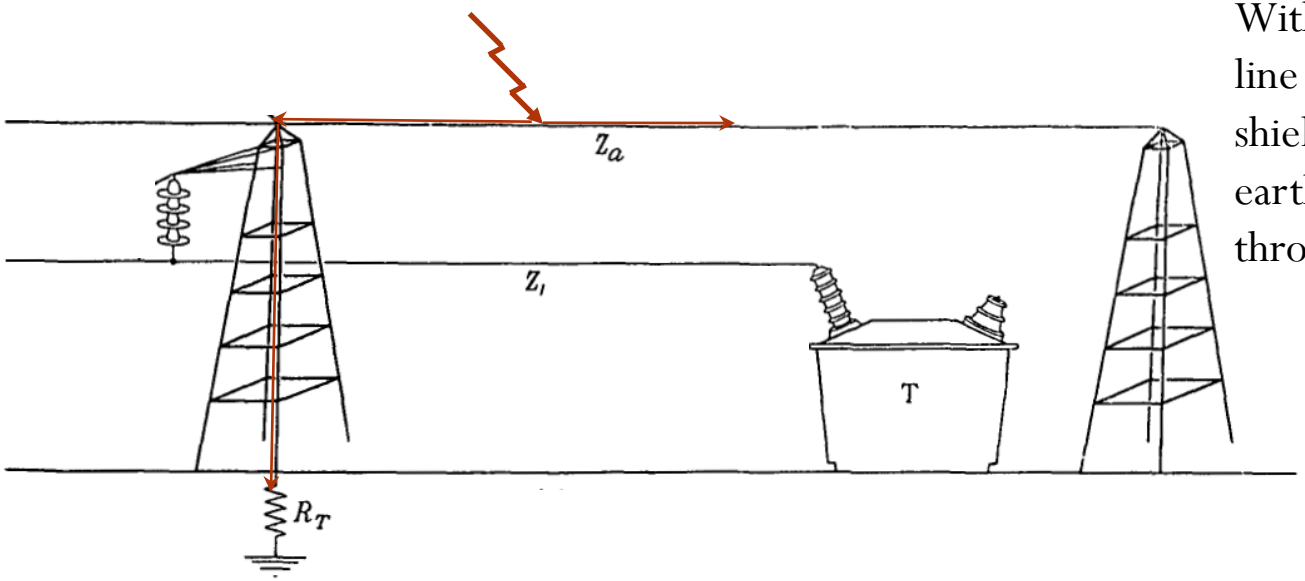
- **Earth Wires**
  - An earth wire mounted above the line conductors reduces the surge voltage impressed thereon by induction
  - It acts as a shield to prevent the connection of lightning strokes with the conductors, and reduces the risk of flashover from a tower to a line conductor
  - They are installed generally for the prime purpose of preventing outages and not as a transformer protection.
  - Their effectiveness as shields, however, is dependent on their being of very low resistances in the earth connections at the tower feet, and in practice it has been found that unless these resistances are maintained below a figure of the order of 10 ohms, flashover will be prone to occur from a tower to a line conductor
  - The connected transformers will then be subjected to surges of a severity for a given line depending on the distance between the point of flashover and the transformers
  - For short distances, these surges become dangerous to the transformers

Protection of transformers from lightning surges

- **Earth Wires**



Without earth wire, lightning strike on line conductor causing flashovers across insulator string on line and also on transformer bushing



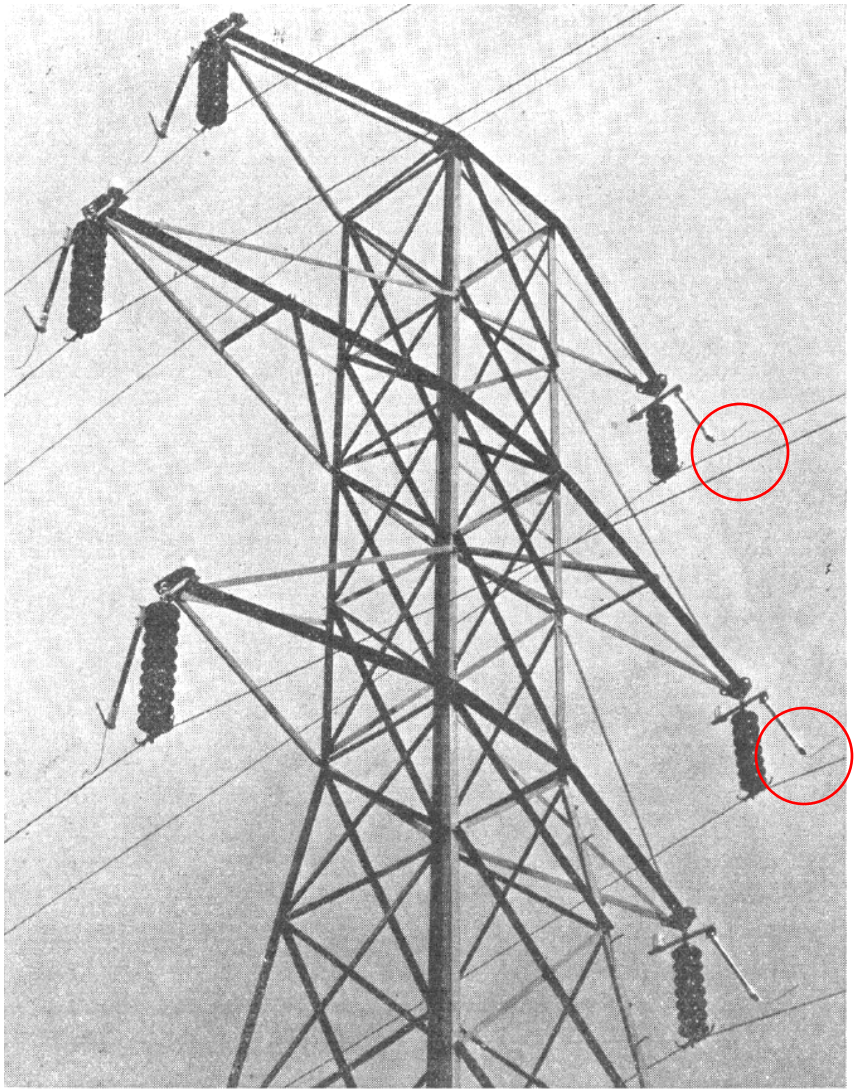
With earth wire on top, the live line conductor is effectively shielded. Lightning strike on earth wire is bypassed to ground through tower foot

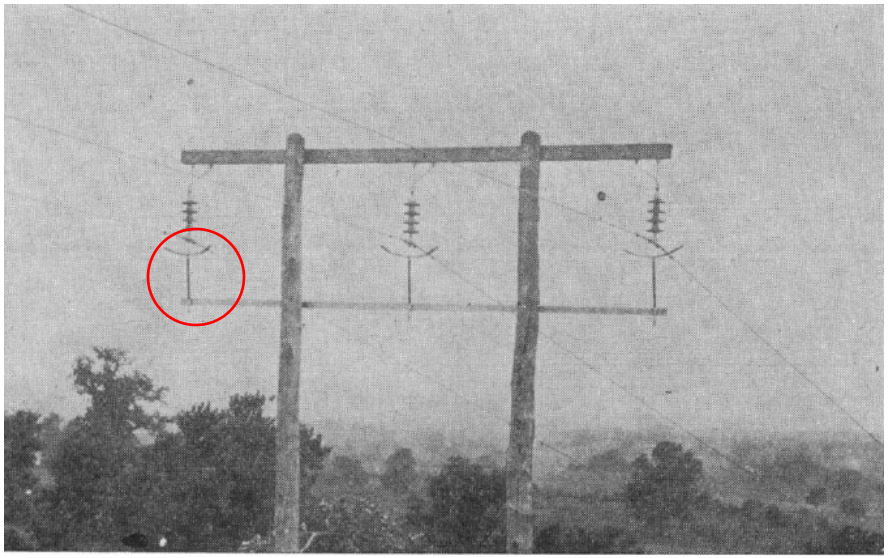
Protection of transformers from lightning surges

- **De-ion Gaps**
  - These gaps, which are connected across the insulator strings, have the property of preventing the formation of a maintained power-frequency arc when a transient flashover has occurred
  - Their main purpose, is therefore to prevent circuit breaker operation and thus to maintain continuity of service
  - Their job thus is to rob the insulators from the flashover
  - In reality, they thus afford protection to connected transformers only in the event that the surge is flashed over across the gaps to ground

Protection of transformers from lightning surges

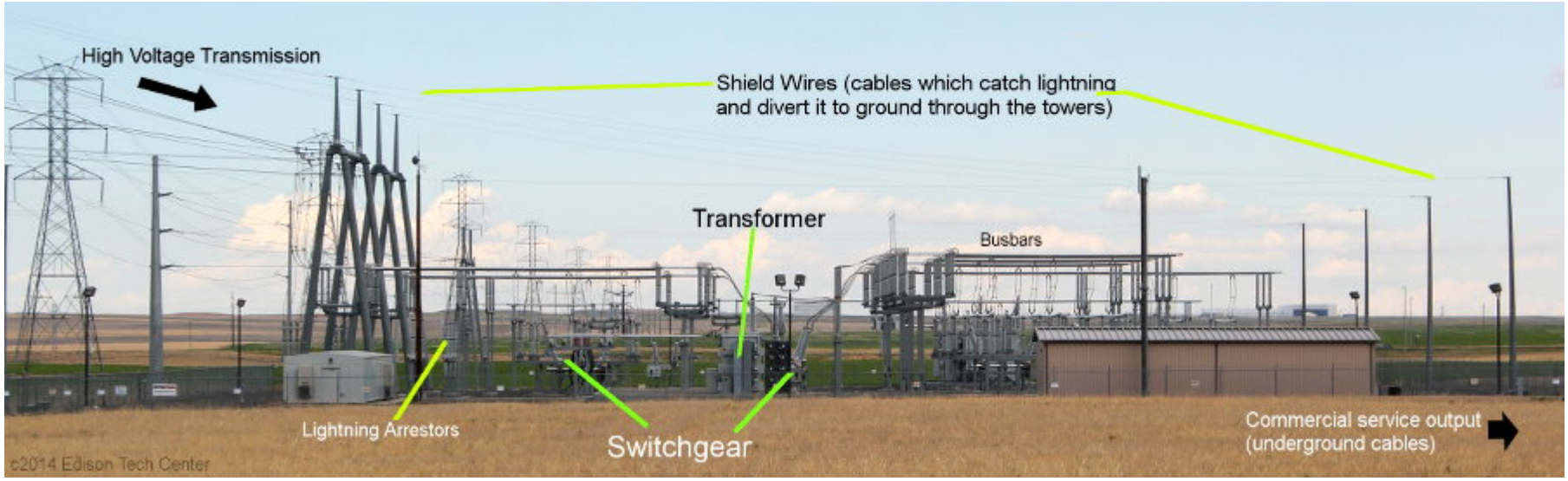
- **De-ion Gaps**





Protection of transformers from lightning surges

- **Substation Shielding**
  - To prevent lightning strikes connecting with apparatus either directly, or indirectly via insulator flashover, several interconnected earth wires are sometimes mounted above large substations and run out for a short distance along the lines
  - This measure of protection results from it being a reasonable proposition to maintain low values of the earth resistance locally at the station thereby effectively shielding the substation apparatus

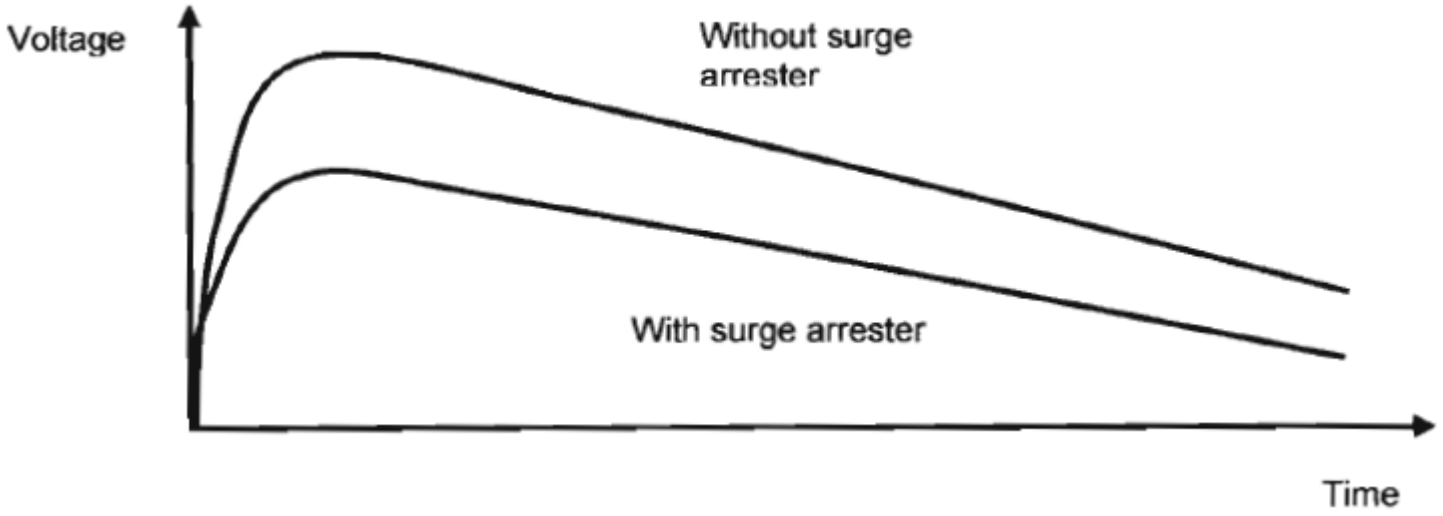


Protection of transformers from lightning surges

- **Surge Arresters**
  - Arresters are used to protect the apparatus connected to the line by reducing the surge-voltage amplitude to a low value rather than to protect the line itself
  - A surge arrester is a protective device for limiting voltage on equipment by discharging or bypassing surge current
  - It prevents continued flow of follow current to ground and it is capable of repeating these functions without requiring to be replaced after one operation
  - An arrester does not absorb lightning or stop lightning, it rather diverts the lightning, limits the voltage and protects the equipment installed in parallel
  - A surge arrester must be able to withstand the continuous power-frequency voltage for which it is intended to operate
  - It must discharge any transient energy from the system in the form of current, while preventing the voltage across the equipment from becoming excessive

Protection of transformers from lightning surges

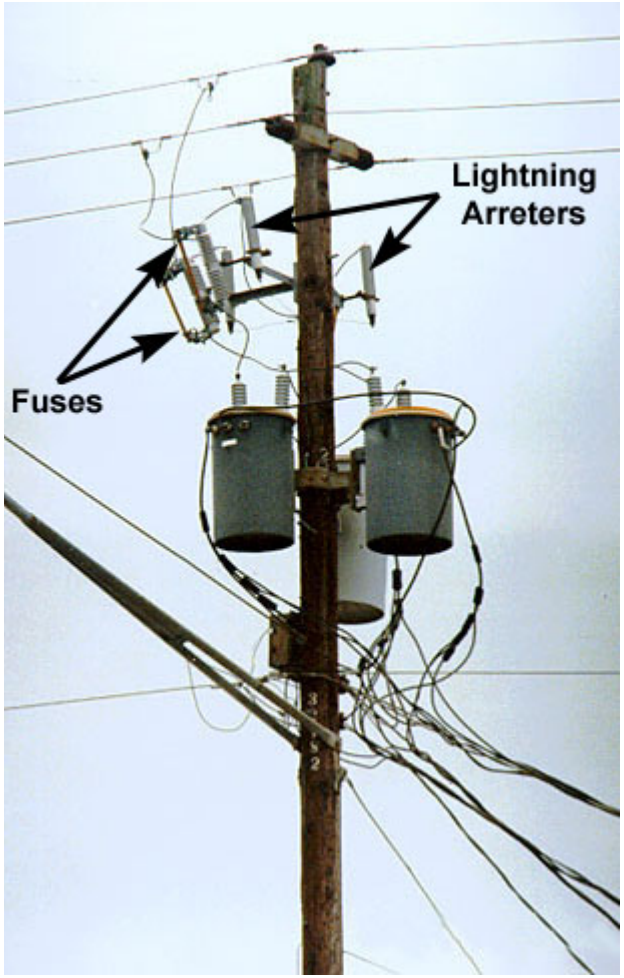
- **Surge Arresters**



- The surge arrester effectively decreases the voltage across the terminals of the transformer being protected

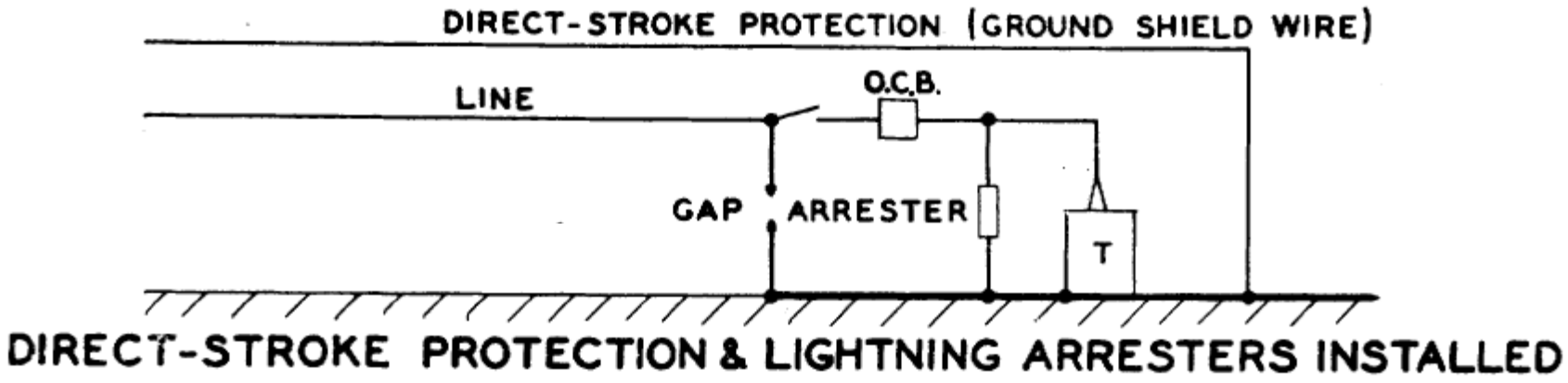
Protection of transformers from lightning surges

- **Surge Arresters**



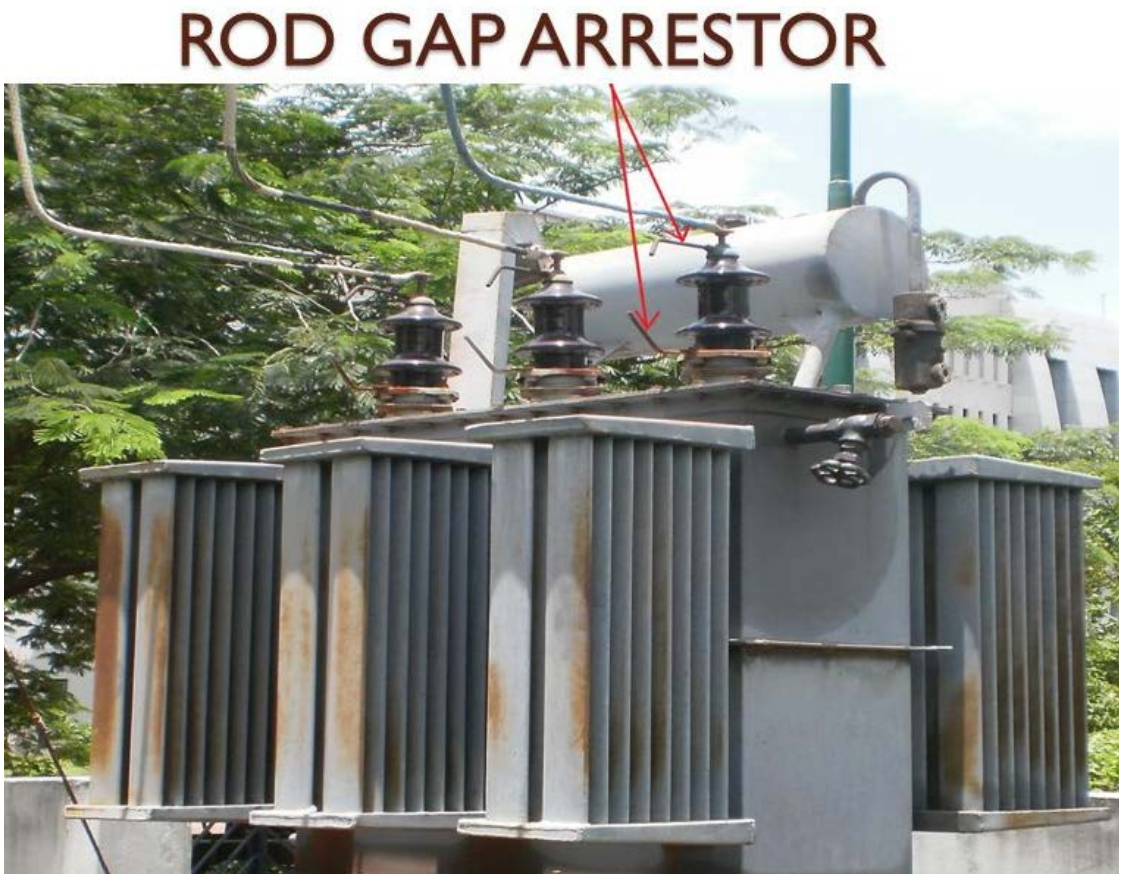
Protection of transformers from lightning surges

- **Coordinating gaps**
  - Rod coordinating gaps are used in an effort to limit to safe amplitudes the over-voltages reaching transformers
  - These are used in parallel with the transformer terminals where the overhead line enters



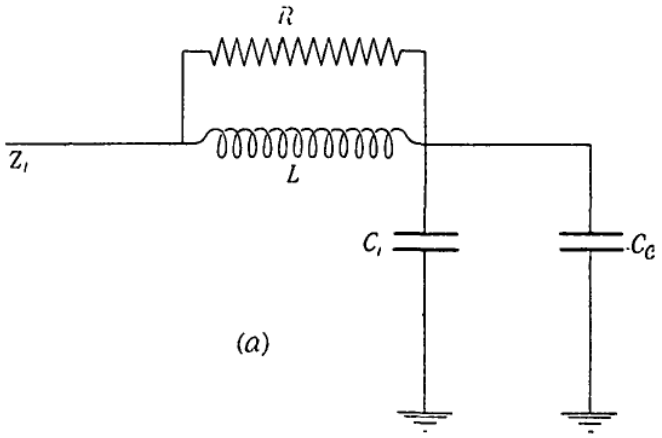
Protection of transformers from lightning surges

- **Coordinating gaps**



Protection of transformers from lightning surges

- **Wave flatteners**
  - The wave-flatteners commonly used are:
    - Absorbers
    - inductance coils
    - Condensers
  - The first two are connected in series with the line and transformer
  - Capacitor is connected in shunt with the transformer
  - Their object is to flatten the fronts and tails of transients to an extent such that the axial gradients in the protected winding are reduced to a safe level



- When properly designed RLC wave-flattener are used, under travelling-wave conditions it does not oscillate and cause an increase of voltage at the transformer terminal
- Under flashover conditions the rate of collapse of voltage there does not exceed a predetermined value

Protection of transformers from lightning surges

- **Wave flatteners**