Substation and equipment surge protection engineering essay

Substation and Equipment Surge Protection: Types, characteristics, related calculations, examples with applications for industrial systems

Gautami BhattAbstract-This paper describes the various types of surge protectors, their types and characteristics. This paper will also describes lightning surge arrestors, about them and how the power system is protected against them.

Index Terms-surge, lightening, switching, BIL, insulation, protection, substation

INTRODUCTION

Each electrical equipment should have a long service life of more than 25 years. The conductors are supported on insulators/embedded in insulation system. The internal and external insulation is continually exposed to normal voltages and occasional abnormal voltages. These abnormal voltages include temporary over voltages at power frequency, lightening surges and switching surges.

Over voltages at power frequency have a low over voltage factor but a longer duration while the latter have higher voltage duration and lesser duration. Protection against power frequency over voltages is achieved by employing an over voltage relay at the secondary of a transformer or by using an Inverse definite-Minimum Time Overvoltage Relay.

Protection against transient voltage surges is achieved by the help of Surge arrtestors. The surge arrestors, coordinated spark gaps, surge suppressors, over heard ground wires, neutral earthing, shunt capacitors etc. are located strategically to intercept the lightening surges or to reduce the peak and rate of rise of surges.

Protective systems for the different abnormal voltages act at different speeds depending on the over voltage. Temporary power frequency over voltage occurs for anything between ms to s and hence the over voltage relay acts within 70ms. Lightening surges last for micro seconds and thus typically the surge arrestor acts within 1. 2micro seconds. Switching surges are in the range of a couple of hundred micro seconds and surge arrestors for them are typically designed for 100micro seconds.

This paper focuses on lightening surges, their types, protection against them, and the different types of lightning surge arrestors.

LIGHTENING OVER-VOLTAGES

Lightening

Benjamin Franklin (1706-90) performed his famous experiment (1745) of kite flying in thunder cloud. Before his discovery lightening was considered to be " Act of God". Franklin proved that the lightening stroke was due to discharge of electricity. Franklin also invented lightening rods to be fixed on tall buildings and earthed to protect them from lightening strokes.

The large spark accompanied by light produced by an abrupt, discontinuous discharge of electricity through the air, from the clouds generally under turbulent conditions of atmosphere is called lightening.

Representative values of a lightening stroke:

Voltage: 200MV

Current: 40MA

Duration: 10^-5 sec

KW: 8×10^9

KWh: 22

Energy:

An overhead conductor accumulates statically induced charge when charged clouds come above the conductor. If the cloud is swept away from its place, the charges on the conductor are released. The charge travels on either sides giving rise to two travelling waves. The earth wire does not prevent such surges.

Another curious phenomenon is the unpredictable paths of lightening strokes. Normally they try to reach the earth and are therefore intercepted by lightning rods, trees, tall structures, etc. Empire state building has been struck by lightning several times. However some lightning strokes do not observe any rules and travel in all sorts of Haphazard fashion.

A B type stroke occurs due to sudden change in the charges of the cloud. If cloud 1 suddenly discharges to cloud 2, there is a sudden change in the charge on cloud 3. A discharge that occurs between cloud 3 and earth is called B stroke. Such stroke does not hit lightening rod, or earth wire. No protection can be provided to the over head line against such strokes.

Attractive effect of Over Head ground wire and earth rods (MASTS):

Earth rods (also called lightning rod) are placed on tall buildings. These are connected to the earth. The positive charges accumulate on the sharp points of the lightning rods; this is why lightning strokes are attracted to them. The earth wires are placed above the over head transmission lines. At every tower this wire is grounded. The positive charges accumulate on this wire. The negatively charged strokes are attracted by the earth wire. In absence of the earth wire the lightening stroke would strike the line conductors causing flashovers in transmission line.

Earth wires do not provide 100% protection. Weak strokes are not attracted by earth wires. B type strokes are not attracted by earth wires. None the less earth wire has proved to be a good solution to very dangerous direct strokes.

Earth wires have a shielding angle. The conductors coming in the shielding zone are protected against direct strokes. The shielding angle is between 30 to 40 degrees. An angle is 35 degrees is said to be economical and satisfactory for Overhead lines.

Overhead Shielding Screen (earthed)

The equipments in a substation are protected from direct lightning strikes by one of the following ways.

Overhead shielding scree(Earthed). Covering the overhead lines approaching the substation

Lightning Masts installed at strategic locations in the switchyard. The tower-top is earthed. Mast is an independent structure.

According to IEC masts are preferred for outdoor switchyards upto 33KV. For 66KV and above, the lightning masts become too tall and uneconomical. The overhead shielding wires are preferred because they give adequate protection and the height of structures in the substation provided with overhead shielding wires is comparatively less than that for the lightning masts

The entire switchyard is provided with earthed overhead shielding screen. The size of conductor is usually 7/9SWG, galvanized steel round stranded conductor.

Transmission line conductors are protected by overhead shielding conductor (earthed). The shielding angle (alpha) is defined as follows. A vertical line is drawn from the earth wire. Angle alpha is plotted on each side of this vertical line. The envelope within angle 2alpha is called the zone of protection.

The shielding angle according to ANSI is defined as 30 degrees while in the IEC world it is 45 degrees.

The clearance between phase conductor and overhead shielding wire should be more than minimum phase to earth clearance.

Lightning Strikes on Over Head Lines

These can be the following: Direct strikes on line conductor, direct stroke on tower top, direct stroke on ground wire and indirect stroke or B stroke on overhead line conductor.

Direct strikes on overhead lines are the most harmful. The voltage being of the order several million volts, the insulators flashover, puncture, and get shattered. The wave travels to both sides shattering line insulators, until the surge is dissipated sufficiently. The wave travels to both sides shattering line insulators, until the surge is dissipated sufficiently. The wave reaches the substation and produces stress on equipment insulators. At times these strikes are prevented from striking the line conductor. All high voltage overhead lines are protected by earth conductors. This mesh covers the complete switchyard.

Direct Strokes on tower-top

Consider,

L = inductance,

I = Current in tower,

R = Effective resistance of tower.

e = voltage surge between tower-top and earth.

So if the change in current with respect to time is 10KA/ and the resistance is 5 ohms and inductance being 10micro Henry. Then e will be 200KV. This surge voltage appears between the tower top and earth. The line conditions are virtually at earth potential because of neutral grounding. Hence voltage appears between the tower top and earth. The line conductors are virtually at earth potential because of neutral grounding. Hence its voltage appears between line conductors and tower-top. If this surge voltage exceeds impulse flash-over level, a flash-over occurs between the tower and the line conductor. Therefore the resistance is kept low for each tower.

A direct stroke on earth wire in the mid-span can cause a flashover between line conductor and earth wire or line conductor and tower.

Indirect strikes on line conductor can have the same effect as direct stroke on conductor. They are more harmful for distribution lines but are not significant for EHV lines. Other factors are low tower footing resistance insulation level of lines. For lines rated above 110KV voltage level, the line insulation is high and back flashovers are rare. For line between 11KV and 33KV, the insulation of lines is relatively low and back flashovers are likely to occur.

Protective devices against lightning surges

Several devices are used in order to protect the power system against lightning surges. An overview of them is given here while some are discussed in detail.

A. Overview of protective devices against lightening surges

Device

Where Applied

Remarks

Rod gaps

across insulator string,

bushing insulator,

support insulator

Difficult to coordinate

Flashover voltage varies by

Create dead short circuit

Cheap

Over heat ground wires (earthed)

Above overhead lines

Above substation area

Provides effective protection against direct strokes on line conductors, towers, substation equipment

Vertical Masts

In substations

Used instead of providing overhead shielding wires

Lightning spikes/rods (earthed)

Above tall buildings

Protects buildings against direct strokes. Angle of protection between 30 to 40

Lightning arrestors

On incoming lines in each substation

Near terminals of transformers and generators

Pole mounted on distribution lines

Diverts overvoltage to earth without causing short-circuit

Used at every voltage level in every substation and for each line

Phase to ground

Surge absorbers

Near rotating machines or switchgear

Across series reactor valves

Resistance capacitance combination absorbs the over voltage surge and reduces steepness of wave

B. Rod gaps

The simplest protection of line insulators, equipment insulators and bushings is given by Rod gaps or coordinating gaps. The conducting rods are provided between line terminal and earthed terminal of the insulator with an adjustable gap. The medium in the gap is air. The rods are approximately 12mm in dia. or square. The gap is adjusted to breakdown at about 20% below flash-over voltage of insulator. The distance between arc path and insulator should be more than 1/3 of the gap length.

Precise protection is not possible by rod gaps. The break-down voltage varies with polarity, steepness and wave-shape, weather. The power frequency currents continue to flow even after the high voltage surge has vanished. This creates an earth fault only to be interrupted by a circuit breaker. Operation of rod gap therefore leads to discontinuity of supply. The advantage of gap is low cost and easy adjustment on site. For more precise operation, surge arrestors are used.

Horngaps, the gap between the horns is less at the bottom and large at the top. An arc is produced at the bottom during high voltage surge. This arc commutes along the horn due to electromagnetic field action and length increases. The arc may blow out.

Impulse ratio of protective devices is the ratio of breakdown voltage on specified impulse wave to breakdown voltage at power frequency.

Typical impulse ratio values are

Sphere gap: 1

Rod gap: 1. 6 to 3

Horn gap: 2 to 3

LIGHTNING ARRESTORS

Surge arrestors are usually connected between phase and ground in the distribution system; around the terminals of large medium voltage rotating machines and in HV, EHV, HVDC sub-stations to protect the apparatus insulation from lightning surges and switching surges.

The resistor blocks in the surge arrestor offer low resistance to high voltage surge and divert the high voltage surge to ground. Thereby the insulation of the protected installation is not subjected to the full surge voltage. The surge voltage does not create short-circuit like rod gaps and retains the residual voltage across its terminals.

Surge arrestor discharges current impulse surge to earth and dissipates energy in the form of heat.

After discharging the impulse wave to the earth, the resistor blocks in the surge arrester offers a very high resistance to normal power frequency voltage, acting like an open circuit.

Some of the types of surge arresters being used today in the industry are

Gapped-Silicon-carbide Surge arrestors called the valve-type or conventional Gapped arrestors. These consist of silicon-carbide discs in series with spark gap units.

Zinc-Oxide Gapless Arrestors called the ZnO Arrestors or metal oxide arrestors. These are gapless and consist of Zinc oxide discs in series. ZnO arrestors have superior V/I characteristics and higher energy absorption level. They are preferred for EHV and HVDC installations.

Fig. 1-A ZnO surge arrestor[1]

Gap-type Sic Arrestors are connected between phase and earth. It consists of silicon-carbide resistor elements in series with gap elements. The resistor elements offer non-linear resistance at power frequencies, the resistor elements in series offer high resistance with gap elements. The resistor elements offer non linear resistance, at power frequency frequency over voltages, the resistance offered is large. For discharge currents the resistance is low. The gap unit consists of air gaps of appropriate length. During normal voltages, the surge arrestor does not conduct. When a surge wave travelling along the line reaches the surge arrester, the gap breaks down. Since the resistance being offered to it is low, the wave is diverted to earth. After a few micro seconds the normal frequency wave reappears across the arrester. Therefore arc current in gap unit reduces and the voltage across the gap is not enough to keep up the arc. Therefore the current flowing to the earth s automatically interrupted by and normal condition is restored. Thus, the high voltage surge is discharged to earth and the insulation of the equipments connected to it are protected.

Fig. 2- Charecteristics of ZnO block[1]

CLASSIFICATION OF SURGE ARRESTORS

Surge arresters can be classified based on voltage, current, and energy capability as follows

Station Type

Line Type

Distribution Type

Standard normal current peak(A)

10, 000

5000

2500: 1500

Voltage rating

(Kv rms)

3. 3-245

3. 3-123

Upto 3. 3

Application

Large power stations and large substations

Intermediate and medium substations

Distribution system; rural distribution

SURGE ARRESTORS, SPECIFICATION AND TERMS

Some of the terms and definitions related to surge arrestors are given here in order to better understand the content given in this paper.

Surge Arrestor is a device designed to protect electrical equipment from transient high voltage, to limit the duration and amplitude of the follow current.

Non-linear resistor. The part of the arrester which offers a low resistance to the flow of discharge currents thus limiting the voltage across the arrestor terminals and high resistance to power frequency voltage, thus limiting the magnitude of follow current.

Rated voltage of the arrester is the maximum permissible RMS voltage between the line terminal of the arrestor as designated by the manufacturer.

It should be noted that all equipments are rated by the phase to phase voltage rating but for surge arresters phase to ground rating is the rated voltage.

Follow Current is the current that flows from connected power source through lightening arrester following the passage of the passage of the discharge current

Normal discharge current is the surge current that flows through the surge arrester after the spark over, expressed in crest value (peak value) for a specified wave. This term is used in classifying surge arrester as station type, line type distribution type.

Discharge current is the current flowing through the surge arrester after the spark over.

Power frequency spark-over voltage is the rms value of the power frequency voltage applied between the line and earth terminals of arrester and earth which causes spark over of the series gap.

Impulse spark over voltages. Highest value of voltage attained during an impulse of given polarity, of specified wave shape applied between the line terminal and the earth of an arrester before the flow of discharge current.

Residual Voltage (discharge voltage) is the voltage that appears between the line terminals and earth during the passage of the discharge current.

Rated current of a surge arrester is the maximum impulse current at which the peak discharge residual voltage is determined.

Coefficient of earthing is the ratio of the highest rms voltage of healthy phase to earhh to the phase to phase nominal voltage time hundred expressed in percentage during an earth fault on one phase.

Thus, for an effectively earthed system the coefficient of earthing Ce < 0. 8

Therefore surge arrester voltage is

Ua > 0. 8 * Um rms

Surge voltage (Vs) KV instantaneous is taken as 2. 5 times Critical Flash Over Voltage (CFOV) of line insulation. Therefore discharge current Ia is given by

. TESTS ON SURGE ARRESTERS

The following are the list of standard tests performed on a surge arrester according to the IEC

1/50 impulse spark over test.

Wave front impulse sparkover test.

Peak discharge residual voltage at low current.

Peak discharge residual voltage at rated diverter current.

Impulse current withstand test.

Switching-impulse voltage test.

Discharge capability of durability.

Transmission line discharge test.

Low current long-duration test.

Power duty cycle test.

Pressure-relief test.

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Gautami Bhatt (MEE’10) is a M. E. E in Power and Control Engineering from the University of Houston.