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Electromagnetics in Power Systems Applications

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Lightning Arresters and Substation Protection

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Abstract

The following considers the effectiveness of metal oxide surge arresters as a means of controlling the overvoltages that occur during switching and lightning in power transmission networks. An approach for assessing the insulation insulation integrity has been outlined using computer simulation, thus verifying the choice of arrester.

1. Classification of Dielectric Stress

The following classes of dielectric stress may be encountered during the operation of the transmission system:-

- Power frequency voltage under normal operating conditions.
- Temporary overvoltages.
- Switching overvoltages.
- Lightning overvoltages.

The voltage-time characteristic of insulation used in equipment must be carefully assessed when comparing performance with lightning and switching surges. Also the voltage-time characteristics of protective devices must be considered, for example, co-ordinating gaps in air will not offer practical protection of gas insulated switchgear (GIS) against switching or lightning surges because the voltage-time characteristics are totally incompatible.

2. Factors affecting Switching Overvoltages

When energising or re-energising transmission lines, severe overvoltages can be generated. The overvoltage magnitude is dependant on many factors including the transmission line length, the transmission line impedances, the degree and location of compensation, the circuit breaker characteristics, the feeding source configuration and the existence of trapped charge from prior energisation of the transmission line.

3. Factors affecting Lightning Overvoltages entering Substations

The magnitude and rate of rise of overvoltages due to lightning strikes on transmission lines is an important consideration for substation insulation design.

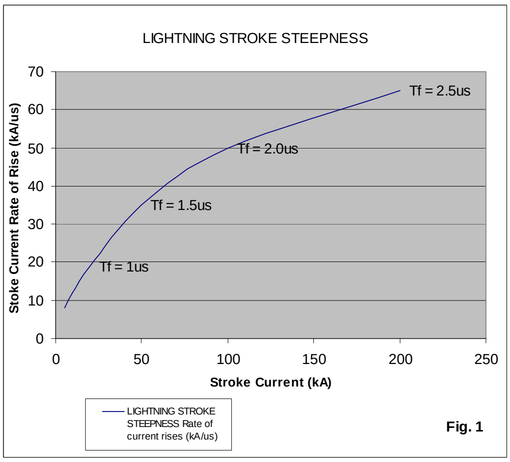

Fig. 1

Having determined the insulation required for the line it is usual to find the lightning withstand level is in excess of commercially available lightning impulse withstand levels (LIWL) of the substation equipment. Thus, unless precautions are taken, overvoltages entering the station can cause undue insulation failure.

Surge arresters can be situated at the line entrance but consideration must be given to the voltage profile as the surge travels through the substation. Alternatively consideration may be given to rod gaps set to operate marginally below the station LIWL and switching impulse withstand level (SIWL), fitted to the first 3 or 4 towers out from the substation. However, consideration must be given to the voltage-time characteristic of the substation equipment in comparison to that of line gaps. GIS at voltage levels 132kV – 550kV can not be adequately protected by line co-ordinating gaps alone.

3a. Backflashover (Direct strike to earth wire)

A backflashover occurs as a result of the tower or shield wire being struck by lightning, the current passes to earth via the tower steelwork causing a voltage difference between the tower cross arms and the line conductors. The magnitude of this current can vary from a few kA to over 200kA. The steepness of lightning currents is given in Fig. 1 derived from data published by Anderson and Eriksson.

The risk of a backflashover can be reduced by keeping the tower foot impedances to a minimum, particularly close to the substation (first 5 - 7 towers). The terminal tower is usually bonded to the substation earth mat and will have a very low grounding impedance (typically 1 ohm). However the procedure for “gapping” down on the first 3 or 4 towers where line co-ordinating gaps are reduced in an attempt to reduce incoming voltage surges will increase the risk of a “close in” backflashover.

3b. Shielding Failure (Direct strike to phase wire)

Most transmission line towers will be equipped with shielding wires (earth wires), the purpose of which is to divert the lightning stroke away from the phase wire and thus provide shielding. Any lightning strike which can penetrate the shield is termed a “direct strike” or “shielding failure”. For the purpose of insulation co-ordination the direct strike may not warrant further investigation if the transmission line is effectively shielded, particularly in the last 1 km of the line approaching the substation.

4. Selection of Surge Arrester Rating

The temporary overvoltage (TOV) level and duration must be carefully considered before selecting the rating of the surge arrester. The surge arrester must be capable of withstanding, from thermal constraints, the TOV which in most circumstances determines the surge arrester rated value. From the rated value stems the protective or voltage limiting characteristics of the surge arrester – the higher the rating, the higher the limiting or residual voltage the arrester will have. Thermal constraints are very important with surge arresters since if the rating is too low, temporary overvoltage may cause excessive heating resulting in thermal instability with a runaway condition being produced and subsequent failure.

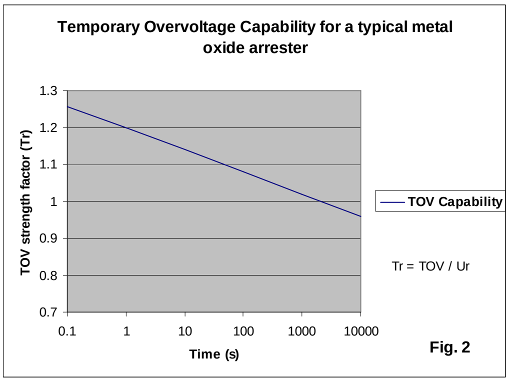

Fig. 2

Fig. 2 shows typical TOV capability for surge arresters. The energy capability of the surge arresters are usually expressed as kJ/kV of arrester rating. The maximum continuous operating voltage is considered as 80% of rated voltage. Typically for 400kV systems an arrester rating of 360kV will be used which gives a maximum continuous operating voltage of 1.25pu of nominal system voltage. The surge arrester voltage-current characteristic exhibits an extremely non-linear relationship once the "knee" point voltage has been exceeded, which causes large increases in current for a small voltage increase, (see Fig. 3). Fig. 3 shows the LIWL and SIWL applicable for 400kV substation equipment of 1425kV and 1050kV, respectively.

5. Location of Surge Arresters

Considering the system shown in Fig. 4, where the transmission line is directly connected to a 400kV GIS, a computer model can be created to take into account the parameters previously discussed. A transient study would reveal the level of lightning stroke current required to cause a backflashover. Then according to the numbers of lineflashes/100km/yr calculated for the transmission line and by using the probability curve for lightning current amplitude, a return time for the stroke current can be assessed (e.g. 1 in 400 yrs) in say the first 1 km of the line. The voltage then arriving at the substation can be evaluated and compared with the LIWL for the substation equipment.

The open circuit breaker condition at the line entry point must be studied since if the line disconnector is open, the surge voltage will "double-up" at the open terminal.

Various levels of stroke current can be simulated at different tower locations and the resultant substation overvoltages can be assessed. If it is considered that the LIWL of the substation will be exceeded or that there is insufficient margin between the calculated surge levels and the LIWL to produce an acceptable risk, then surge arrester protection must be applied.

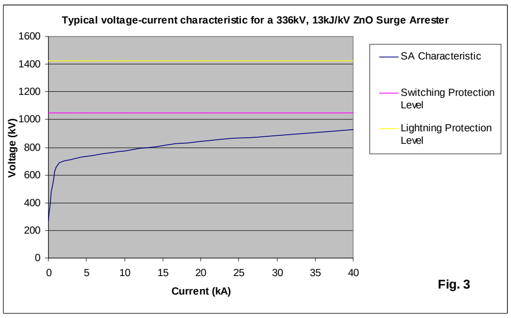

Fig. 3

The rating of the surge arresters will have been assessed from TOV requirements and from manufacturers data a surge arrester model can be included in the system model.

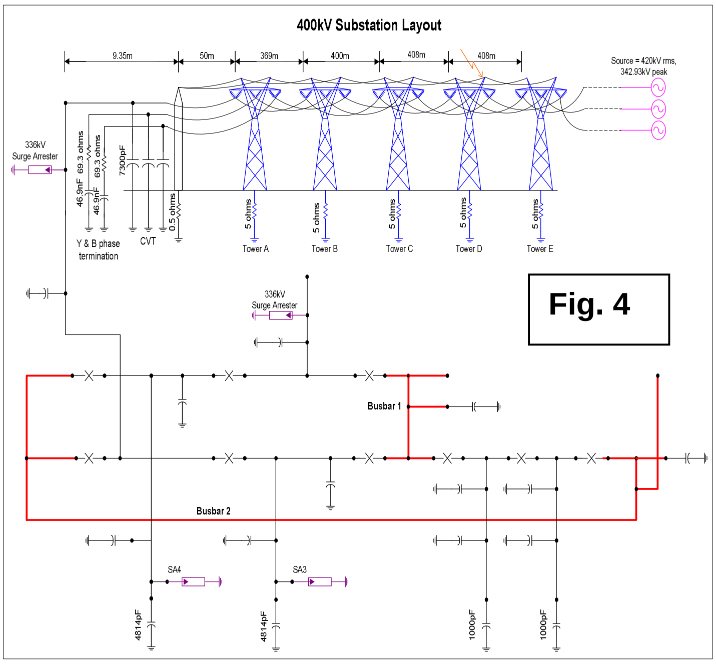

Fig. 4

Performing various studies, representing the overhead line and substation will reveal the protective level of the arrester and from this the safety factor for this system configuration can be assessed. IEC 71 recommends a safety factor for lightning withstand of 1.25 for 550kV equipment (safety factor = LIWL / protective level). A lesser safety factor of 1.15 is normally adopted for the switching withstand level.

The surge arrester current calculated for this condition should be the "worst" case and can therefore be used to assess the nominal discharge current requirements of the surge arrester (5kA, 10kA or 20kA).

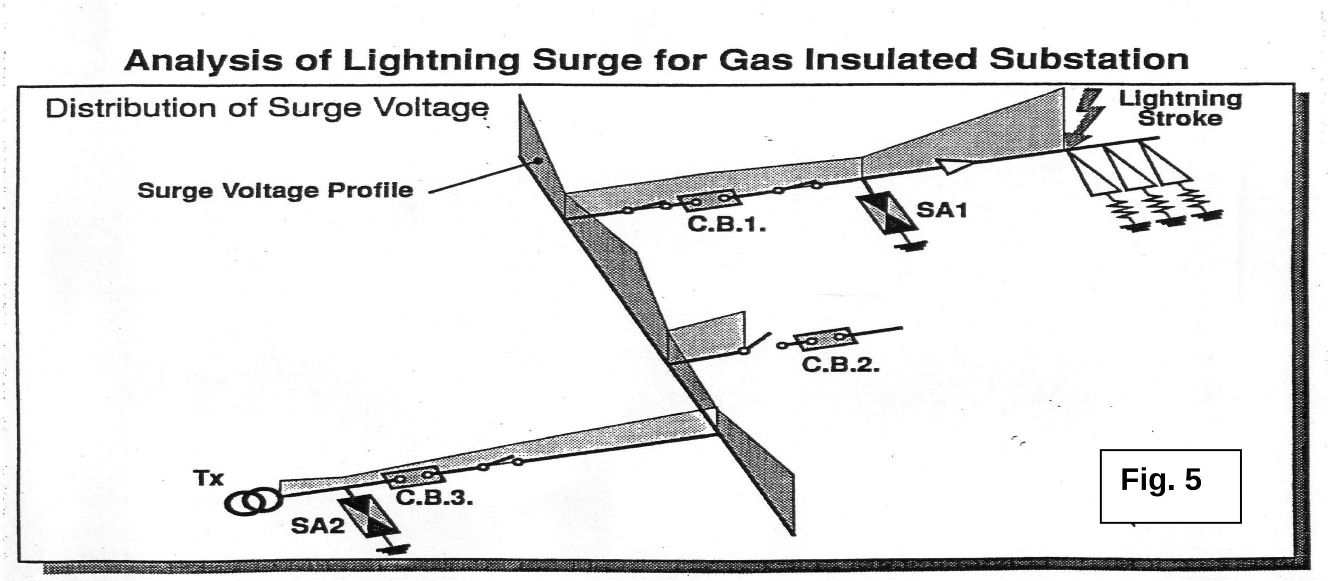

Fig. 5

To make full use of the surge arrester protective level the arrester should be placed as close as possible to the equipment being protected. In case of the open line circuit breaker this may well be 10-20 metres distance.

Fig. 5 illustrates the surge voltage profile of the GIS with the line circuit breaker closed. It shows that additional surge arresters may be required because of the distances

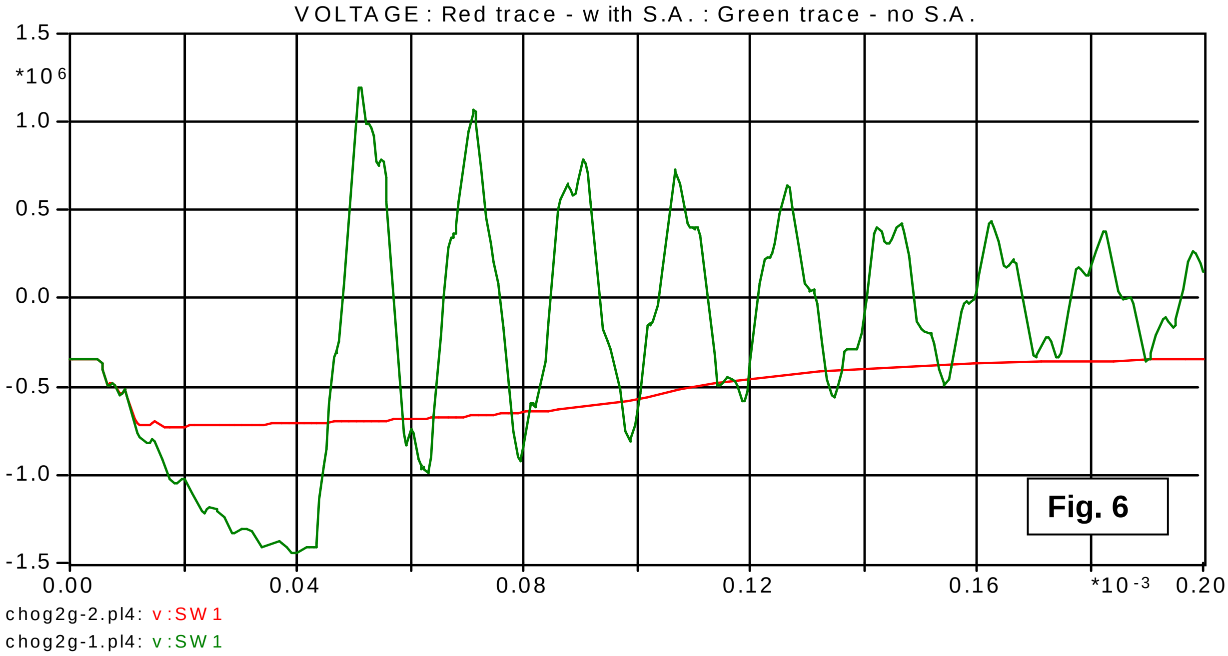

Fig. 6

involved in the layout of the substation.

It follows that surge arresters have a "protective distance" which is sensitive to the rate of rise of incoming surge voltage and this must be taken into consideration when assessing the lightning overvoltage on equipment remote from the surge arrester.

Fig. 6 shows the effect of with and without surge arresters at the line entry point, (line entry circuit breaker closed).

6. Conclusion

To summarise, the application of surge arresters can be used to control switching and lightning overvoltages. Once an appropriate surge arrester has been selected, a computer simulation of the network will allow verification that all overvoltages are within the substations SIWL's and LIWL's and that the energy absorbed by the arrester also remains within rating.