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PERFORMANCE OF PARALLEL SURGE ARRESTERS

A. HADDAD, H GRIFFITHS
Cardiff University, UK,

M. OSBORNE
National Grid, UK

SUMMARY

The operation of parallel surge arresters can improve energy absorption capability if the arresters are similar and are installed close to each other. However, it has been reported that any small difference in the individual V-I characteristics can lead to unbalance in current sharing. When the arresters are installed some distance away from each other, travelling wave effects can modify the effectiveness of parallel arresters for surge overvoltage protection and, in this case, detailed simulations are required to ascertain the level of protection. Such a situation occurs in practice with large substations or short underground cable connections. Various studies have shown that a requirement for two-arrester protection is closely dependent upon the type and length of cable used.

In the case of overhead lines, the distances are much bigger and the main objective of line arresters is to reduce the flashover rates due to surge overvoltages. This is especially relevant to lines located in regions of high lightning activity, lines with compact/uprated design where the phase-to-phase and phase-to-earth air clearances are reduced.

In this paper, we present a study of parallel arresters considering the separation distance and their application to overhead lines. Various scenarios of overhead line configurations were considered and the overvoltage levels were calculated for each case. Assessment of flashover performance is also conducted for a number of conditions. A number of calculation techniques were used and compared.

KEYWORDS

Line arresters, protection distance, backflashover, lightning strikes, transient simulation, EMTP, cable protection, tower surge impedance.

haddad@cf.ac.uk

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Introduction

Parallel sets of surge arresters can improve energy absorption capability if the arresters are similar and are installed close to each other. However, it has been reported that any small difference in the individual V-I characteristics can lead to unbalance in current sharing. When the arresters are installed some distance away from each other, travelling wave effects between the units can modify the effectiveness of parallel arresters for surge overvoltage protection and, in this case, detailed simulations are required to ascertain the level of protection. Such a situation occurs in practice with large substations or short underground cable connections. Various studies have shown that a requirement for two-arrester protection is closely dependent upon the type and length of cable used.

When using surge arresters in parallel within relatively short distances, the issues of protective level, current and energy sharing need careful consideration. Typical examples of how arresters are installed in parallel include:

(a) Multi-column arresters where the distance between the arrester columns is usually less than 0.5m,
(b) Multi-arrester protection of plant within large substations where the separation distances are up to few hundred meters,
(c) Protection on underground cable lengths, usually found at substation entries where the cables are used to connect the substation to the overhead line. In this case, the cable length can vary from a few tens of meters up to a kilometre or more,
(d) Line arresters to reduce flashover / backflashover rates on overhead lines exposed to lightning strike risk. Occasionally, protection against switching surges may be required, e.g. for compact line applications. The distance between arresters for this type of application can vary significantly from one to several span lengths.

In this paper, the above cases of arrester application were examined in order to quantify the effect of surge arresters and their separation distance on the protective levels offered to the system. In addition, the arrester voltages and currents were examined to assess the implications for energy absorption requirements. For the line arrester application, different modelling approaches to represent the towers and arresters with their connection leads were compared in order to identify optimised modelling approaches for such transient situations.

Multi-Column Arresters

In order to increase the energy absorption capability of arresters, multi-arrester column designs were developed. Usually, the V-I characteristic of the parallel column are matched at two points around the rated voltage V_r and nominal current I_r. Such designs have an increased energy absorption capability and, after a high energy operation duty, they exhibit a better temperature recovery time which is facilitated by the increased outside surface area available for cooling the complete multi-column arrester. In addition, the residual voltage at nominal current is lower compared with a single–column arrester due to discharge current sharing between columns.

One difficulty with the construction of the multi column design, however, relates to matching all columns for all points along the V-I curve. High current laboratory impulse tests [1] on two matched arresters connected in parallel have revealed that, even for closely matched arrester units, as much as 6% current sharing mismatch can occur between the two parallel arresters. This difference is enhanced in the highly non-linear region of the V-I characteristic where exact matching is difficult.

Impulse tests on an aged four-column arrester [2] have also shown that up to 17% difference existed between the currents in the four columns. The main consequence of unmatched columns in a multicolumn arrester design is non-uniform ageing. Relatively to the others, the column that conducts most current will undergo an accelerated ageing process which could lead to premature failure of the arrester. Despite this shortfall, the superior residual voltage, increased energy absorption capability and temperature properties of multi-column arresters makes them attractive for high energy applications. To reduce the effect of current sharing mismatch in multi-column designs, series parallel arrester designs are now used by several utilities. In this way, if mismatch occurs on a short section of the arrester, complete failure is avoided and the failed section can be replaced quickly.

Separation Distance Effects

In practice, location of the arrester very close to the high voltage plant to be protected against overvoltages is not always feasible. The separation distance between the two devices and the length of the arrester connection leads is known to affect the surge voltage level at the protected equipment.

Such a voltage increase is caused by travelling waves and inductance effects of the connecting conductors. Simplified equations have been suggested for the assessment of the protective voltage level at the equipment to be protected by a surge arrester located a distance away from the equipment. However, it must be stressed that the accuracy of the equations is limited. For substation applications, a detailed transient simulation study is required. Mitigation of the separation distance effect on surge overvoltage protection requires that the arrester is located as close as possible to the equipment to be protected, and that short connection leads are used to bond the earth terminals of the arrester and equipment. For high frequency applications, use of an extra earth rod at the arrester location helps better impulse current dissipation through access to deeper low-resistivity soil. Additionally, this earth electrode practice contributes the desirable safety benefit in mitigating the rise of earth potential at the arrester location. Recent developments introduced integrated designs of surge arresters with high voltage plant, which provide optimised overvoltage protection. However, issues of reliability and field distribution consequences are yet to be quantified and resolved satisfactorily.

Arrester protection of Line-Cable Junction: Effect of Cable Length

In this section, we consider the separation effect of cables on surge arrester performance, compared with that typically experienced on overhead lines. The effectiveness of the surge arrester is determined by the surge impedance of the network between the surge arrester and the item which it is protecting. Cables offer better protection due to the low surge impedance typically 20-40Ω compared with 300-450Ω for an overhead line. Air insulated busbar systems are in between, typically 100-150Ω, while GIS busbars are slightly lower 80-90Ω. In this investigation, a simplified model of a line terminated with an underground cable is considered (see Fig. 1).

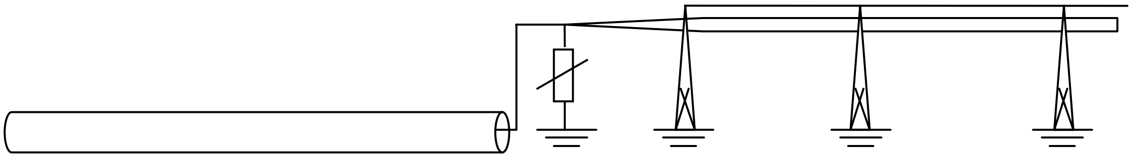
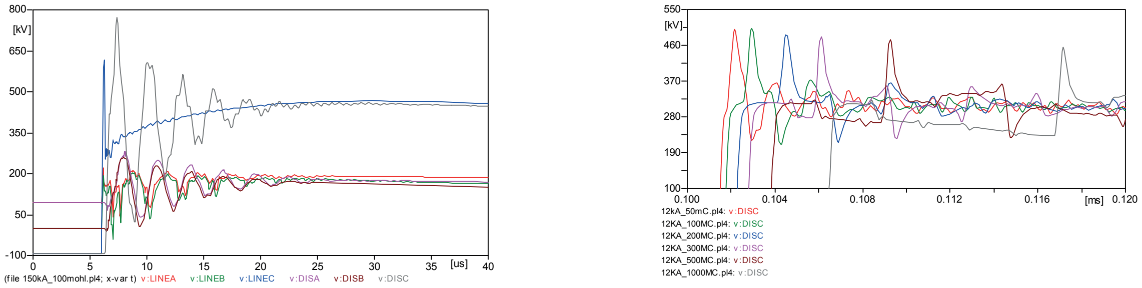


Figure 1: schematic of studied line cable system.

EMTP simulations were used to determine the effect of cable length on the voltage seen at the remote end. The results suggest that there is little effect for the case of shielding failures on the overhead line, while the issue is more pronounced at higher frequencies where the reflections associated with back-flashovers generate higher differential voltages at the remote end of the conductor system. Figure 2 shows typical voltage shapes computed for a 132kV system, and Table 1 summarises the results for the cable length effect. The key observation from the studies (Table 1) suggests that, for shielding failures, the cable further attenuates the travelling wave to a value below the control level of the surge arrester. Backflashovers, however, do not attenuate and higher voltages appear at the remote end, thus requiring an additional arrester [3].



(a) Voltage at sending and receiving end of 100m of 132kV overhead line -150kA back-flashover

(b)Variation of voltage (receiving end) with cable length (132kV) -12kA shielding failure

Figure 2: Computed voltage for cable-line junction model.

Table 1: Voltages calculated on 132kV XLPE cable with a line end arrester exposed to lighting impulses through an overhead line

XLPE Cable length (m)	Voltage (kV_{pk})					
	Shielding failure			Backflashover		
	SA end	Remote end	LIPM %	Surge arrester end	Remote end	LIPM %
50	388	500	23	388	400	39
100	350	502	23	388	390	40
200	372	486	25	389	430	34
300	371	481	26	390	470	28
500	370	474	27	385	520	20
1000	360	450	31	400	620	5

From the above results, it can be said that the presence of cable sections in the overhead line entry to a substation does impact on the nature of overvoltages transferred into the substation. A surge arrester located at the line entry side will control all but the worst case transients. These are typically caused by backflashovers which have fast rise times and generate voltage reflections at high surge impedance boundaries e.g. open disconnectors or unloaded transformers.

Effect of Line Arresters Models on Predicted Flashover Performance of Lines

In regions of high lightning activity and for compact or uprated overhead line designs, line arresters are commonly adopted by utilities to control overvoltage levels and reduce flashover rates on overhead lines.

Several studies have been performed to investigate the optimisation of line arrester applications to improve the line's flashover performance. Specialised software programs to carry out such studies have been developed and a number of approaches were developed and used for the flashover studies.

Statistical approaches were used to account for the parameters of the lightning phenomenon to include impulse shape and magnitude. However, it is worth emphasising the impact on results of the simulation models used for the line towers and arresters in carrying out the flashover studies.

In this work, a number of modelling options for the line towers and arresters connections were investigated to identify the controlling factors of the voltage appearing at towers following a lightning strike. Two types of 132kV lines were considered to illustrate the findings of this investigation; (a) an unshielded line having a portal type pole design and horizontal phase-conductor configuration, similar to those used in UK rural areas (Figure 3.a), and (b) a shielded double circuit "PL16" steel-tower line (Figure 3.b). In order to simulate practical lines, a total length of 20 km was considered. In both cases, the lines were terminated with transformers represented by their capacitance of C=5nF.

Unshielded Portal-type overhead line

A wood pole portal type tower, with horizontal conductors was used for the studies of unshielded line. The span length used was 300m and several combinations of surge arrester locations were studied. As expected, the simulations show voltages in the megavolt region if no line arresters were used, these voltages would cause a flashover for most lightning strike magnitudes. In contrast, if line arresters are used at every pole, the voltages will be limited by the surge arresters to safe levels below the flashover overvoltage. However, if a strike occurs at mid-span, a risk of interphase flashover may happen before the lightning surge arrives to the adjacent poles.

Several combinations of arrester locations were studied by previous investigators [4] and these have established some general facts about which phases have a flashover/backflashover risk and also some optimised arrester locations and distribution along the lines. However, very little information was given on the details and effects of the modelling approaches used for their studies. In particular, the study of tower models and surge arresters with their connections require further clarification. In this paper, we have selected a line configuration with an arrester every 4 spans to illustrate the effect of arrester/tower modelling on the computed results. Figure 3.a shows a section of the EMTP model used for the Portal line. The section depicts the lightning injection point and the two surge arrester separated by four line spans. The simulation results showed that most of the lightning current passes through the two arresters nearest to the strike, only a relatively small proportion is absorbed by arresters located further away down the line. When the effect of arrester connections leads was ignored, much higher current magnitudes were calculated through the two arresters nearest to the lightning strike point. The current magnitudes are more than 12% higher compared with the case with leads. This, of course, could have energy and cost implications, in which the simplified model overestimates the energy demand on the line surge arresters. As expected, the voltage across the insulation will change accordingly for the two models. For an injection of a 32kA lightning current, voltages close to the line BIL of 650kV were calculated when the arrester connection leads were not included in the model (Figure 4.b). The other case predicted much lower voltages and, hence, no risk of flashover (Figure 4.a).

Shielded lines

As can be seen in Figure 3.b, the arrester connection can be achieved either through the tower (represented by its surge impedance and footing resistance) or directly to ground; these alternative modelling approaches were evaluated for the backflashover and shielding failure determination.

(i) Shielding failure: For the shielding failure case, a 12kA strike was applied to the top phase as can be predicted by the shielding angle. As expected, the first two arresters next to the strike point absorb the majority of the lightning strike current.

(ii) Backflashover: For this case, a 100kA strike was used at the mid-line tower to illustrate the effect of tower and surge arrester models on the developed voltages at various nodes on the line. The surge arrester is represented by a non linear resistor (MOV model) and its connection with a series LR equivalent. The tower is represented by its surge impedance, Z=120Ω, in series with a footing resistance R=20Ω. Four different models were used for the arrester - tower combinations with varying degrees of simplification:

a) The surge arrester is connected to the top of the tower, (full model)
b) The surge arrester is earthed directly neglecting its connection lead,
c) The tower is represented by its footing resistance only and the arrester is earthed directly ignoring the effect of its connection leads
d) The surge arrester is earthed directly, and no tower model was used.

For model (a) above, it was found that the voltage at the tower tops along the line decreases exponentially with distance, d, from the strike point. An empirical trend for the tower voltage V_{tower} on phase C (bottom phase) was derived for this case, and is given by

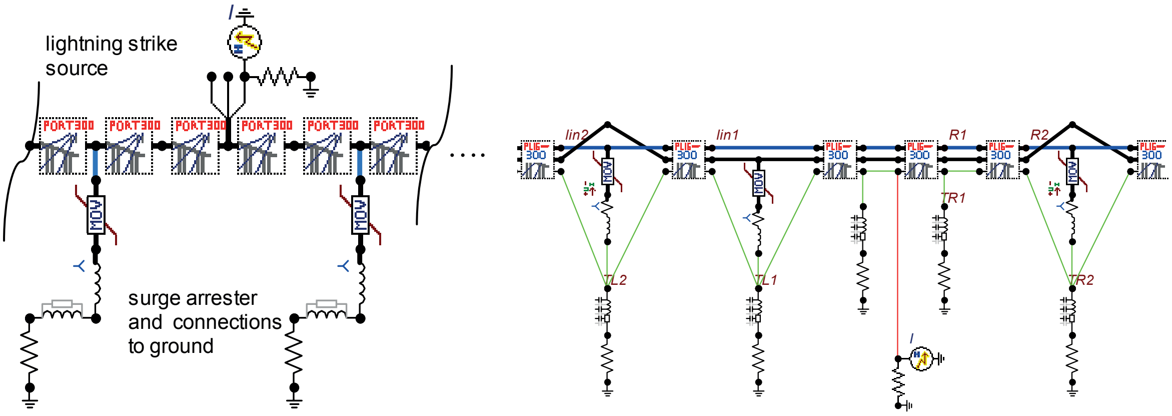
$$V_{tower} = 846.9\, e^{-3.992\, d} \qquad (1)$$

The voltage across the arresters also decreases away from the strike point for all models. However, as can be seen in Figure 5, there is a less steep change in magnitude. The voltage magnitude and shape also change significantly for the different models. Table 2 summarises the magnitudes of voltages across the first arrester for the four models above.

Table 2: Peak voltage at nearest arrester for various models.

Simulation Model	Case (a)	Case (b)	Case (b)	Case (b)
Voltage across first arrester [kV]	76.2	56	52	252

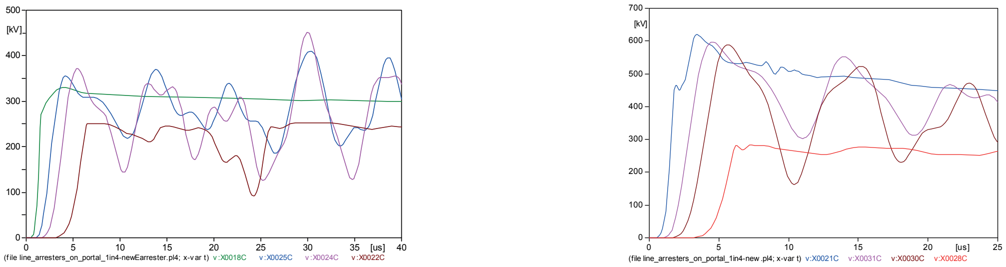
From these simulations, it is shown that the modelling of arrester and tower affect the predicted results which, in turn, have implications for back-flashover determination and arrester current/energy. Further refinement of the arrester/tower connection model was found to have slightly different results. Figure 6 shows the proposed refined model.



a) Section of Portal-type overhead model

b) *Section of shielded line model*

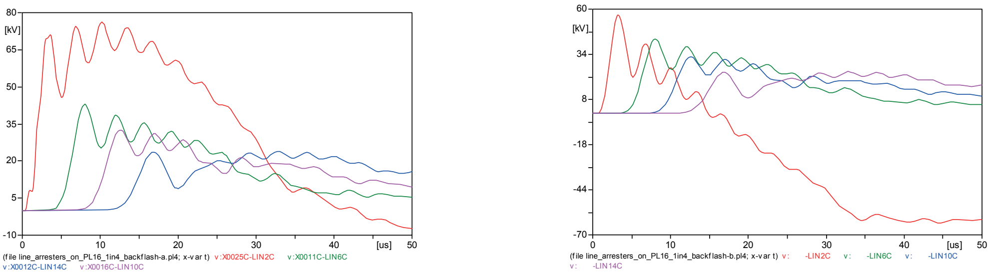
Figure 3: sections of line models showing surge arresters every 4 spans and injection point.



a) voltages at arresters (with connection leads)

b) voltages at arresters (without leads)

Figure 4: Effect of arrester model on voltages at arrester locations away from the injection point.



a) Tower model (a)-

b) Tower model (b)

Figure 5: Examples of voltage shapes across line arresters for two different tower modelling techniques.

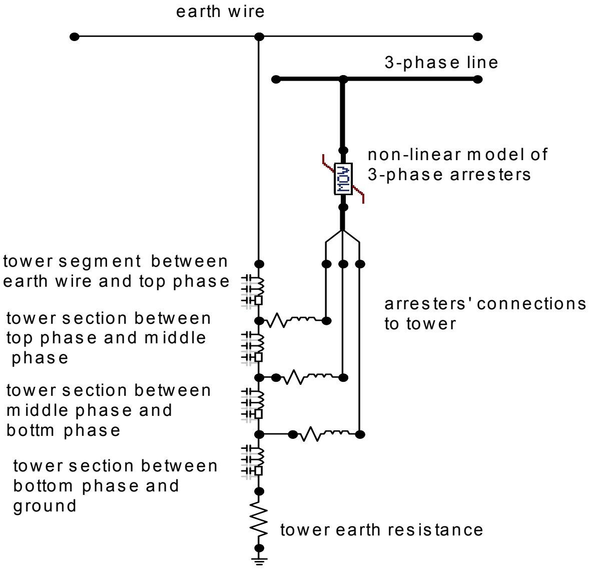


Figure 6: Proposed refined circuit model for tower-arrester assembly for a vertical phase configuration

Discussion and Conclusions

This analysis has considered a number of different scenarios. The nature of the incident lightning is a key. Obviously, the system voltage will have a major effect on the suitability of arrester application. Transmission is typical solidly grounded with very high BIL, while distribution systems will be impedance earthed with a much lower BIL. Therefore, trying to apply common guidelines is impractical. Coupled with this is the different electromagnetic nature between the two types of system, these effects are much more significant at transmission, although the design and security criteria may be quite different.

This paper has presented the results from a number of studies examining the degree of protection afforded from parallel surge arresters and their impact on the proximity effect for nearby equipment. There are many factors in the studies which can affect the results, variation between models being a major one. The main aim of this paper was to illustrate some of the general trends, but reinforces the case that this is a complex problem and for regional applications local design, operational, and topological factors must be incorporated into the model.

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