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Impact of Lightning Surge on Surge Arrester Placement in High Voltage Substation

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Abstract: This study generalizes the modeling details to be used in modeling the high voltage substation and performing the analysis on the impact of lightning surge on surge arrester placement in high voltage substation using the PSCAD/EMTDC software. Modeling parameters and the substation layout design are based and adapted from 132 kV substation in Johor Baharu, Malaysia, courtesy of the Tenaga Nasional Berhad (TNB). The model is based on single phase line model as it was suggested by the IEEE to be adequate to represent the substation in transient analysis simulation. The outcome of this paper would be the results of prediction of the breakdown current and effect of surge arrester placement in terms of voltage level measured at particular points in substation.

Key words: Insulation coordination, lightning, surge arrester, PSCAD/EMTDC

INTRODUCTION

Lightning interference occurs mainly on overhead lines and has been a problem since the earliest days of the electricity supply industry. Overvoltages which occur on the lines, travel toward the terminal or substation and can cause damage, particularly to expensive equipment such as transformers. In view of their importance, cost and the difficulty of making internal repairs, the protection of large transformers against lightning overvoltages is usually given special consideration. Lightning activity in South East Asia, especially in Malaysia, ranks as one of the highest in the world. Tenaga Nasional Berhad Research (TNBR) Malaysia has recorded as high as 320 kA lightning impulse current in Malaysia using their lightning detection network system (LDNS). Every year, million dollars worth of damage is caused by the devastating effects of lightning including to electrical power systems. The transmission line trip in Malaysia is majorly caused by lightning, which is about 70%.

Therefore, thorough knowledge on insulation coordination studies is urgently needed strategic planning and protection of the expensive assets especially in the substation section. Lightning overvoltages are fast front overvoltages with times to crest from 0.1-20 msec. For substations, shield failures, backflash and induced overvoltages generate surge voltages that impinge on the substation equipment.

Lightning induced voltages are generally below 400 kV and are important only for lower voltage systems. The incoming surges caused by the backflash are more severe than that caused by shielding failures. As these surges travel from the stroke terminating point to the station, corona decreases front steepness and the crest magnitude. The shield wire has significant impact on the wave propagation. A shield wire grounded at each tower makes the propagation velocity of the ground mode wave component very close to the conductor mode component. The magnitude of the surges caused by a backflash ranges from 70 to 120% of the positive polarity critical flashover voltage (CFO) of the line insulation. The front steepness is a function of the conductor size, the distance between the location of the backflash and the station (IEEE Power Engineering Society, 1999).

The objectives of this study are to model the high voltage substation and perform the analysis on prediction of the level of current that causes the transformer to breakdown and determine the effect of surge arrester placement at the substation. This will be done by comparing the voltage level measured close to the transformer with the suggested basic insulation level (BIL) value used by the utility.

MODELING OF THE SYSTEM

The main emphasis of this research is to model a high voltage substation for the lightning surge analysis. This modeling must include the tower, power line, tower footing resistance, lightning, substation equipments and insulation coordination. Figure 1 shows the modeling

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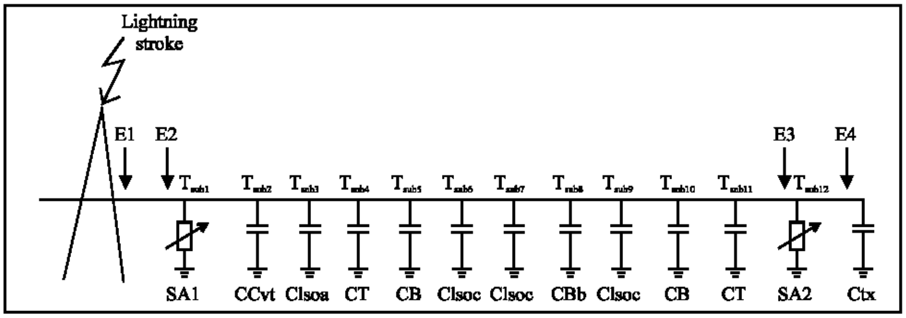

Fig. 1: Substation model for case studies

Table 1: Key parameters used for modeling the system

Model	Sub-Component	Details/Reference
Lightning strike		Double exponential current source with a varying front time according to the peak current (CIGRE, 1991) and negative polarity.
Overhead line	Phase conductor	Single phase conductor, 300 Ω surge impedance, lowest phase conductor at 20 m. Modelled with frequency dependent travelling wave model. Distance of 50 m between tower and substation section.
Tower	Main structure	Surge impedance of 155 Ω and travelling wave velocity of speed of light modelled with a Bergeron model
	Tower footing	DC resistance of 10 Ω in a soil resistivity of 100 Ωm. Soil ionisation modelled (Woodford, 1998).
Substation equipments		The overall substation model derived from substation layout drawings. The buswork and conductors between the discontinuity points inside the substation and connections between the substation equipments are represented by line sections. The substation equipments, such as circuit breakers, substation transformers and isolators, are represented by their stray capacitances to ground as in Table 2.

Table 2: Comparison of capacitors value between TNB calculation and IEEE recommendations

Capacitor	TNB (calc)	IEEE recommendations
C_{CVT}	7592.98 pF	8000 pF
C_{ISOa}	116.12 pF	100 pF
C_T	385.16 pF	250 pF
C_B	92.25 pF	100 pF
C_{ISOc}	116.12 pF	100 pF
C_{Bb}	82.78 pF	80 pF
C_B	92.25 pF	100 pF
C_{TX}	1485.13 pF	2027 pF

arrangements at the substation, which is adopted for the case studies and based on real configurations of the TNB's 132 kV substation. The lightning strike is placed at the tower close to the substation. The distance between the tower and the substation entrance is 50 m. Point E1 measures the entrance voltage induced by the lightning and point E2 is the point-of-connection (POC) of the surge arrester, where the voltage is expected to be clamped before passing through the capacitive voltage transformer, labeled as C_{CVT}. Whilst points E3 and E4 are the second surge arrester, SA2 and the power transformer, labeled as C_{TX}, respectively. Further of specific details relating to the model are described in Table 1.

Table 2 describes the comparison of capacitor value between TNB calculation approach and IEEE recommendation base on 115 kV US substation system model. For this study, TNB calculation approach of capacitor values was adapted to model the system as it more or less agreed with the value recommended by IEEE WG 3.4.11 (1992) and for the actual analysis. The distance between each substation equipments are as below:

T_{sub1} = 3.0 m	T_{sub5} = 4.0 m	T_{sub9} = 14.5 m
T_{sub2} = 3.5 m	T_{sub6} = 4.5 m	T_{sub10} = 3.0 m
T_{sub3} = 3.5 m	T_{sub7} = 3.0 m	T_{sub11} = 3.0 m
T_{sub4} = 3.0 m	T_{sub8} = 3.0 m	T_{sub12} = 5.0 m

SURGE ARRESTER MODELING

Several models of arrester had been described elsewhere in literature (IEC, 1993; Martinez and Castro-Aranda, 2004; IEEE WG 3.4.11, 1992). Most of the arrester model must include two nonlinear resistances A0 and A1 as shown in Fig. 2, with other combination of the components. However for different approach, it is basically using different type of lumped parameter arrangement. The frequency-dependent surge arrester model which was recommended by IEEE WG 3.4.11 (1992). is used in this work. This model is shown in Fig. 2 and it was reported as the most accurate representation based on single phase line model (Goudarzi and Mohseni, 2004). Adjustment procedure of parameters is described by IEEE WG 3.4.11 (1992).

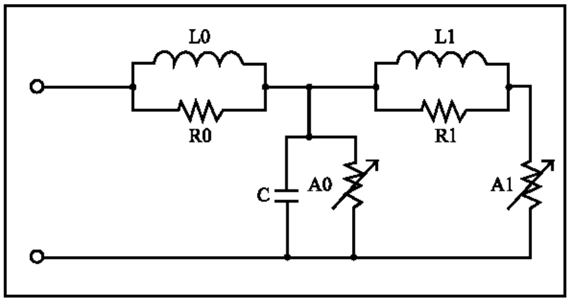

Fig. 2: IEEE frequency-dependent model

RESULTS AND DISCUSSION

Surge arrester breakdown current: There are two cases are considered under the critical conditions; when the surge arrester 1 (SA1) is not operated and also when both surge arresters (SA1 and SA2) are not operated. The idea is to demonstrate the effect of floating surge arrester (missing of copper conductor connected between surge arrester and substation earthing) due to the vandalism cases as reported by the utility company in recent years.

Table 3 shows the data for the case where no SA1 is installed. As the currents increase, the voltage level also increases. The BIL used by TNB Malaysia for the 132 kV rated transformer is 550 kV. Therefore, the probability of the capacitive voltage transformer, C_{CVT} damage can be estimated when the lightning current reaches 144 kA.

Table 4 shows the data for the case when both surge arresters are not operated. This is the worst case scenario that could possibly happen involving the case of vandalism on the surge arresters. For the case of capacitive voltage transformer, C_{CVT}, it is estimated that the probability of the damage is at the current of 33 kA, whilst for the case of power transformer, C_{TX}, current of 31 kA can already cause the breakdown on the equipment.

Effect of surge arrester placement: Table 5 demonstrates the effect of surge arrester placement at the substation. For the first case, SA2 is placed 8 m before power transformer, C_{TX}, instead of the real placement which is just 5 m. For the distance of 8 m, Table 5a shows that the voltages level at point E4 is slightly higher compared to the result in Table 5c for the original placement. Whilst for the SA2 placed at 11 m away from T_x, voltages level at point E4 are also increased, as shown by the data in Table 5b. Having the differences for only few kilovolts, the results perhaps very difficult to be judged. However, this is very good analysis in determining a proper insulation coordination studies. In this case, having the surge arrester located at the proper location is very crucial and without having all the related knowledge, it is very difficult in making a decision.

Table 3: Case of no SA1 is installed

I (kA)	E1 (kV)	E2 (kV)	E3 (kV)	E4 (kV)
140	2011	541	271	287
141	2022	543	271	288
142	2032	545	272	289
143	2043	547	272	289
144	2053	549	273	290
145	2064	551	273	291
146	2074	554	274	291
147	2084	556	274	292
148	2094	558	275	293
149	2105	560	275	293
150	2115	562	276	294

Table 4: Case of both surge arresters are not operated

I (kA)	E1 (kV)	E2 (kV)	E3 (kV)	E4 (kV)
25	510	426	447	450
26	528	442	463	467
27	545	457	480	483
28	562	473	496	499
29	579	489	512	516
30	595	504	528	532
31	612	520	544	548
32	628	535	561	564
33	645	551	577	580
34	662	566	593	596
35	678	581	609	612

Table 5: Effect of surge arrester placement

I (kA)	E1 (kV)	E2 (kV)	E3 (kV)	E4 (kV)
(a) at 8 m away the C_{TX}				
20	426	195	194	198
40	759	216	207	214
60	1055	222	224	236
80	1321	227	231	244
100	1564	231	236	250
120	1794	234	240	258
140	2011	239	245	265
160	2213	244	249	272
180	2414	248	252	279
200	2603	252	256	285
(b) at 11 m away the C_{TX}				
20	426	195	196	200
40	759	216	210	219
60	1055	221	233	245
80	1321	227	243	255
100	1564	231	249	263
120	1794	234	255	272
140	2011	236	261	280
160	2213	241	267	288
180	2414	245	273	296
200	2603	249	277	303
(c) original placement at 5 m				
20	426	195	191	195
40	759	216	204	208
60	1055	222	214	226
80	1321	228	220	231
100	1564	232	223	235
120	1794	235	226	241
140	2011	241	228	247
160	2213	246	229	253
180	2414	250	231	259
200	2603	255	232	264

CONCLUSION

Detail modeling guidelines and parameters for high substation are successfully presented. Results for the first part have clearly shown that the impact of lightning surge can be very dangerous even at low value of current if there is no surge arresters are in operating or used for protection. Overall results have demonstrated the importance of having a right location of surge arrester placement as it is crucially needed in order to optimize the substation performance in term of its reliability and cost effective. In other words, this surge arrester must be placed as close as possible to the equipment to be protected, as fail to do so will cause a significant damage to the equipment.

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