Journal of Science & Technology 131 (2018) 049-054

Effect of Transmission Line Configuration on the Installation of Surge Arrester

*Ninh Văn Nam [1,3] *, Phạm Hồng Thịnh[2], Trần Văn Tớp[1]*
[1] *Hanoi University of Science and Technology, No. 1, Dai Co Viet, Hai Ba Trung, Hanoi, Viet Nam*
[2]*Underground Systems Inc., Milford, CT, USA*
[3]*Hanoi University of Industry, No. 298, Cau Dien Street, Bac Tu Liem District, Hanoi*
Received: February 02, 2018; Accepted: November 26, 2018

Abstract

As a transmission line has a specific configuration at an operating voltage, the installation of surge arresters thereof has to take into account the line configuration in order to achieve the best total flash rate. This paper deals with the characteristics in installing surge arresters in the 110 kV and 220 kV transmission lines in Vietnam. Best locations of surge arresters in a given line are determined by studying the effect of main parameters of the transmission lines, such as the type of tower, the number of shield wire, the number of surge arrester to be installed and the footing resistance. The total flashover rate of each transmission line was calculated by the electrogeometric model (EGM) and the electromagnetic transient program simulation (EMTP/ATP), which can be used as a practical guide for the utilities.

Keywords: Coupling factor, transmission line, surge arrester, EMTP simulation

1. Introduction

When a lightning stroke terminates on the shield wire, either on the tower top or on the mid-span, a part of the lightning current will flow to the ground via the tower while the remaining will propagate on the shield wire to adjacent towers. The propagation wave on the shield wire will induce a voltage on the phase conductor, which is characterized by the coupling effect. As described in [1], the coupling factor varies depending on the line configuration including the tower type, the footing resistance and the conductor height. The potential difference between the shield wire and the phase conductor therefore varies with the line configuration, which results in different flashover behaviors of the insulator at different operating voltages, even though the same lightning current is applied. Using surge arrester has been one of the most effective methods to improve lightning performance in both 110 kV and 220 kV transmission lines [2-5]. In the 220 kV transmission line, the calculation in [2] and the field data showed that the surge arresters should be prioritized in the order from the upper phase to the lower phase. However, this calculation was only performed for the 220 kV twin circuit. The shield failure was also omitted in estimating the effectiveness of surge arrester installation. As the coupling factor is very different for different transmission lines, the best location of installing surge arrester in the 220 kV line might no longer be valid in the 110 kV line.

This paper deals with the characteristics of installing surge arresters in 110 kV and 220 kV transmission lines. Key parameters are considered to recommend the most suited locations for installing surge arresters in transmission lines of Vietnam.

2. Configuration of transmission lines

The actual configuration of 110 kV and 220 kV transmission lines in Vietnam are used in this study. The 220 kV line includes twin circuit with 2 SW, type tower Đ222A+6.5 (Fig. 1.a) or one circuit with 1 SW, type tower Đ212A+6.5 (Fig.1.b). The 110 kV line can be twin circuit with 1 SW, type tower N121-33A; B (Fig.1.c) or one circuit with 1SW type tower Đ111-30A; B (Fig.1.d). Parameters of each tower are shown in table 1.

Table 1. Tower parameters

Transmission line		h (m)	D_1 (m)	D_2 (m)	D_3 (m)	D_4 (m)	S_g (m)
220 kV	Twin circuit	46	5	6	6	29	8.6
	One circuit	40	5	6	-	29	8.6
110 kV	Twin circuit	33	6	4	4	19	7
	One circuit	30	4	4	-	22	5

* Corresponding author: Tel.: (+84) 912.485.051
Email: ninhnamhaui@gmail.com

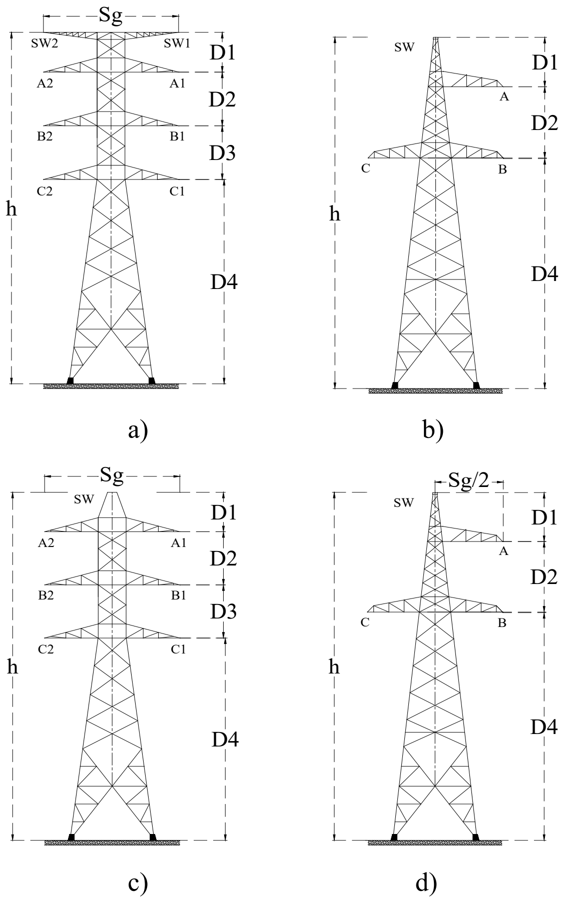

Fig. 1. Configuration of 220 kV towers (a and b) and 110 kV towers (c and d)

3. Lightning stroke to transmission lines equiped with surge arresters

3.1. Stroke to tower top or shield wire

The induced voltage in phase conductor due to coupling phenomenon decreases the voltage across insulators when compared with that without induction coupling [1]. The coupling factor depends on several parameters of the line among which the distance between conductors/wire and the conductor/wire height are of the utmost importance [6]. Fig. 2 depicts the coupling factor of the 110 kV and 220 kV lines as a function of the distance between the conductor and the shield wire. For the sake of illustration, only the coupling factor of one circuit - 1 SW lines was calculated for the conductor of phase A (the largest coupling factor). Similar results were also found in twin circuit - 2 SW.

It is found that the coupling factor decreases with the distance between the conductor and the shield wire, which implies that the voltage across insulators in lower phases would be smallest for a given lightning current. The coupling factor can decrease from 0.28 to 0.21 for 110 kV lines and from 0.27 to 0.21 for 220 kV lines, which corresponds to the conductor moving from upper phase to lower phase. This decrease results in lowering 41 kV and 75 kV in voltage across insulators of 110 kV and 220 kV lines, respectively. For an assumed surge impedance of 400 Ω of the conductor, such lowering voltages results in decreasing 205 A and 375 A of lightning current. As a result, the flashover is more likely to occur in lower phases than in upper phases

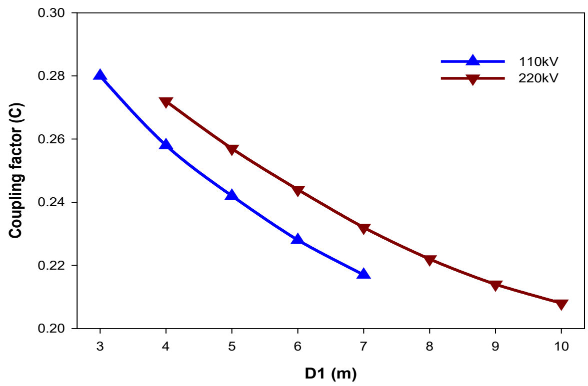

Fig. 2. Coupling factor of transmission lines of 1 circuit, 1 shield wire versus the distance between the upper conductor and the shield wire

3.2. *Shield failure*

Technically, only the SW is purposely used to protect the phase conductor from direct strokes. However, the higher conductor is also seen as a SW for the lower conductor. For the twin circuit in both operating voltages (110 kV and 220 kV), the shield angle of the upper phase is biggest and is equal to zero for the middle and lower phases (Fig. 1). This configuration makes the shield failure flashover rate in middle and lower phases to be the same for both transmission lines. For one-circuit lines, the shield angle of the lower phase of the 110 kV line is smaller than that of the 220 kV line, which results in a smaller SFFOR of the lower phase in 110 kV line. Therefore, the installation of surge arrester should be carefully studied for each transmission line in order to achieve the best total failure rate.

4. Results

4.1. Backflashover rate

The blackflashover rate (BFR) is determined by the CIGRE method [1,7-9], which depends on the critical lightning current I_c and the number of flash to the line N_L. The value of N_L is calculated by the electrogeometric (EGM) and I_c is determined by the EMTP simulation [2,9]

4.2. Shield failure flashover rate

The shield failure flashover rate (SFFOR) is determined by two parameters, i.e, the range current at which the lightning can terminate on the phase conductor and the critical current I_c. Again, the range of lightning current is determined by the EGM method and the I_c is calculated by the EMTP simulation [1,8,9]

4.3. Total flashover rate

The total flashover rate is the sum of the backflashover rate and the shield failure flashover rate as:

$$N_c = BFR + SFFOR \quad \text{(flashover/100km/year)} \tag{1}$$

5. EMTP models

Line components such as towers, insulators, footing resistances, surge arresters are represented in EMTP simulation as described in [9-11]. The transmission lines are assumed to locate in areas with the flash density of 10 flashes/km^2/year. The footing resistance varies depending on the local soil resistivity, which are assumed to be from 5 Ω to 50 Ω.

6. Results and discussion

6.1. 220 kV transmission line

6.1.1. Twin circuit with 2 SWs

Fig. 3 shows that installing 1 surge arrester (SA) on any phase substantially decreases the total flashover rate. For footing resistance R_f smaller than 15 Ω, SA on the upper phases (A1) is found to be the most effective. For R_f greater than 15 Ω, the SA on the middle phase (B1) provides the least flashover rate. The simulation results also show that if the footing resistance is greater than 35 Ω, flashover takes place on the lower phases first. This observation confirms the importance of coupling effect in areas with high values of soil resistivity. To clarify this point, take an example of the footing resistance of 5 Ω. When a lightning current of 45 kA terminates on the tower top, 92 % of the total current (41.4kA) is mitigated into the footing resistance via the tower. A small portion (~ 8 %) of the total current, or about 3.6 kA, travels on the SWs to adjacent towers, which also produces a negligible induced voltage on the phase conductor. For R_f = 50 Ω, 36% of the total lightning current (or 16.2 kA) would flow in the SW towards adjacent towers to induce a significant voltage on the conductors. Therefore, the effect of induced voltage on the flashover behavior of the upper phase is negligible in low values of footing resistances (R_f <35 Ω), although the coupling factor of this conductor is highest. On the other hand, the SFFOR of the upper phase is highest due to its shield angle, which makes the installation of surge arrester on the upper phase most effective to reduce the shield failure rate. When the footing resistance is high enough (R_f>35 Ω), an opposite trend is observed. As the induced voltage decreases with the conductor height, the voltage across insulators of middle and lower conductor is higher than that of the upper conductor. Therefore, installing surge arresters in the middle and lower phases becomes most effective.

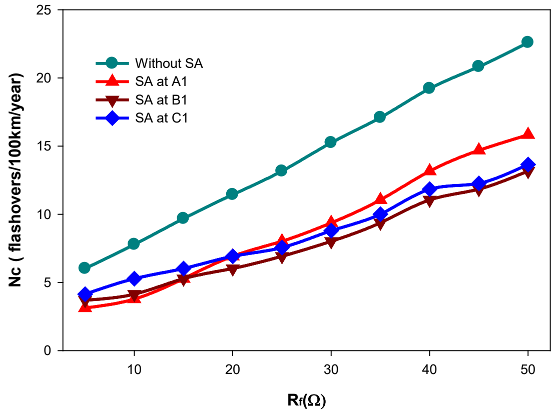

Fig. 3. Total flashover rate of a 220 kV twin-circuit with 2 shield wires, equipped with 1 SA versus the footing resistance

If two SAs per tower are used and one of them is operational when lightning terminates on that tower, the effect of coupling effect on the voltage across insulators becomes quite different from the case with 1 SA per tower. The lightning current not only flows in the SWs, but also in the phase conductor where the SA is operated. As seen from Figure 4, installing SAs on upper and middle conductors is most effective for R_f <20 Ω. For R_f>20 Ω, SAs on middle and lower phases provides the best total flash rate. In the area with extremely high footing resistances (R>40 Ω), SAs applied on upper and lower phases is the least effective solution.

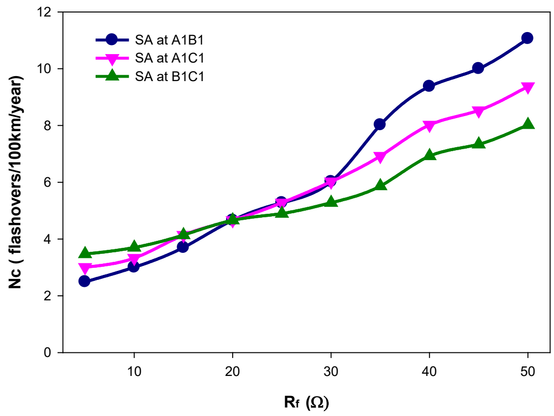

Fig. 4. Total flashover rate of a 220 kV twin circuit- 2 SWs, equipped with 2 SAs versus the footing resistance

When 3 SAs are installed in one circuit, the flashover at that circuit is completely eliminated but the flashover rate of the other circuit remains intact. Fig. 5 shows that when 3 SAs are installed, the location of these 3 SAs in the tower should be changed in accordance with the footing resistance to achieve the lowest total flashover rate. In areas with the footing resistances smaller than 15 Ω, two SAs on two upper phases of both circuits and one SA on one middle phase would provide the best flashover rate. For 15 Ω<R_f <30 Ω, the configuration with two SAs on two upper phases and one SA on the lower phase (A1A2C1 or A1A2C2) would be better. For any other R_f over 30 Ω, 3 SAs in one circuit is the most effective solution. This observation again confirms the effect of coupling factor at high values of footing resistance, since the lightning current flows in the SWs increases with the footing resistance.

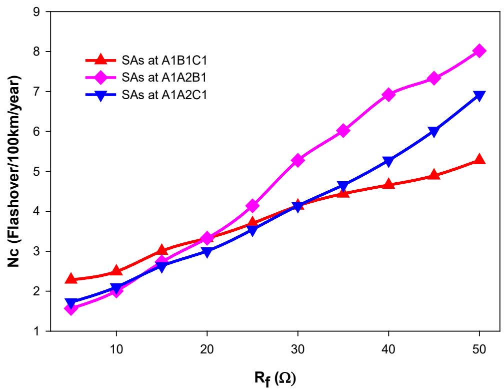

Fig. 5. Total flashover rate of a 220 kV line, twin circuit- 2 SWs, equipped with 3 SAs versus the footing resistance

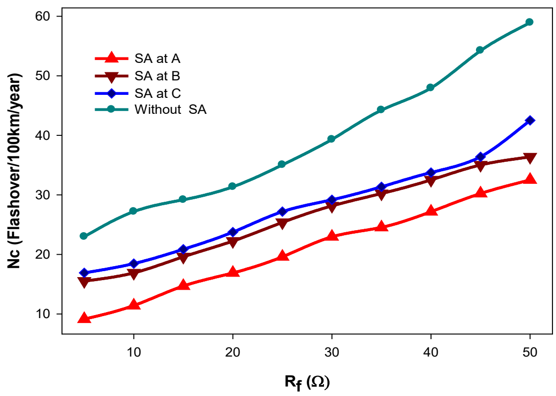

Fig. 6. Total flash rate of a 220 kV one circuit- 1 SW, equipped with 1 SA versus the footing resistance

6.1.2. One circuit with 1 SW

In this transmission line, installing 1 SA on the upper phase is the most effective for any given value of footing resistance (Fig. 6). Since there is only one SW, the equivalent surge impedance of the shield wire is doubled and thus the lightning current flowing in the shield wire is halved when compared with the configuration of 2 SWs. Therefore, the induced voltage due to the coupling effect in phase conductor is almost negligible. The total flash rate is only determined by the flashover behavior of the upper phase, which has the highest shielding angle. If 2 SAs are used, the configuration AC (one SA in the upper phase, the other one on the lower phase) would provide the best result (Fig. 7).

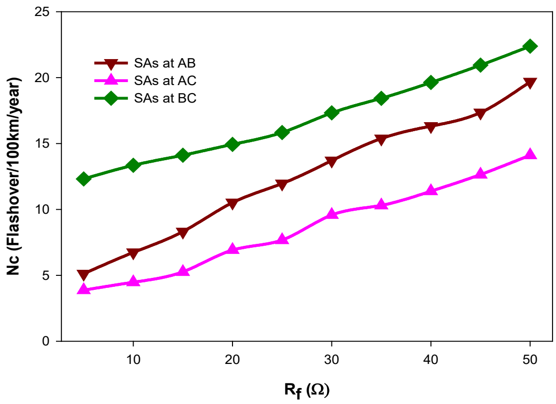

Fig. 7. Total flash rate of a 220 kV one circuit- 1 SW, equipped with 2 SAs versus the footing resistance

6.2. 110 kV transmission line

6.2.1. Twin circuit with 1 SW

In this line configuration, the shielding angle of any conductor is much higher than that of the 220 kV line. Therefore, the arrester installing should be prioritized for higher conductors. If only one SA is used, SA mounted on the lower phase almost has no effect on the total flash rate (Fig. 8). The SA equipped on the upper phase has the biggest impact on the flashover rate for any value of footing resistance.

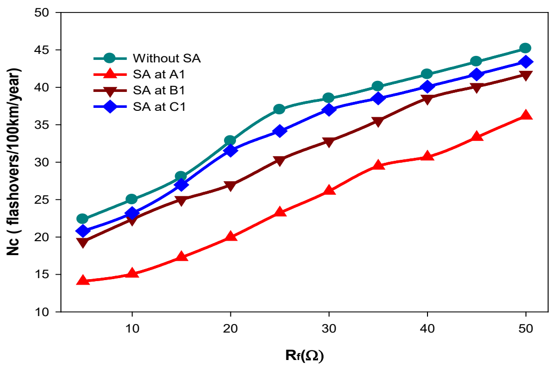

Fig. 8. Total flash rate of a 110 kV, twin circuit- 1 SW, equipped with 1 SA versus the footing resistance

If 2 SAs are used, the same results as that of the 220 kV line, twin circuit with 2 SW are observed (Fig. 9). The best configuration for installing SA would be the upper phase and lower phase (A1C1). Installing SAs on the middle phase and lower phase results in the same total flash rate as using 1 SA mounted on the upper phase in Figure 8. If 3 SAs are afforded, two SAs on upper phases of both circuits and the other SA on one middle phase would provide the best total flash rate (Fig. 10).

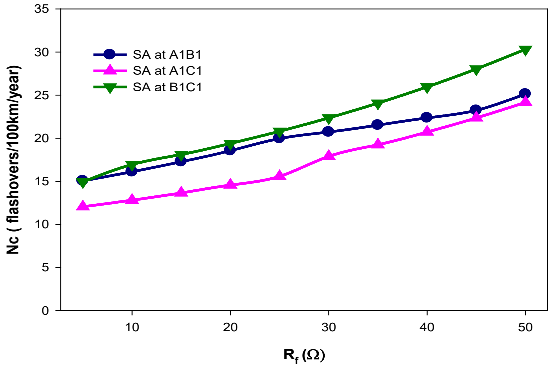

Fig. 9. Total flash rate of a 110 kV, twin circuit- 1 SW, equipped with 2 SAs versus the footing resistance

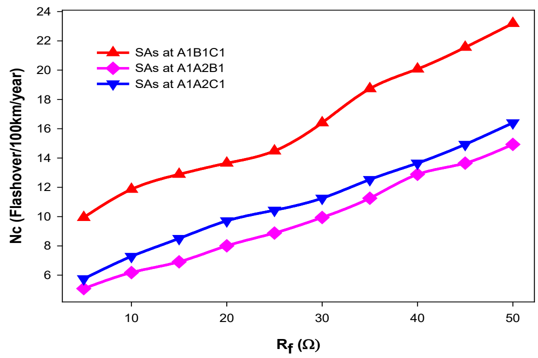

Fig. 10. Total flash rate of a 110 kV, twin circuit- 1 SW, equipped with 3 SAs versus the footing resistance

6.2.2. One circuit with 1 SW

The upper phase SA is found to be most effective in any value of footing resistance (Fig. 11). The flashover rate remains nearly unchanged when a SA is installed in the middle phase. This behavior is due to the fact that the upper conductor, which is already protected by the SW, shields the middle phase. Thus, the SFFOR of middle phase is very low and installing SA in the lower phase becomes much more effective than that in the middle phase. If 2 SAs are used, the same results as that of the 220 kV one circuit - 1 SW are observed (Fig. 12), i.e. the SAs should be installed in the upper and lower phases.

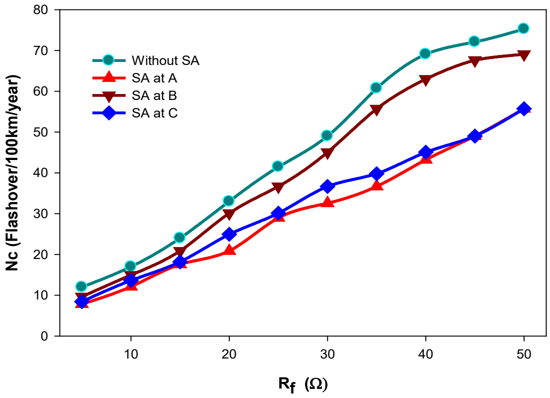

Fig. 11. Total flash rate of a 110 kV, one circuit- 1 SW, equipped with 1 SA versus the footing resistance

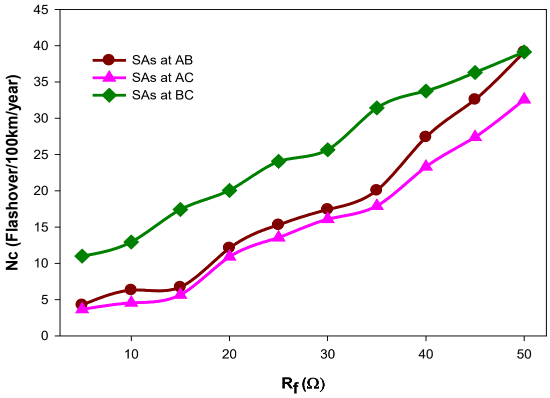

Fig. 12. Total flash rate of a 110 kV, twin circuit- 1 SW, equipped with 2 SAs versus the footing resistance

Table 2. Best locations for installing SAs in 220 kV transmission lines

	Twin circuit	One circuit
1 SA	• $R_f < 15$ Ω: Upper phase • $R_f \geq 15$ Ω: Middle phase	Upper phase
2 SAs	• $R_f < 20$ Ω: Upper and middle phases (AB) • $R_f > 20$ Ω: Middle and lower phases (BC)	Upper and lower phases (BC)
3 SAs	• $R_f < 15$ Ω: Upper phases of both circuit and one middle phase (AAB) • $15 \leq R_f < 30$ Ω: Upper phases of both circuit and one lower phase (AAC) • $R_f \geq 30$ Ω: all three phases of one circuit (ABC)	---------------

Table 3. Best locations for installing SA in 110kV transmission lines

	Twin circuit	One circuit
1 SA	Upper phase (A)	Upper phase (A)
2 SAs	Upper and lower phases of 1 circuit (AC)	Upper and lower phases (AC)
3 SAs	All three phases of one circuit (ABC)	--------------------

5. Conclusion

As the height and the distance between conductors and shield wires are very different in different operating voltages of the transmission line, the installation location of SAs should be customized based on the line configuration such as the number of circuit, the number of shield wire and the value of footing resistance. The best locations to be equipped with SAs are summarized in tables 2 and 3.

For the 220 kV transmission line, twin circuit with 2 SW, the best location for installing SA strongly depends on the value of footing resistance. For the parameter set of lightning current using in this study, the footing resistance is divided into different ranges to determine the best conductor phase to be equipped with SAs. Up to 2 SAs, only two ranges of footing resistance were identified for prioritized locations for SAs. If 3 SAs per tower, which is a common configuration in the actual transmission lines in Vietnam, can be afforded, three ranges of footing resistance value needs to be considered for installing SAs to achieve the best total flashover rate.

The installation of SAs on the 220 kV, one circuit and all the 110 kV transmission lines has the same characteristic regardless of value of footing resistance. If 1 SA is installed, the upper phase should be used while the upper and lower phases are the best locations if 2 SAs are allowed.

References

[1] Andrew R. Hileman, Insulation Coordination for Power Systems, Boca Raton, FL: CRC, 1999.

[2] T. H. Pham, S. A. Boggs, H. Suzuki, and T. Imai, Effect of externally gapped line arrester placement on insulation coordination of a twin-circuit 220 kV line, IEEE Trans. Power Delivery, vol. 27, no. 4 (2012) 1991–1997.

[3] IEEE guide for improving the lightning performance of transmission lines, IEEE Std 1243-1997, 1997.

[4] S. Sadovic, R. Joulie, S. Tartier and E. Brocard, Use of line surge arresters for the improvement of the lightning performance of 63 kV and 90 kV shielded and unshielded transmission lines, IEEE Transactions on Power Delivery, vol. 12 (1997) 1232-1240.

[5] Juan A. Martinez, Ferley Castro-Aranda, Lightning Performance Analysis of an Overhead Transmission Line Protected by Surge Arresters, IEEE Latin America Transactions, vol. 7, no. 1 (2009) 62-70.

[6] Ninh Nam V, Thinh H. Pham, Top V. Tran, Coupling effect in transmission line submitted to lightning strikes, The 9th RCEEE 2016, Hanoi University of Science and Technology (2016) 20-24.

[7] CIGRE WG 33-01, Guide to Procedures for Estimating the Lightning Performance of Transmission Lines, CIGRE Brochure 63, 1991.

[8] A. Ametani and T. Kawamura, A Method of a Lightning Surge Analysis Recommended in Japan Using EMTP, IEEE Trans. Power Delivery, vol. 20, no. 2 (2005) 867-875.

[9] Nam V Ninh, Thinh Pham, Top V. Tran, A Method to Improve Lightning Performance of Transmission Lines in High Footing Resistance Areas, 2017 International Symposium on Electrical Insulating Materials (ISEIM), Toyohashi, Japan (2017) 761-764.

[10] J. A. Martinez, F. Castro- Aranda, Lightning performance analysis of overhead transmission lines using the EMTP, IEEE Trans. on Power Delivery, vol. 20, no. 3, (2005) 2200-2210.

[11] Samir Bedoui, Abdelhafid Bayadi, A. Manu Haddad, Analysis of Lightning Protection with Transmission Line Arrester Using ATP/EMTP Case of an HV 220kV Double Circuit Line, The 45th UPEC2010, Cardiff, Wales, UK, 2010.