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Research Article

Investigation of Overvoltages Caused by Lightning Strikes on Transmission Lines and GIS Substation Equipment

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Keywords

Lightning,
Overvoltage,
Transmission Line Tower,
GIS substation,
Grounding System,
Insulation Coordination.

Abstract

Overvoltages caused by lightning strikes on the power system can damage the power system and reduce the reliability of the system, and this is always one of the main challenges in designing power transmission lines. Due to their relatively high height, they are one of the most vulnerable parts of the transmission line against lightning strikes. In this paper, we have tried to model the transient state of power and lightning network equipment using EMTP-RV software. Different lightning strikes on the tower and the phase conductor for a 400 kV double-circuit transmission line to be clay. To achieve this goal, an attempt was made to use the precision modeling mode of each network equipment, also since in recent years, the use of GIS substation has been considered due to the smaller space required for the construction of this type of substation and one of the main causes of equipment failure is this type of substation. Fast transient Overvoltages. Because the transmission line leads to a 400 kV GIS substation, an attempt has been made to model the substation equipment for this type of overvoltage on substation equipment and insulation coordination. It should also be examined.

1. Introduction

Lightning is the appearance of an electric light with intense light and sound that the time of this transient wave is very short but the frequency of this wave is very high [1-6]. The main cause of lightning surges is the transient waves. When lightning strikes a transmission line, voltage or current waves are generated on the line, which has a speed close to the speed of light [7]. When these waves reach the terminals of the line, the waves are reflected and returned along the line and are combined with the initial wave. Transformer insulation or line insulators. The analytical study of this issue requires knowledge of the rules of refraction and reflection of mobile waves and familiarity with the ladder diagram to calculate the transient voltages in the lines [8]. However, due to losses in the transmission line, the transient waves are weakened and destroyed after several reflections, and the inductances of this series of transformer windings block these mobile waves and prevent them from entering the generator windings [9] When lightning strikes a phase wire (mainly the highest phase wire) there is no other way to divide the lightning current, and as a result, lightning strikes unprotected lines by the guard wire, often with overvoltage on the phase wire, causing the transmission line to exit circuit [10]. The amplitude of the lightning wave that strikes the conductor is significantly dependent on the geometry of the transmission tower and the protective effect of the guard wires. In a direct collision, lightning is transmitted to the conductor [11]. Also, in direct contact of lightning with the guard wire, it should be known that, in principle, the guard wire is designed to deal with lightning. Therefore, this collision mode is the most desirable type of direct lightning collision with the transmission line because the guard wire is directly connected to the tower and the grounding system at the foot of the tower and can transmit the lightning wave to the ground. The transmission wires of the transmission line are made of steel and are connected directly to the body of the towers. Sometimes, to better connect the wires to the ground, copper belts are installed on the tower and the guard wire is connected to it from the top of the tower [12].

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According to the above, the purpose of this paper is to investigate the overvoltage caused by lightning strikes with a 400 kV transmission line and to investigate the effect of these Overvoltages on GIS substation equipment in the path of this transmission line. The importance of this issue is that careful study of the performance of lightning and the amount of overvoltage resulting in transmission lines and substations in the transmission line is considered important and plays an important role in the design of transmission lines and the discussion of insulation coordination in pressure substations. It has a strong connection to it, as well as the power to discuss network stability.

2. Optimal Lightning Model

Among the two models provided for the lightning source, this model is used for simulation due to the fact that the Cigre model is available in EMTP-RV software.

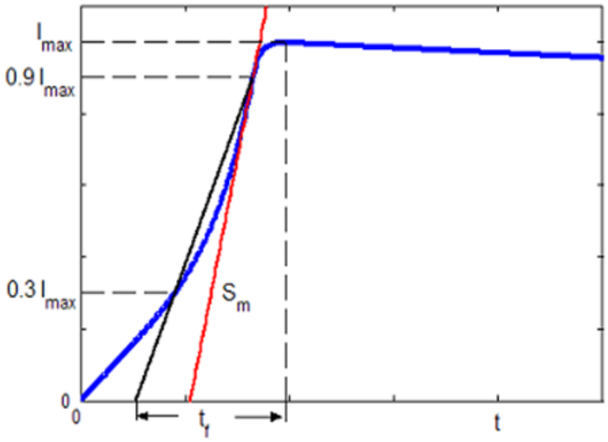

Figure 1. The flow waveform in the Cigre model [13]

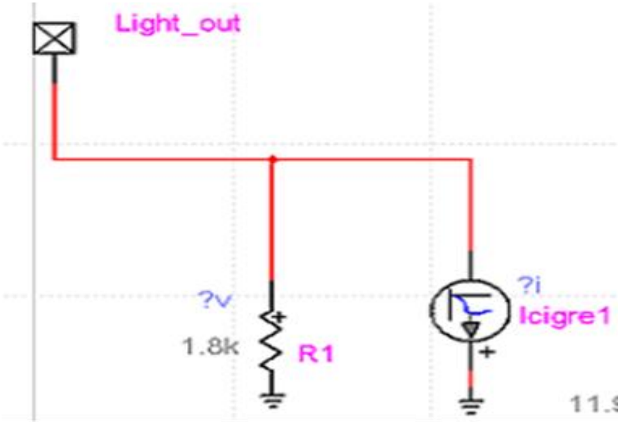

Figure 2. Lightning Cigre Model [14]

2.1. Optimal Transmission Line Tower Model

According to the studies, the amplitude of overvoltage due to lightning strikes on the insulators of the multistory model is the highest value and the simplified wide line model is the lowest value and in the simplified multistory model between these two values, it is the best model for simulating the transmission line tower. The power system is intended to use the multistory model, but since the above model is designed for 500 kV lines, it is possible to use the parameters used in [14] to measure the parameters used from the voltage level of 500 kV to 400 kV, according to the dimensions. Converted the geometry of the tower. The value of the above multistory tower parameters is as follows:

$Z_1=136.06\ \Omega$ $R_1= 14.237\ \Omega$ $L_1=4.196\ \mu H$
$Z_2=136.06\ \Omega$ $R_2= 17.128\ \Omega$ $L_2=5.036\ \mu H$
$Z_3=136.06\ \Omega$ $R_3= 17.128\ \Omega$ $L_3=5.036\ \mu H$
$Z_4=136.06\ \Omega$ $R_4= 48.529\ \Omega$ $L_4=14.268\ \mu H$

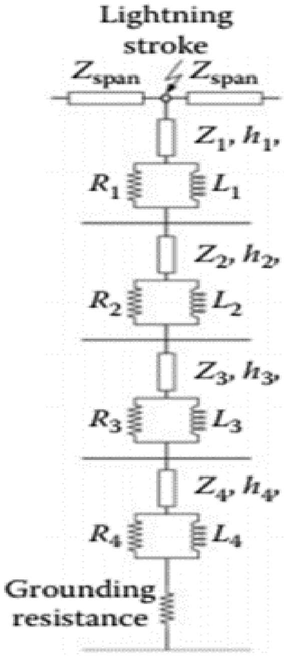

Figure 3. Multistory tower model [15]

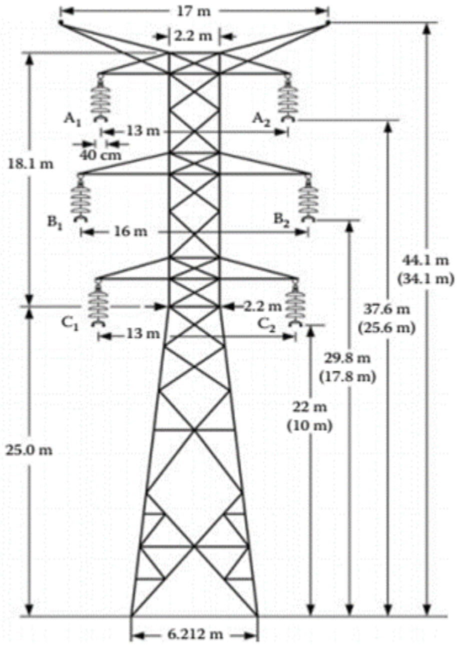

Figure 4. 400 kV line tower model [15]

2.2. Optimal Model of Grounding System in Transmission Line Tower

According to the models offered for modeling the grounding tower transmission system, studies show that modeling the tower ground system with an ohmic resistance does not have accurate results, because all capacitive, inductive and conductive effects must be considered considering the phenomenon. Soil ionization and grounding system configuration were taken into account on the maximum overvoltage generated in the insulator chain. Therefore, to consider the effect of soil ionization, the following grounding system model is used. Through the grounding system, the mast is transferred to the ground, sampled and flowed by I_g (current Compares soil ionization), if the measured current value is less than the value of I_g current, the resistance of the tower grounding system is modeled with a 16-ohm resistor, and if the above current is greater than the value of I_g current, it indicates this. That the ionization of the soil at the foot of the tower is possible [16-19].

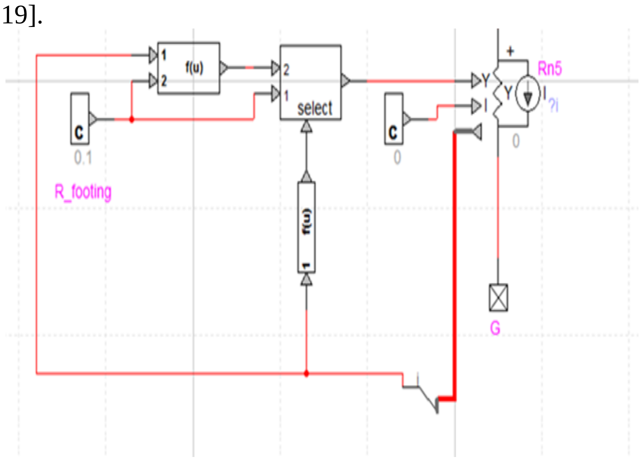

Figure 5. Model of the grounding system of the transmission line tower considering the ionization phenomenon

2.3. Optimal Model of Insulator String

According to the models offered for modeling the insulator string as well as the mechanism of electrical failure in the insulator string, considering that EMTP-RV software uses the same standard method in modeling the insulator string, the leader model compared to the Air gap model is a more advanced model and offers more accurate results and is used to simulate a chain of insulators. It is possible to determine the length of the insulator string by using Table 1, which is proportional to the voltage level of the desired tower (400 kV) [20-22].

Table 1. Number of insulators required, proportional to the voltage level of the power system

Spacing of the gaps in(m)	K	$V_0(kV)$	D
0.8	0.92	343	01e1.4
0.71	0.92	311	.01e1.3
0.61	0.93	276	01e1.1
0.4	0.93	205	02e6.9
0.35	0.93	188	02e5.6
0.28	0.92	167	.02e3.7

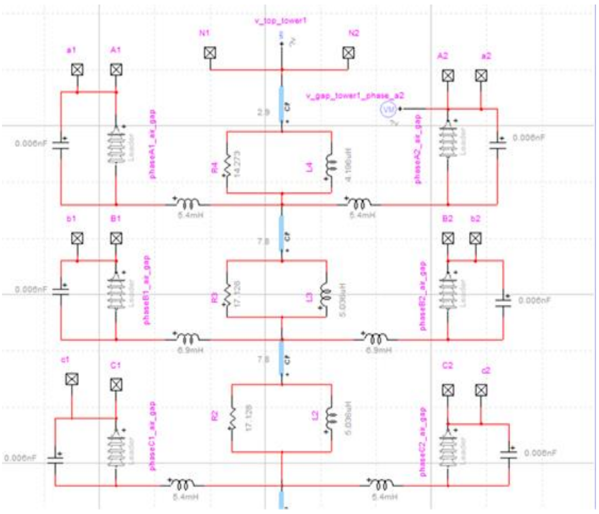

Figure 6. Transmission line tower insulator string model in EMTP-RV software

2.4. The optimal Arrester Model

Transient power supply models include two IEEE (dynamic) models and a simplified IEEE model, which is one of the above two models because the amount of surge arrester voltage in the IEEE model is specified more accurately [23-25].

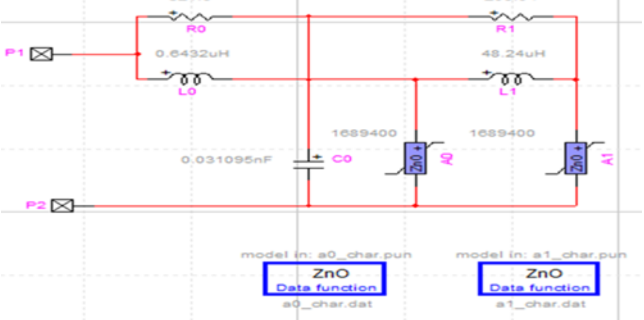

Figure 7. The IEEE model in arrester by EMTP-RV software

Table 2. Parameters of model elements IEEE arrester

Parameter	Amount
R_0	321.6 Ω
L_0	0.6432 µH
R_1	209.04 Ω
L_1	48.24µH
C_0	31.095 PF

2.5. Optimal mModel of Capacitive Voltage Transformer

To model the capacitive voltage transformer (CVT) in transition mode, it is modeled with a grounded capacitor. Also, in transient state calculations after surge arrester and transformer, the capacitive voltage transformer is a determining element due to its high capacitor value, and the value of this capacitor is considered to be about 5 Nanofarads [26].

2.6. Optimal Model of the Power Switches and Sectioner

It can be modeled as a power switch to model a Sectioner, but we have modeled it with a single key to slow down the software's computational speed. The following model is used to model the power switch, which has an impedance of 70 ohms and a grounded capacitor of approximately 32 to 45, however, different models for the breaker model are stated in different sources and in some sources instead of using wave impedance in The impedance is used to reduce the computational speed without the effect of the transient wave speed [26].

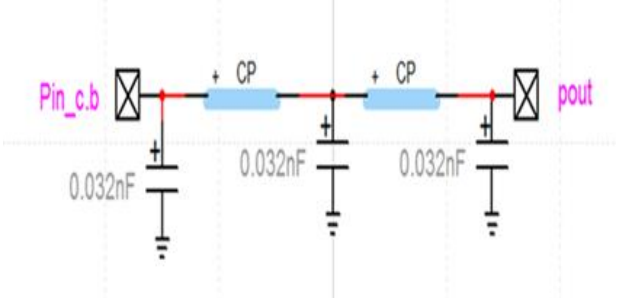

Figure 8. Power switch model in EMTP-RV software

2.7. Optimal Model of GIS Substation Bus Bar

Distributed elements are used single-phase to model the GIS substation bus bar and the information related to the load bus includes its wave impedance and wave propagation speed and the length of the bus bar and the bus bar resistance are stated in the simulated impedance substation. The bus bar wave is equivalent to 90 ohms and the wave speed is about 270 m/µs and the load bus resistance is 0.231 ohm per meter [26].

2.8. Optimal Power Transformer Model

For power transformer modeling, if precise modeling of the power transformer is not required, it can be modeled with a capacitor of 2 nanofarads. The software's modeling can also be used to model power transformers, and the values of the capacitor equivalent to the high pressure and low-pressure side and between the high and low voltage windings in proportion to the apparent power of the transformer are shown in Table 3 [20].

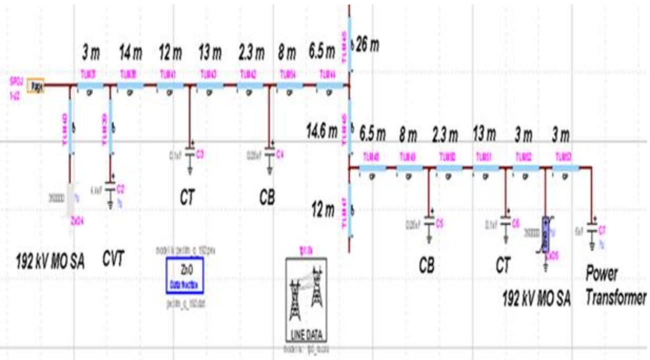

Figure 9. Overview of bus bars of substation with equipment installed

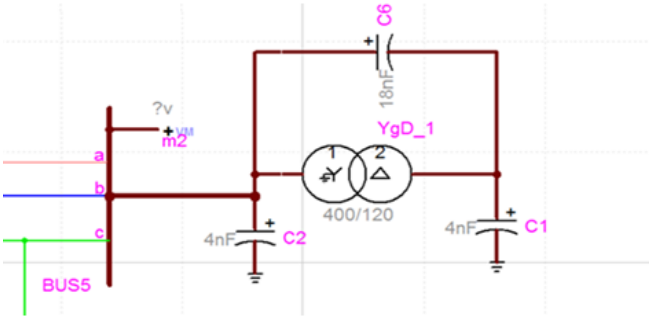

Figure 10. Power transformer simulation in EMTP-RV software

Table 3. Equivalent capacitors on both sides of the power transformer

Transformer	Core type			Shell type			Autotransformers		
MVA	C_{hg}	C_{hl}	C_{lg}	C_{hg}	C_{hl}	C_{lg}	C_{hg}	C_{hl}	C_{lg}
1	14-1.2	17-1.2	16-3.1	-	-	-	-	-	-
2	16-1.4	18-1	16-3	-	-	-	-	-	-
5	14-1.2	20-1.1	17-5.5	-	-	-	-	-	-
7	11-2.7	17-3.5	16-8	-	-	-	-	-	-
10	7-4	11-4	18-8	-	-	-	-	-	-
25	4.2-2.8	18-2.5	20-5.2	7-4	17-10	8-4	18-8	8-3.5	8-3
50	6.8-4	11-3.4	24-3	9-6	16-8	15-4	10-5.5	13-5.3	17-6
75	7-3.5	13-5.5	30-2.8	13-7	17-7	25-4	11-7	20-6	18-11
100	7-3.3	13-5	40-4	14-6	19-7	30-5	12-8	20-9	17-12
200	-	-	-	18-4.5	25-8	27-5	40-8	22-7	26-16
300	-	-	-	21-5.5	22-11	40-20	40-6	24-5	32-12
400	-	-	-	24-8	21-14	45-17	25-6	20-5	23-11
500	-	-	-	30-6.5	24-17	46-18	22-6	20-5	24-10
600	-	-	-	40-5	29-16	46-16	20-6	20-4.5	26-14
700	-	-	-	39-4	30-15	43-14	18-6	20-5	28-12
1000	-	-	-	41-4	30-11	54-6	12-6	23-7	30-16

3. General Specifications of the Studied Power System

The power system studied is a 400 kV double-circuit transmission line leading to a GIS substation, 230/400 kV. The length of the span in the masts leading to the substation is 400 meters and the rest of the transmission line is modeled with a transmission line 100 km long which is connected to a source. It causes ionization of soil (E_0) equal to 400 kV/m and the specific resistance of soil at the foot of the tower is considered to be 200 Ω. At the input of the GIS substation and the input of the power transformer, the ZnO surge arrester is used in the path of each phase, the length of the surge arrester is 3.216 meters. The maximum value of the surge arrester voltage for one lightning wave with an amplitude of 10 kA and the front and back time of the 8/20 µS wave is 844 kV.

4. Overvoltage Analysis Due to Lightning Strikes on Tower and Conductors

At this stage, the amount of Overvoltages caused by lightning strikes is assumed to hit lightning with the head of tower number two of the studied power system and for different ranges of lightning current according to Table 4 and front and back wave time 1.2/50S according to standard 60071IEC (wave specifications Standard) We have reviewed.

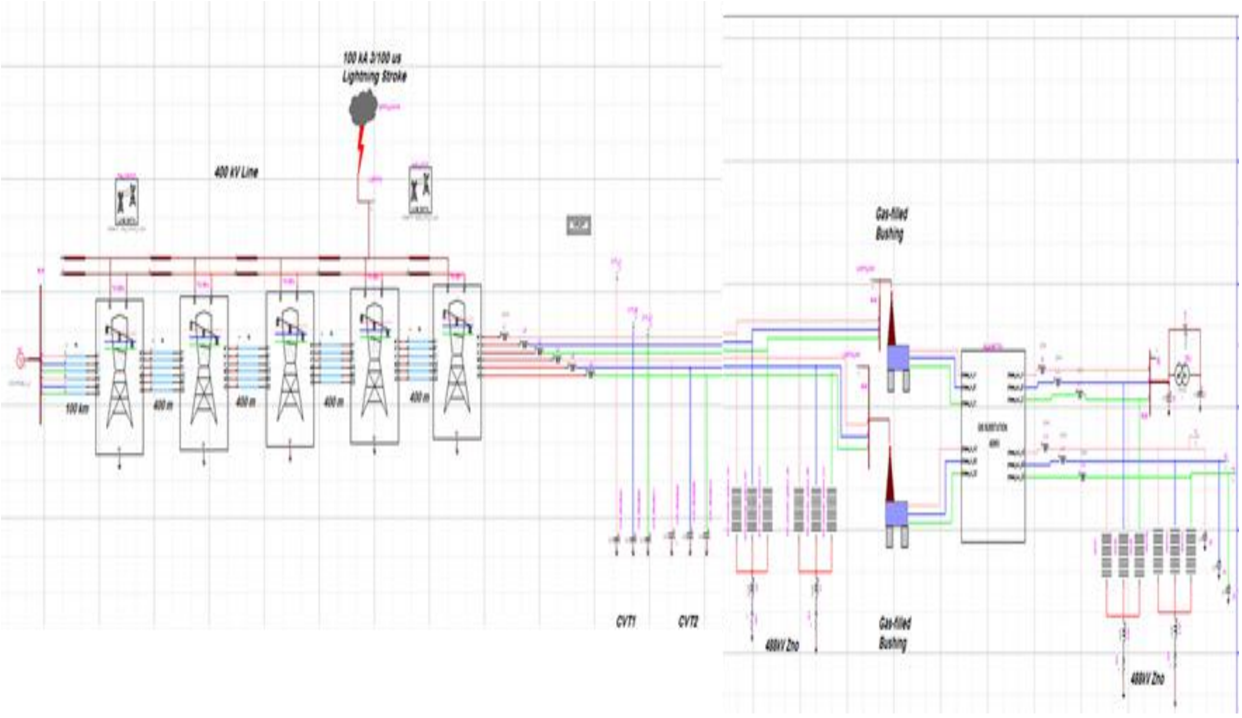

Figure 11. The general outline of the 400 kV system simulated in the EMTP-RV software environment

Table 4. Probability of lightning occurring according to the amplitude of the current

Current amplitude (KA)	200	800	60	28	8	3
Probability of occurrence(%)	1	10	40	50	90	99

Table 5. The amount of overvoltage caused by lightning with phase conductors

The range of lightning current (KA)	Maximum overvoltage (KV)							Wave duration (µS)	Footing current of tower 2 (kA)
	CVT first circuit	CVT second circuit	The total of the two ends of a phase insulator						
			Tower 5	Tower 4	Tower 3	Tower 2	Tower 1		
3	368	145	450	459	466	954	485	1.2/50	0.89
8	435	359	1116	1316	1323	2511	1315	1.2/50	2.2
28	512	713	1194	1256	1358	8090	1667	1.2/50	11.4
60	590	1558	1833	2020	2400	19200	3490	1.2/50	22.1
80	680	1850	2220	2500	6020	25400	3490	1.2/50	28.1
200	1000	3260	4685	5626	7000	26700	11800	1.2/50	77.3

Table 6. The amount of overvoltage caused by lightning with phase conductor on the surge arrester

The range of lightning current (KA)	Maximum overvoltage of surge arrester (KV)			
	Transformer first circuit breaker	Transformer second circuit breaker	Arrester substation on the first circuit	Arrester substation on the second circuit
3	57	67	367	145
8	124	132	360	638
28	161	233	713	512
60	-309	417	1558	590
80	-270	510	1858	679
200	446	716	3260	1000

Table 7. The amount of overvoltage caused by lightning with the phase conductor on the power transformer

The range of lightning current (KA)	The highest amount of power transformer overvoltage (KV)	
	The first circuit transformer	The second circuit transformer
3	57	67
8	132	124
28	233	161
60	417	-309
80	510	-270
200	716	446

5. Conclusion

In this paper, after reviewing the modeling modes of each of the equipment used in the power system studied and selecting the most accurate equipment modeling, we simulated the power system in the EMTP-RV software environment because we tried to In order to achieve accurate results, the best equipment modeling should be used. This issue increased the calculation time by the software. The system was surveyed for two modes of a lightning strike on the tower and lightning strike with the phase conductor, and according to the results, it was determined that the lightning strike on the system phase conductor is the worst possible case of a lightning collision with the power system because this type of collision causes additional voltage surges. Insulation became the insulators of the towers and increased the probability of insulation failure and phase fault to ground. Also, in the study of lightning strike with the tower head, it was found that in this type of collision for the higher amplitude of lightning wave than lightning strike with phase, insulating failure of insulators causes, but, in this type of collision, the flow of tower foots can be increased. It found a consideration and increased the likelihood of soil ionization at the foot of the tower and the occurrence of a return sparks phenomenon. However, in the event of a lightning strike with a phase conductor, there is a possibility of ionization of the soil at the foot of the tower and the occurrence of a return sparks phenomenon only for a very high amplitude of the lightning current (200 KA), which is very unlikely. It has been shown that the designed grounding system, which considers soil ionization, provides more accurate results than when we model the grounding system of the tower with only one resistance. The results showed that the use of the advanced IEEE surge arrester model in both the input and input of the power transformer prevents the creation of excessive insulating voltages of the power transformer.

Conflict of Interest Statement

The authors declare no conflict of interest.

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