ATP Analysis of Tower Footing Resistance Effect in 220kV High voltage Transformers Insulation Level for Protection Against the Direct Lightning Strokes

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ABSTRACT

Exposed electrical power network to directly lighting strokes hits on top of tower of transmission line or shield wires seldom hits with a transmission line causes many outages for electrical network components due to back flash over may ultimately lead to the its destruction. For this reason, it is very important to study the effect of these lighting strokes as well as protection methods study to modification the network performance under this circumstances. This paper describes the effect of the tower footing resistance in 220kV substation insulation level for protection against the direct lightning strikes by using An Alternative Transient Program / Electromagnetic (ATP / EMTP). The testing circuit consists of three towers and a 220kV substation with its components, This circuit where exposed to lightning current strikes ranging between (150 to 200kA) on shield wire directly for first tower near the substation after modification the tower footing resistance from 10Ω to 70Ω. The results showed that if the increased tower footing resistance at 50Ω for 150KA lightning current is going to happen breakdown of the substation. Whereas find that if the increased tower footing resistance at 15Ω for 200KA lightning current is going to happen breakdown of the substation. To improving the protection performance of substation reduce the tower footing resistance near the transformers less than 10Ω .

Keywords: lighting currents, overvoltage, flash over, tower footing resistance, ATP/EMTP, BIL insulation level.

1. Introduction

The main causes of the transients in power system can be classified into natural and technical causes. The natural cause is related with the lightning strokes Whereas technical cause is related with the switching transients, Lightning has been one of the main cause of power outage and has important damage to the power system components. The overhead lines, due to their height, are the electric networks elements the most exposed to the lightning strokes. Too, due to their length, quite big lightning’s collection area results. Even if the insulation of the overhead lines is a self-healing one, the lightning strokes can initiate short circuits and lines’ outages involving unfavorable effects over the power grids` operational reliability [1,2]. The modeling transient behavior of a tower is very important at time of lightning and for a transmission line which has been designed well, direct collision of lightning with conductors of phases seldom occurs. Lightning causes many outages due to back flash over, When lightning collides with shield wire or tower, the injected current on tower to soil and causes an increase of voltage and this issue cause's back flash over [3]. This highest current increases its voltage considering tower impedance With increase of tower voltage, ignition may be created between the arms of the tower and earth and between two arms of the tower [4,5]. The stress of the lines' insulators is analyzed on factors like: towers' surge impedance, pulse surge impedance of the grounding network, the electrostatic and electromagnetic induced voltages, the modification of the coupling factors in presence of the corona discharge, the polarity of the pulse and line's span [6].

There are certain studies showed on this theme of which: in [7]. Study the lightning strikes on a number of transmission lines in the electrical network (200kv, 400kv), It was the yearly haunts these lines rate calculation resulting from lightning strikes and using the program ATP/EMTP, It was too haunts rate is calculated by mathematical calculations and comparing the results of the program, In [8] it was given Around effect of lightning strokes on the electrical network, After reaching the results showed a clear picture of the importance of lightning arresters using the program (ATP) for simulation of lightning strike hits the overhead transmission line with no arrester again with use. In [9] it was specified About study the effect of separation distance of lightning arresters to protect the 400kV substation against the direct lightning strikes lightning strokes on the electrical network, The results showed that if the increased separation distance at 15m for porcelain arrester is going to happen breakdown of the substation, Whereas find that if the increased distance from 5 to 30 m for silicone polymer be a good transformer protection, As well as showed Comparative Study between Porcelain and Silicone Polymer Lightning Arresters under Direct Lightning Strokes for A 400KV Substation Protection that silicone polymer arrester is better and more acceptable than the porcelain at tower footing resistance is 10 ohms by lighting current ranging between(260 to 300 kA) on ground wire for the same studied network [10] .

In the present paper, the characteristics of the tower footing resistance for A 220KV Substation protection against the directly lightning strikes have been presented based on lightning currents simulation by using program (ATP) with negative polarity. The paper is organized as follows: in section 2, the Insulation Coordination and Protection against Lightning Surges are presented. system model including the studied tower and Zinc Oxide arrester are evaluated in section 3. Result of system model included in the paper is mentioned in section 4 and finally the most important results are elaborated in section 5.

2. Insulation Coordination and Protection against Lightning Surges.

Insulation coordination is the connection of insulation of electrical equipment with the characteristics of protective devices such that the insulation is protected from excessive over voltages. In a substation, for example, the insulation of transformers, circuit breakers, bus supports, etc., should have insulation strength in excess of the voltage provided by protective devices [11-13].

2.1 Basic Insulation Level (BIL):

BIL is defined as the peak value of the standard impulse voltage wave. Standard BILs adopted by the Institute of Electrical and Electronics Engineers (IEEE) are shown in Table 1. Equipment conforming to these BILs must be capable of withstanding repeated applications of the standard waveform of positive or negative polarity without insulation failure [13-15].

Table 1: *Standards Basic insulation level*

Nominal System Voltage $kVrms$	Standard BIL kV	Reduced BIL*
161	750	650
196	900	750
230	1050	825 – 900
28 7	1300	1000 – 1100
345	1550	1175 – 1300
500		1300 – 1800
765		1657 – 2300

Overvoltages due to lightning strokes can be avoided or minimized in training by using shield wires above the phase wires, using ground rods and counter-poise wires, and including protective devices like expulsion gaps, protector tubes on the lines, and Metal-Oxide Surge Arrester with resistors made of zinc-oxide (ZnO) blocks at the line terminations and substations [16-19].

2.2 Protection Using Ground Rods and Counter-Poise Wires (Tower Footing Resistance)

The effective tower footing resistance, is reducing by providing driven ground rods and counter-poise wires connected to tower legs at the tower footing. Ground rods are a number of rods about 15 mm diameter and 2.5 to 3 m long driven into the ground. In hard soils the rods may be much longer. They are usually made of galvanized iron or copper bearing steel. The spacing of the rods, the number of rods, and the depth to which they are driven depend on the chosen tower footing resistance. With 10 rods of 4 m long and spaced 5 m apart, connected to the legs of the tower, the effective resistance may be reduced to 10 Ω. The above effect is alternatively achieved by using counter-poise wires. Counterpoise wires are wires concealed in the ground at a depth of 0.5 to 1.0 m, running parallel to the transmission line conductors and connected to the tower legs. These wires may be 50 to 100 m long [11,15].

3. System Model

This part introduces single line diagrams of the 220kv network composed of three towers and the substation. The 220kv double circuit transmission line has double bundle conductors. Tower footing resistance of this system ranging between (10 to 70) ohms, , and the separation distance of the arrester at transformer is 5 m, and the range of lighting current ranging between(150 to 200 kA) on shield wire directly for first tower near the substation with negative peak and the following figure 1. shows model for a 220 kV network using a program ATP.

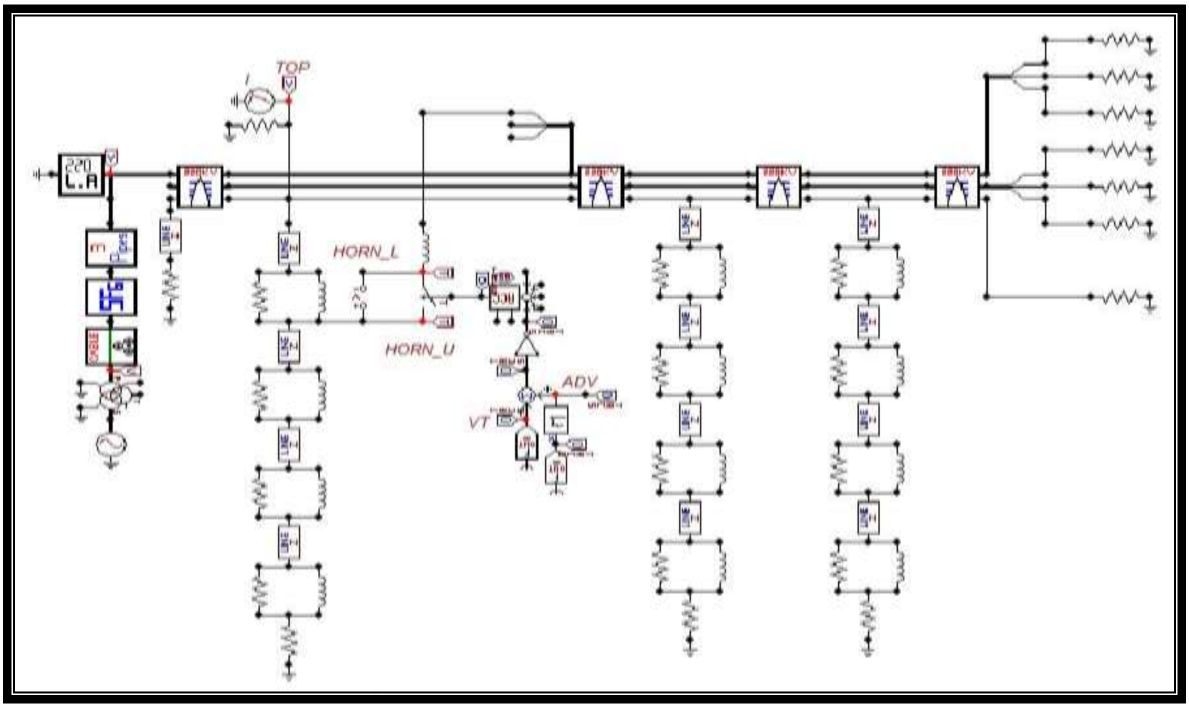

Figure 1. Shows the structure of 220kv studied system [10,24]

3.1 Transmission Tower model

The steel towers are usually represented as a single conductor distributed by line parameter terminated by the tower footing resistance (R_i), Each tower is divided in four parts. First part is from tower top to upper arm, second part from upper arm to middle arm, third part from middle arm to lower arm and the last part from lower arm to ground, Tower surge impedances are calculated using equation (1) and the tower footing resistance (R_i) is at high impulse current may be estimated by “(2)” [20-22].

$$Z = 60 \, . \{ \ln(\frac{H}{R}) \text{ -1 } \} \qquad (R<<H) \qquad (1)$$

$$R_i = \frac{R_0}{\sqrt{1+\frac{I_R}{I_g}}} \qquad (2)$$

where R_o is footing resistance measured with low current, I_R is the lightning current through the footing resistance, I_g is the current required to produce a soil gradient, E_0, at which soil break down occurs. This current is given by “(3)”

$$I_g = \frac{1}{2\pi} \frac{\rho E_0}{{R_0}^2} \qquad (3)$$

where ρ is the soil resistivity (Ω-m) and E_0 is the soil breakdown gradient, assumed as 400 kV /m. The flashover voltage of insulator string is calculated using “(4)” [23].

$$V_{fo} = \left(400 + \frac{710}{t^{0.75}} \right) L \qquad (4)$$

where V_{fo} is flashover voltage (kV), t is flashover time (µs) and L is insulator string length (m).

The figure 2. Shows the structure of the studied tower, Physical specifications of conductors and geometrical parameters of the tower are given in tables 2 – 4 [13,14,24].

Table :2 *Physical specifications of conductors*

Line voltage	**Conductor**	**GMR(ground wire)**	**GMR(conductor)**
220kV	AAAC	1.89mm	13.715mm

Table :3 *Geometrical parameters of the tower*

Parameter	**H total m**	**H1 m**	**H2 m**	**H3 m**	**H4 m**	**B m**
Value	46.85	11.72	6	6	23.13	6.4

Table :4 *Equivalent parameters of the tower*

Resistance	**value**	**Inductive**	**Value**	**Impedance**	**value**
R_1 Ω	24.26	**L_1 mH**	0.00722	**LINE Z_1 Ω**	220
R_2 Ω	12.42	**L_2 mH**	0.00388	**LINE Z_2 Ω**	220
R_3 Ω	12.42	**L_3 mH**	0.00388	**LINE Z_3 Ω**	220
R_4 Ω	34.48	**L_4 mH**	0.01046	**LINE Z_4 Ω**	150

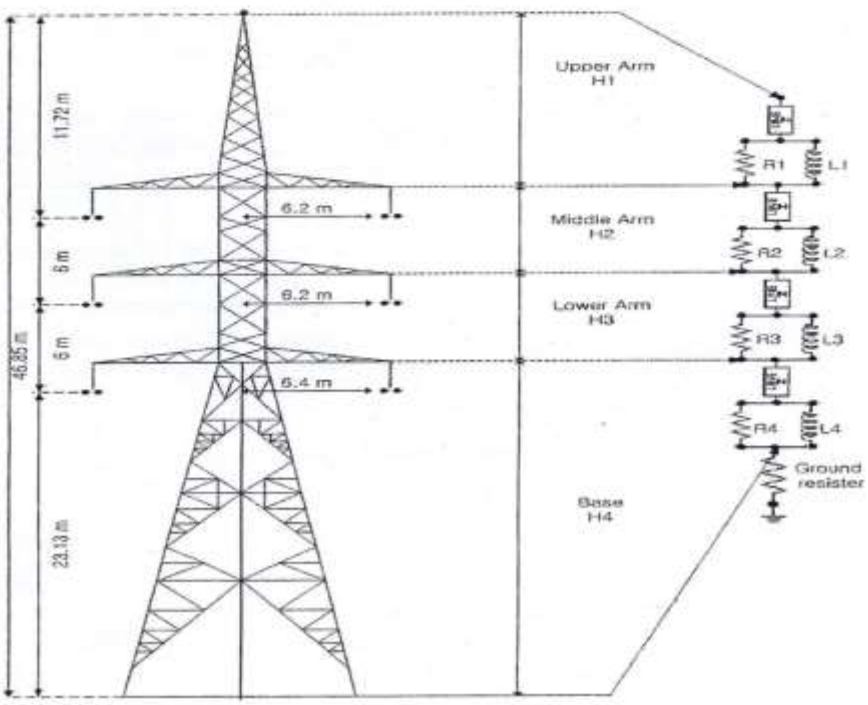

Figure 2. 220kV Tower configuration

3.2 Zinc Oxide Arrester Model

Based on the IEEE references and standards, the Zinc Oxide (MO) arrester model is taken, which is determined through nonlinear resistance $A_{0,}$ and A_1 , as well as other values, respectively L_0, L_1 induction and R_0, R_1 resistance, the model is shown in Figure 3, Equivalent parameters of the MO arrester are given in tables 5,6 [8,18].

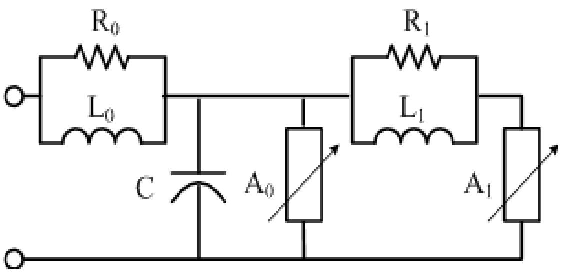

Figure 3. Model of MO arrester according to IEEE standards.

Table 5. V-I characteristics of nonlinear A_0 and A_1.

I [kA]	V [p.u]	
	A_0	***A_1***
0.1	0.963	0.769
1	1.05	0.85
2	1.088	0.894
4	1.125	0.925
8	1.169	0.956
12	1.206	0.975
16	1.25	0.994
20	1.313	1.006

able :6 *Equivalent parameters of the MO arrester*

Parameter	R_0 (Ω)	R_1 (Ω)	L_0 (μH)	L_1 (μH)	C (pF)
Value	100d / n	165d / n	0.2d / n	15d / n	100 n / d

d: is the estimated height of the arrester in meter, *n:* is the number of parallel columns of MO in the arrester.

4. ATP Analysis of 220kV Circuit Diagram

Two cases was done to test the system under study ,In First case will study the resulting voltage from a blow by lightning current has a rang 150 kilo amperes on ground wire and the transmission line directly with changing the tower footing resistance from 25Ω to 70Ω, The second case will study the resulting voltage from the lightning current strikes ranging between(150 to 200kA) with modifying the tower footing resistance by (10Ω), In each case it will be calculated extent the basic insulation level (BIL) of the transformer and then shows the impact of the lightning on the transformer insulator.

4.1 First Case

In this case, results of study are based on ATP / EMTP software. lightning current has a range of 150 kilo amperes, with a changing of the tower footing resistance from 25Ω to 70Ω, increase the resistance 5Ω in each step, Figures 4,5 Show the values of the internal voltages of the transformer on the primary side 220KV when resistance 25Ω and 35Ω by current (150 kA) Respectively. Thus, it increase the tower footing resistance width by 5Ω and test the system. In each step, it calculate the basic insulation level of the transformer BIL using the following formula:

$$\%BIL = \frac{BIL - max\,overvoltage}{max\,overvoltage} \times 100 \quad (5)$$

Where: (BIL) equal 1050 kV [13-15].

(max overvoltage) Is the maximum voltage on the primary side 220kV for transformer.

To be a good insulation level for transformer in front of the lightning wave must be this ratio does not less than 20%, If this ratio was less than 20% will result in destructive damage for entire transformer [13-15].

-When be the tower footing resistance is 25Ω be BIL: Then:

$$BIL = \frac{1050 - 695.44}{695.44} \times 100 = 50.98\%$$

the rest of results have been listed in the table 7.

The table 7. and the figure 6. show the change extent of insulation level (BIL) for the transformer by 150kA lightning current on the primary side 220Kv of the transformer when be the tower footing resistance ranging from 25Ω to 70Ω.

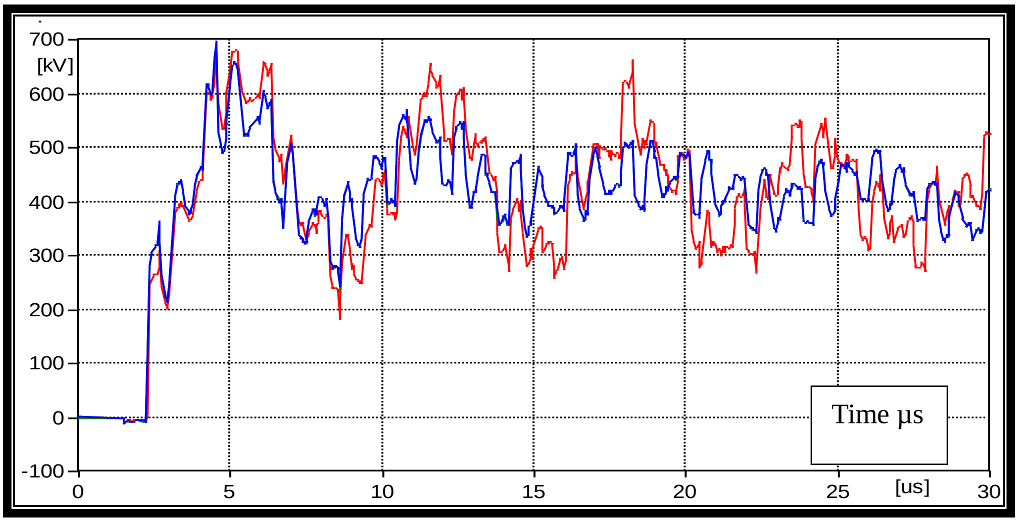

Figure 4. The inside voltage of the transformer at R_{foot} 25Ω by current 150KA

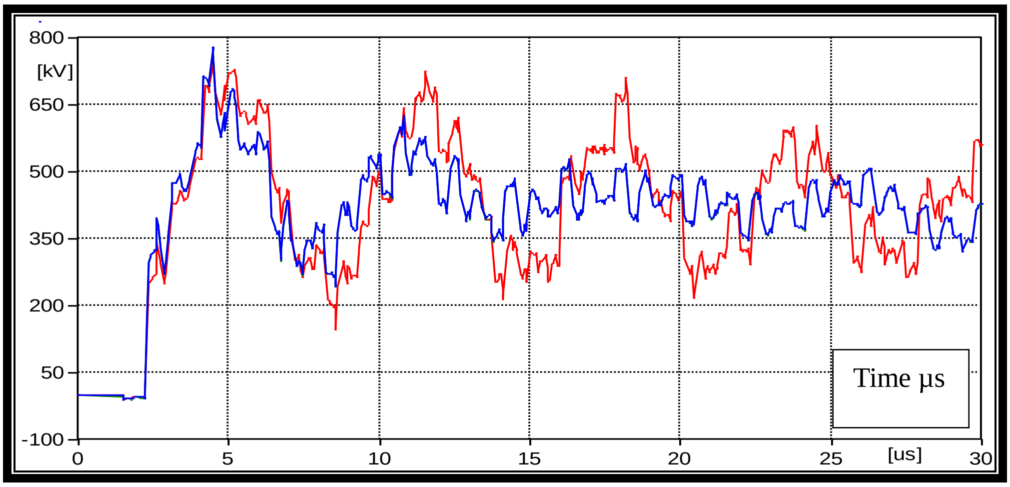

Figure 5. The inside voltage of the transformer at R_{foot} 35Ω by current 150KA

Table 7: *Effect of the tower footing resistance on inside voltage of transformer when be 150KA lightning current.*

R footing Ω	25	30	35	40	45	50	55	60	65	70
voltage kV	695.44	742.47	779.74	811.55	840.10	862.52	882.44	897.1	908.7	919.2
BIL %	50.98	41.42	34.66	29.38	24.98	21.73	18.98	17.04	15.54	14.22

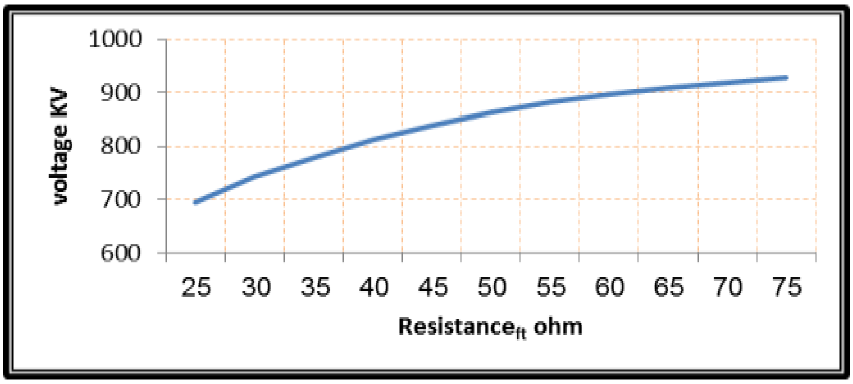

Figure 6. Effect of the tower footing resistance on inside voltage of transformer when be 150KA lightning current.

4.2 Second Case

Lightning current it is not constant value, It was necessary to study the effect of lightning on the transformer by different values ranging from 150 to 200KA, For this Will study the resulting voltage from the lightning current strikes on ground wire directly with modifying the tower footing resistance by (10Ω). The following values have been developed and an increase 10KA in each case, Figure 7. Shows the values of the internal voltages of the transformer

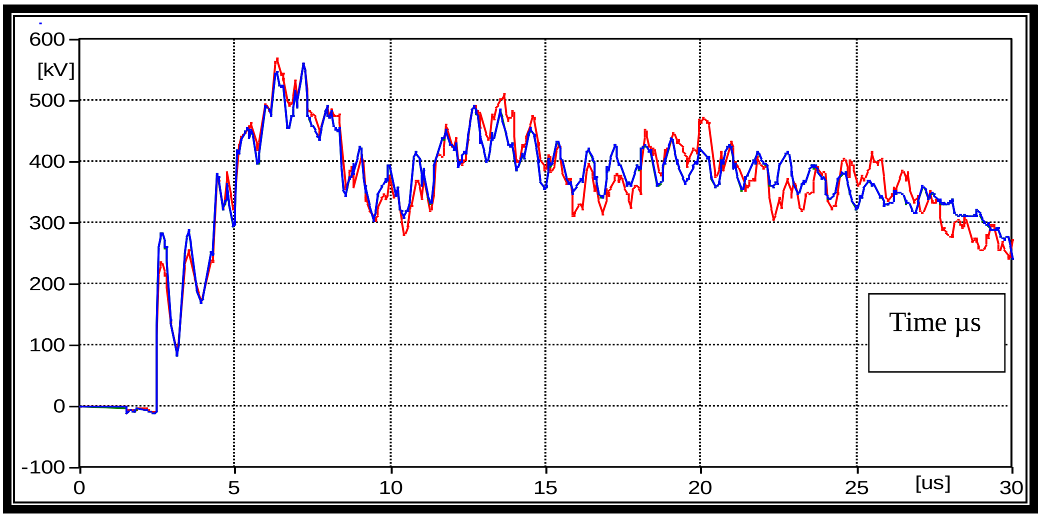

Figure7. The inside voltage of the transformer at R_{foot} 10Ω by current150KA

Thus, it increase the lightning current on ground wire width by 10kA and test the system. In each step, it calculate the basic insulation level of the transformer BIL using the last law.

The table 8. and the figure 8. shows the variation range of insulation level (BIL) for the transformer when lightning currents ranges from 150-200kA when tower footing resistance 10Ω.

Table 8: *Effect of the lightning current strikes on inside voltage for transformer at R(10Ω)*

Current kA	150	160	170	180	190	200
voltage kV	568.14	621.53	632.10	640.67	654.85	684.24
BIL %	84.81	69.00	66.11	63.89	60.34	53.43

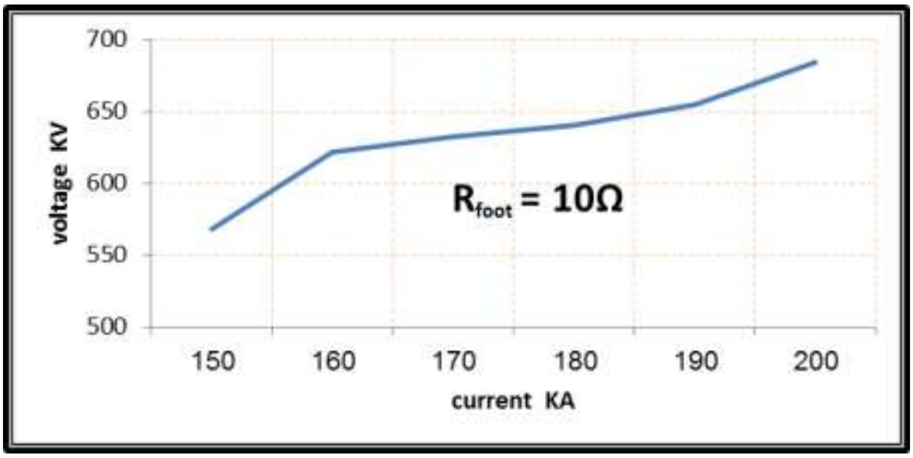

Figure 8. Effect of the lightning currents on inside voltage for transformer at R_{foot}(10Ω)

5. Conclusions

The purpose of this paper was to study the range of the effect of tower footing resistance in 220kV substation for protection against lightning strokes and by applying waves with negative polarity on the ground wire and transmission line directly using the ATP program. The results showed that When using tower footing resistance ranging from (25Ω to 50Ω) and by using the lightning current (150 KA) it is good protection for system, But when be tower footing resistance (55Ω) and above the same the value of lightning current (150KA) will break down the transformer insulation level. When using lightning currents ranging from (150 to 200KA) and at tower footing resistance (10Ω) be a good transformer protection, But when using the tower footing resistance (25Ω) by lightning current (200KA) the protection be near to breakdown. Better value for the tower footing resistance helps protect the network from lightning strikes are 15Ω and less. Calculating the basic insulation level (BIL) of the transformers illustrations the range of the effect of voltages rises duo to increasing the tower footing resistance at transformer, For this occurs substation destruction if the value of BIL is less than 20%.

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