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Back flashover Analysis for Egyptian 500kV and 220kV Transmission towers

M. A. Abd-Allah , T. Elyan and Eman Belal

Electrical Engineering Department
Faculty of Engineering at Shoubra
Benha University

Abstract- Lightning is still the main cause of transmission and distribution lines outages and represents an important problem for insulation design of power systems through the back-flashover phenomenon. This paper discusses the back flashover phenomenon on the Egyptian 500kV single circuit tower and 220 kV double circuit tower lines. The induced voltages across the insulator strings of the two lines are calculated. The effects of the lightning stroke magnitude and shape, the striking distances and the tower footing resistance on the induced voltage across the insulator strings are discussed.

Index Terms- Lightning stroke, Back Flashover, Induced Voltage, tower footing resistance, ATP Simulation

I. Introduction

Lightning is one of the major causes of sudden line outages [1]. Lightning generates traveling waves on overhead lines, which travel to different devices connected to both sides of line and represent a dangerous for line insulators and equipment insulation connected to that line [2]. Lightning return-stroke current and the charge delivered by the stroke are the most important parameters to assess the severity of lighting strokes on power lines and apparatus [3]. The lightning damages a power apparatus in two ways: the first, it raises the voltage across the apparatus such that the terminals across the struck apparatus spark over causing a short circuit of the system or the voltage punctures through the apparatus electrical insulation, causing permanent damage. The second is the energy of the lightning stroke may exceed the energy handling capability of the apparatus, causing meltdown or fracture [4]. Back Flashover (BFO) is one of the several phenomenon which decreases transmission lines reliability. It occurs as a result of direct lightning stroke to the tower structure or guard wires and injects wave currents with high amplitude and very high steepness to the phase conductors. Injection of these wave currents produce voltages with high amplitude and very high steepness, which in turn cause phase to ground faults in transmission lines[5, 6]. Even if lightning strikes a shield wire, the generated traveling voltage wave will travel to the nearest tower, produce multiple reflections along the tower, causing back flash across an insulator [7]. Back flashover will occur when these voltages exceed the line critical flashover (CFO).

II. TRANSMISSION SYSTEM MODELING

Egyptian High-Dam 500kV Single-Circuit tower with two overhead ground wires and Egyptian 220kV tower double circuit transmission lines with one overhead ground wire are modeled to discuss the back flashover phenomena. The High-Dam500 kV transmission line tower has a flat configuration, as shown in Figure (1). The line has three sub-conductors per phase and two ground wires. The span length is equal to 400 m. The distance between the adjacent phases is equal to 12 m. Modeling of transmission line tower is an essential part for travelling-wave analysis of lightning surges in overhead transmission lines. The equivalent circuit of the tower is simulated by ATP program. The model consists of main legs and cross-arms, as shown in Figure (3). The Egyptian 220kV tower double circuit line modeled with one overhead ground wire transmission towers. The J. Marti overhead line model was used for modeling in ATP-EMTP software. Height of the transmission-line tower was 41m and the span length is equal to 400 m. The tower is of vertical configuration as shown in Figure (2).

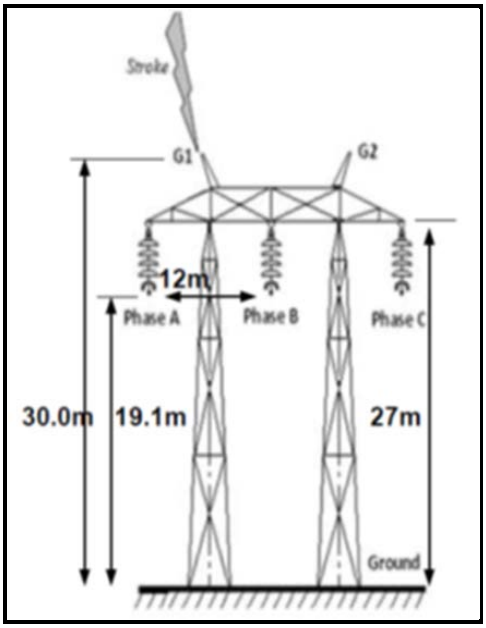

Figure (1) Egyptian high dam 500kV tower

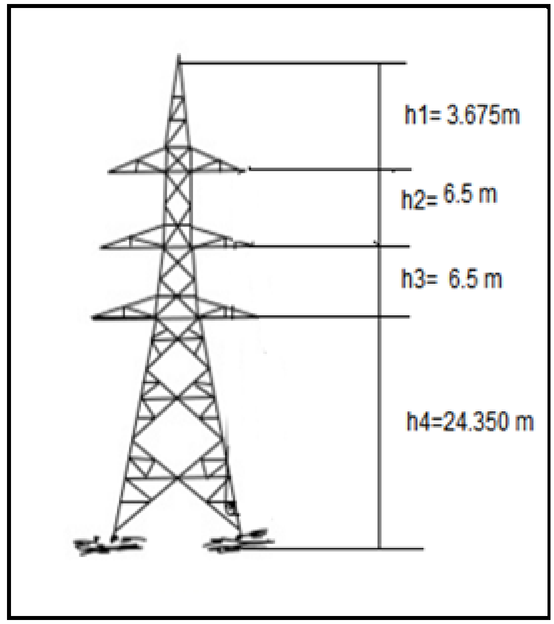

Figure (2) Egyptian 220kV tower

1. Transmission tower model

For single circuit Egyptian High-Dam 500kV tower, the model consists of main legs and cross-arms. The surge impedance of each part is expressed by the functions of their dimensions and geometry. The surge impedance in ohm, propagation velocity in meter per second and length in meter of each tower's part are indicated in Figure (3), for double circuit Egyptian 220kV tower. In recent years, there are various models of transmission tower proposed by the researchers. One of the more well-known models is the multistory model. It is composed of four sections that represent the tower sections between cross-arms. Each section consists of Constant-Parameter Distributed Line (CPDL) model in series with a parallel RL circuit, included for attenuation of the traveling waves.The propagation velocity of a traveling wave along a tower is taken to be equal to the light velocity. The tower is represented by four lossless Constant Parameter Distributed Line (CPDL) models as illustrated in Figure (4), where Zt1is the impedance of tower top to the upper phase conductor, which is equal to the impedance of upper phase to middle phase conductors and to the impedance of middle phase to lower phase conductor. Zt4 is the impedance of lower phase to tower bottom.

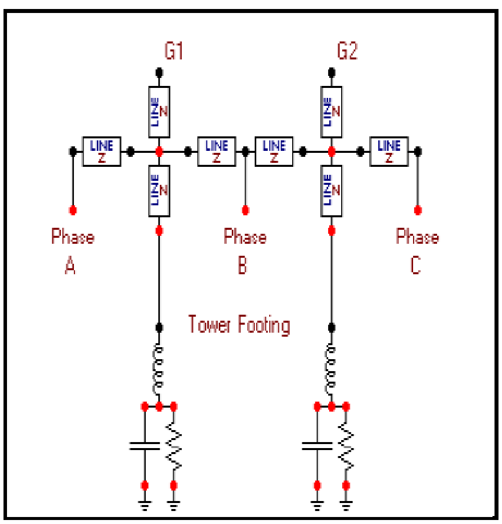

Figure (3) ATP Model of Egyptian High-Dam 500kV tower

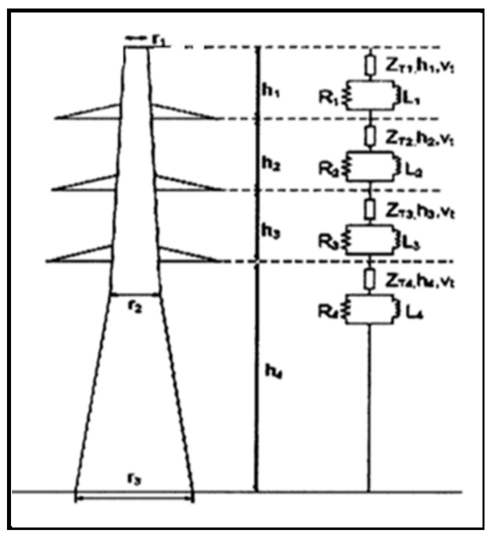

Figure (4) Egyptian 220kV double circuit multistory tower

2. *Lightning source model*

In ATP- EMTP software, lightning-strike model is represented by a current source with parallel resistance. The parallel resistance is actually lightning-path impedance. Lightning-path impedance is selected as 400 Ω. The model used in this study is the Heidler current model, where four characteristics of lightning current quantities at striking point must be considered: lightning-current peak, maximum of current-steepness, rise time, and decay time .Figure 5 shows the Heidler model in ATP-EMTP.

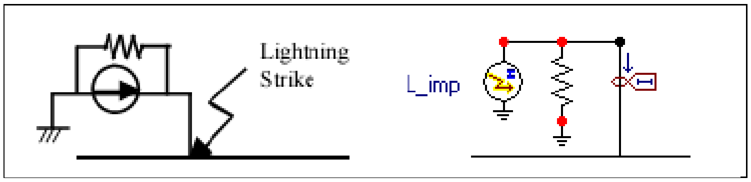

Figure (5) Lightning Stroke Heidler Model

3. *Tower surge impedance*

The surge impedance of the tower was determined from surge-impedance formula recommended by IEEE and CIGRE [8].

$$Zt = 60 * \ln[\cot\{0.5 * \tan^{-1}(\frac{R}{h})\}] \quad (1)$$

Where R is the equivalent radius of the tower represented by a truncated cone, h=is the tower height

$$R = [r1*(h1+h2+h3) + r2*h + r3*h4]/h \quad (2)$$

$$h = h1+h2+h3+h4 \quad (3)$$

The tower traveling time is: $\tau = 2h/v$ (4)

Where, V = speed of light (3 x 10^8 m/s) and the value of a parallel RL circuit can be calculated as [9]:

R1= r1xh1, (5), R2 = r1xh2, (6), R3 = r1xh3, (7), R4= r2xh4 (8)

L1= R1x τ (9), L2 = R2xτ (10), L3 = R3xτ (11), L4= R4xτ (12)

4. *Tower footing resistance*

An accurate footing-impedance model is important for decreased resistance value when discharge current value increases. Resistance value is agreed to be greater when lightning currents are small. Its variation to low current and low frequency values is only significant for large soil resistivity. A footing-impedance model incorporating soil ionization effect can be approximated a

$$RT = \frac{Ro}{(\sqrt{1+(\frac{I}{Ig})})} \quad (13)$$

Where, Ro is footing resistance at low current and low frequency, Ig the limiting current to initiate sufficient soil ionization, and I the strike current through resistance. The limiting current is given by:

$$Ig = \frac{Eo*\rho}{2\pi Ro^2} \quad (14)$$

Where ρ is soil resistivity (ohm-m) and Eo is soil ionization gradient (400kV/m).

III. Simulation Results of Egyptian High-Dam 500kV Single-Circuit Tower

The 500 kV High-Dam overhead transmission line tower of a flat configuration has been modeled using ATP program, as shown in Figure (6). The system consists of three towers with span length of 400 m. The lightning stroke hit the ground wire (GR1) of tower 1 with a peak value of 20 kA.

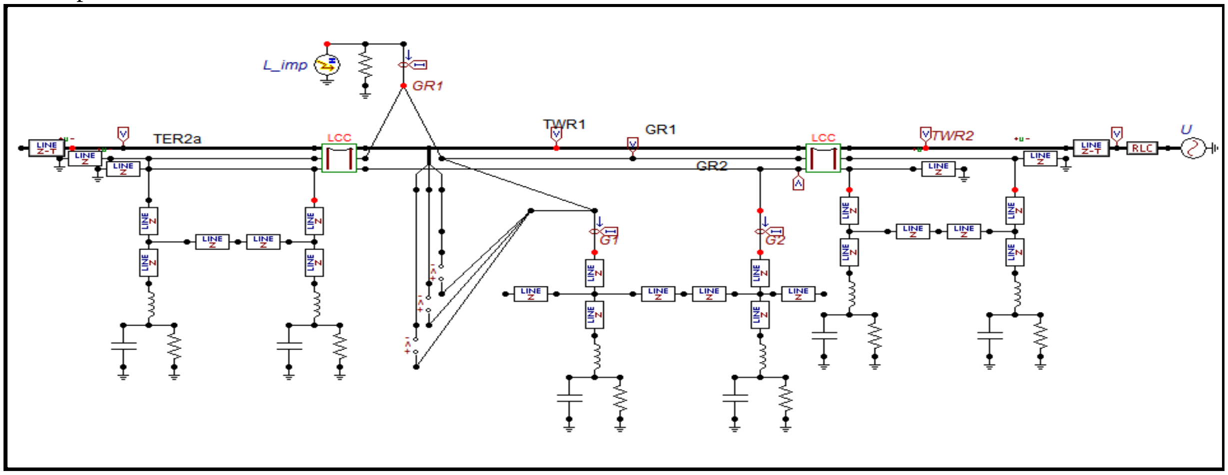

Figure (6) ATP simulation of the system

1-Voltage induced on the struck tower

A 1.2/50µs lightning stroke of 20kA peak current hits one of the two ground wires (G1). The induced voltages across insulator string wave forms of phases A, B and C of the struck tower are shown in Figure (7). It is noticed that, due to asymmetry, the induced voltages across insulators are not the same in the three phases.

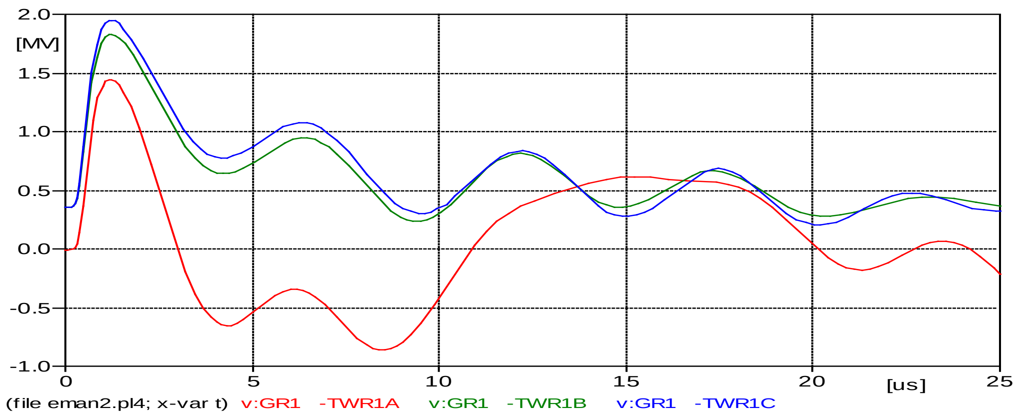

Figure (7) Voltage across insulator strings of phases A, B and C of tower1

2-Effect of Lightning Stroke Parameters on Voltage across insulator strings

The parameters of the Lightning Strokes are the impulse current amplitude (peak value), wave front time and wave tail time. The Voltage across insulator strings with various peaks of 1.2/50µs lightning current stroke are shown in Figure (8). The amplitude of the lightning stroke current used in the analysis are 10, 20, 30 and 40 kA. It is noticed that the magnitude of the back flash over voltage across insulator increases with increasing the peak of the lightning current.

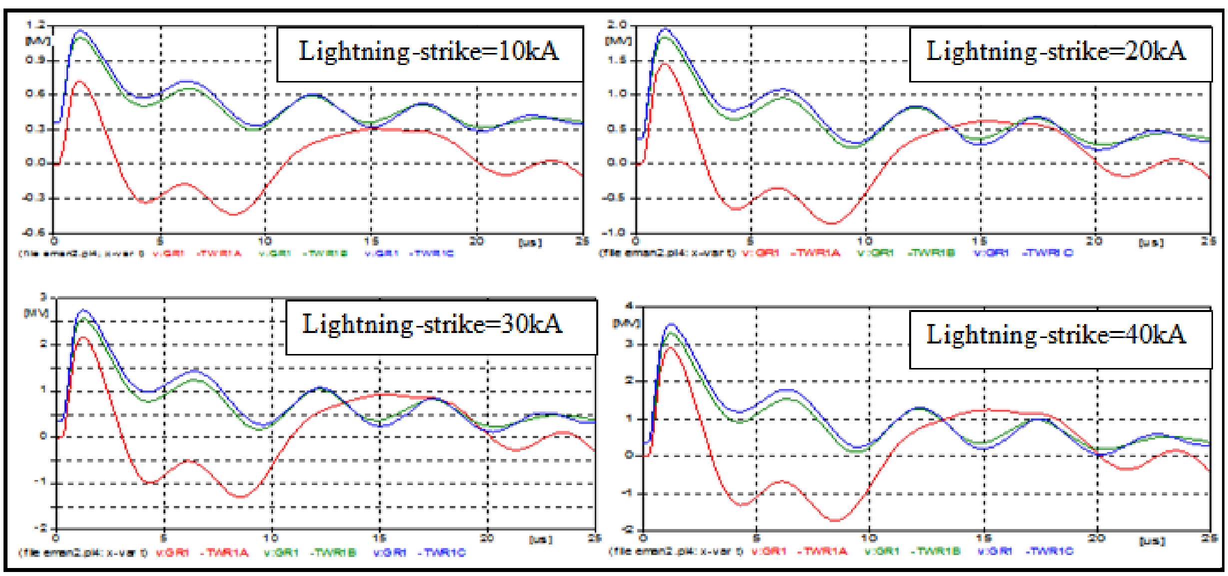

Figure (8) Voltage across insulator strings with various peak value of lightning Current

The effect of lightning wave front time on voltage across insulator strings is shown in Figure (9). The peak value of the lightning stroke current hit the ground wire of tower1 is 40kA with a wave tail time of 40µs. It's noticed that the shorter front time of lightning current, increases the back-flashover voltage across the insulators.

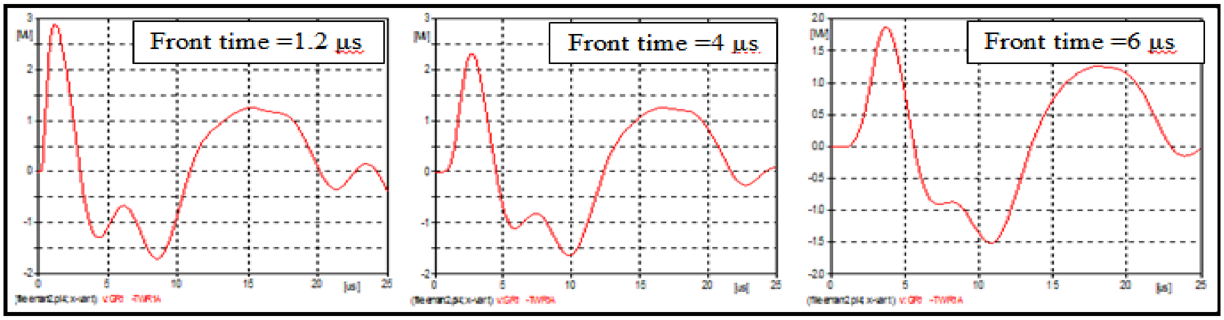

Figure (9) Voltage across insulator strings with various front time of lightning Current

The effect of lightning wave tail time on voltage across insulator strings are shown in Figure (10). The peak value of the lightning stroke current hit the ground wire of tower1 is 40kA with a wave front time of 1.2μs. It's clear that, the longer the tail time of lightning current, the larger the back-flashover voltage.

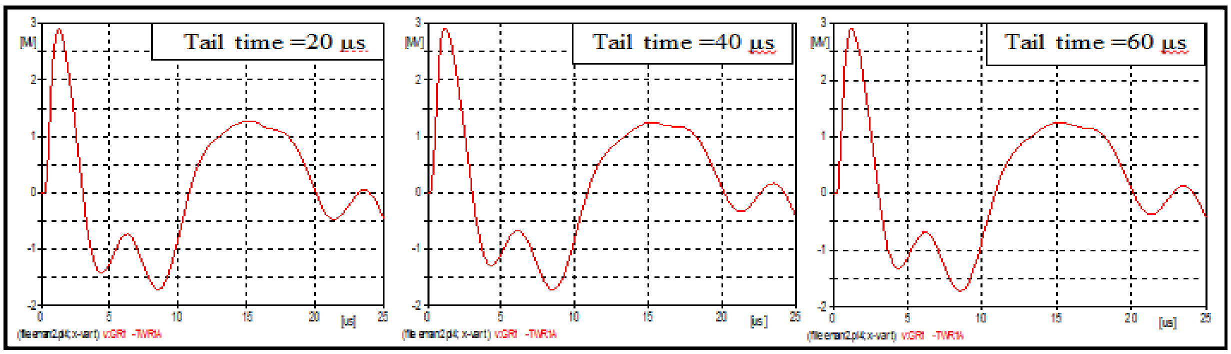

Figure (10) Voltage across insulator strings with various tail time of lightning Current

It observed that as the lightning wave tail time increased, the maximum value of back-flashover voltage is increased. It is clear that, as the tail time increased from 20μs to 60μs, the maximum value of back-flashover voltage is increased by about 6%.

IV. SIMULATION RESULTS OF EGYPTIAN 220KV DOUBLE CIRCUIT TRANSMISSION LINE TOWER

The consider system of 220 kV double circuit overhead transmission line consists of five towers each tower has length of 41m with span length of 400 m from each other

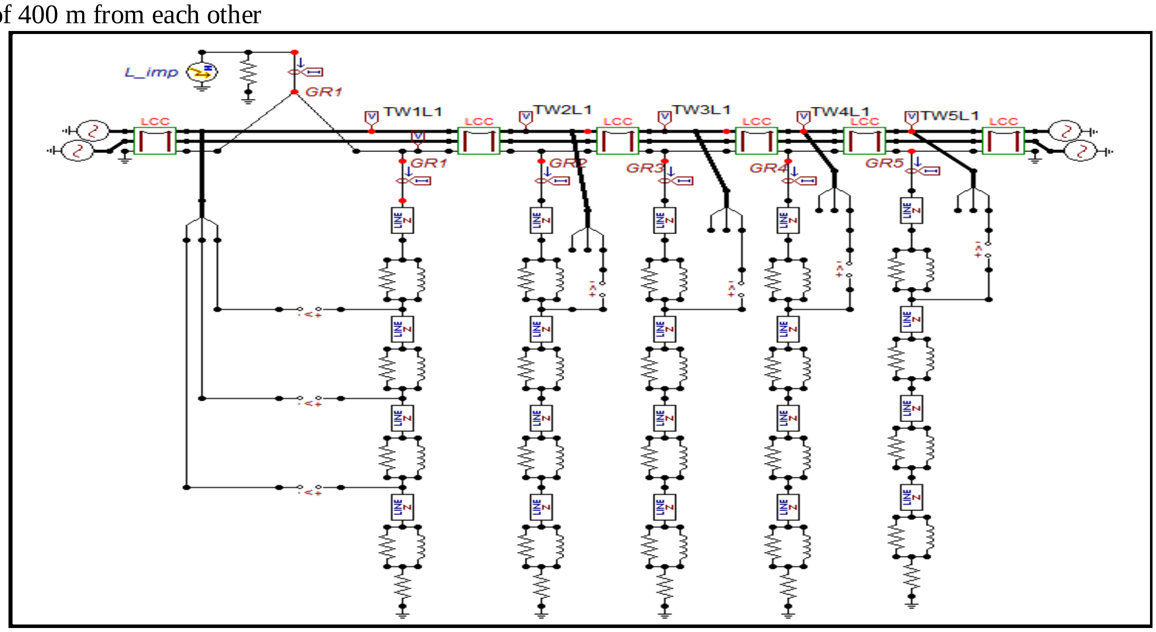

Figure (11) ATP simulation of the system under study

1-Effect of Striking Distance on Voltage across insulator strings

A lightning current stroke with peak value of 40 kA, hits the ground wire at the first tower. Figure (12) shows the voltage across insulator strings wave forms of phase A, which is the nearest phase to stroke point, at the five towers. It is noticed that the voltage across insulator strings magnitude decreases with increasing striking distance. The peak value of back flash over versus the distance from the struck tower is shown in Figure (13). It is noticed that the value of the back flash over voltage decreased as the distance increased. The peak value decreased to about 67% from its value at 400m from the struck tower, to about 52% at 800m, to about 43% at 1200m, and to about 39% at 1600m from the struck tower.

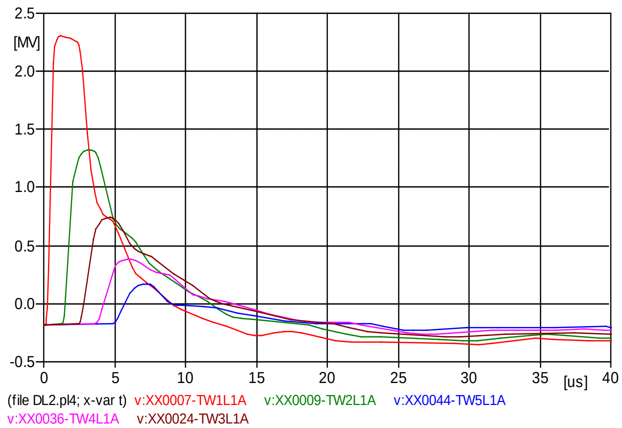

Figure (12) Voltage across insulator strings for various striking distances

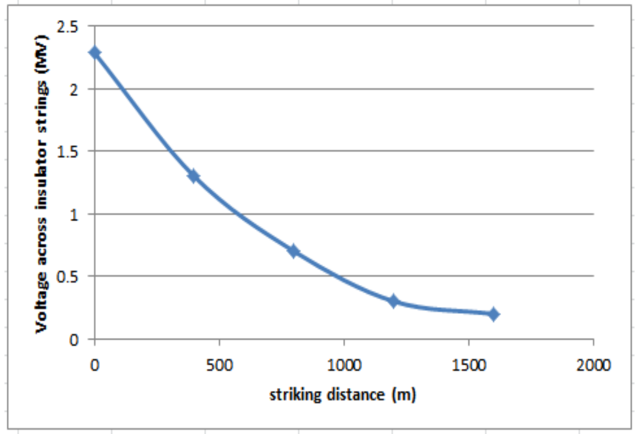

Figure (13) the effect of Striking Distance on voltage across insulator strings

2-The effect of Lightning Stroke on Voltage across insulator strings

The effect of peak value of 1.2/50µs lightning current surge on the Voltage across insulator strings .the peak value of Voltage across insulator strings (Back-Flashover Voltage) versus the peak value of the lightning current is shown in Figure (14). It is noticed that the back-flashover voltage increased as the peak value of the lightning current increased. The back-flashover voltage is increased by about 263% from its value as the peak value of the lightning current increases from 20 to 50kA

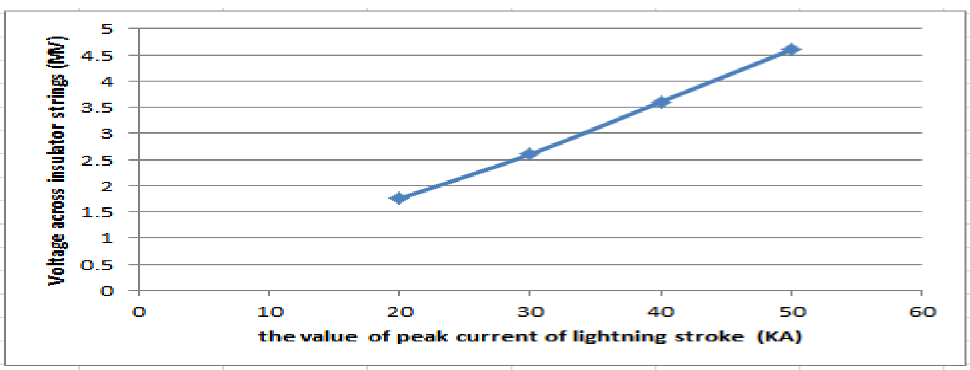

Figure (14) Effect of peak of lightning stroke wave on voltage across insulator string

The effect of the lightning front time of the lightning impulse on the peak value of the induced voltage across insulator string is shown in Figure (15). The peak value of the impulse wave is taken as 40 kA, with a tail time of 50µs. It is noticed that the shorter front wave time, the larger is the back flashover voltage. The maximum value of the back-flashover voltage is decreased by about 13.5%, as the front time increased from 1.2µs to 6µs,

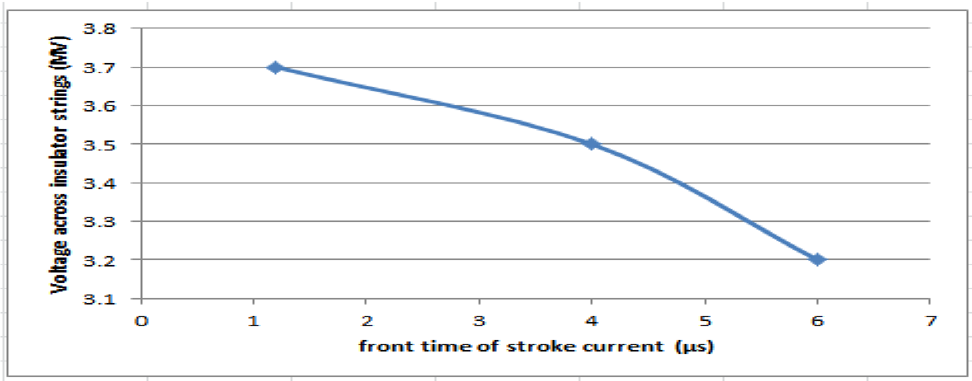

Figure (15) the effect of front time of lightning Stroke wave on voltage across insulator strings

The effect of the tail time of the lightning impulse wave on voltage across insulator strings is shown in Figure (16). The peak value of the impulse wave is taken as 40 kA, with a front time of 1.2µs. It is clear that as the tail time increased from 20µs to 60 µs, the maximum value of the back-flashover voltage is increased by about 6%.

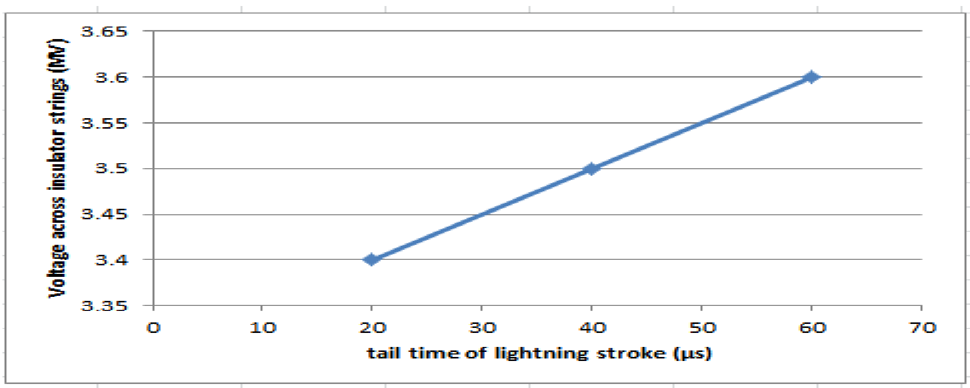

Figure (16) Effect of tail time of lightning Stroke wave on voltage across insulator strings

3- Effect of insulator string on Back-Flashover Voltage

For the simulation, lightning-surge current was injected into the top tower of the first tower. Back-flashover voltage across insulator string was measured at each phase, for single-circuit line, by using probe branch voltage. As has been explained, back flashover occurs when voltage across line insulation is equal to or greater than Critical Flashover Voltage (CFO), which is determined from Basic Insulation Level (BIL) calculated via the equation below [10].

$$BIL = CFO\left(1 - 1.28 * \frac{\sigma f}{CFO}\right) \qquad (15)$$

Where, σf is the coefficient of the variation, for lightning impulse, the sigma is 2% to 3 % [10]. According to ANSI C92 IEEE1313.1 [11], the suggested BIL for 220kV is (900-1050) kV. With this BIL value and σf of 2%, the CFO is approximately 1050kV. The lightning stroke is assumed to hit the ground wire of first tower with value of 15kA, the induced voltage across insulators of phases A, B and C is shown in Figure (17). If the voltage across insulator string equal or larger than the Critical Flashover Voltage (CFO), this mean that back-flashover will be occurred on this phase. It is clear that the voltage at the upper and middle phases exceeds the CFO, i.e. the back-flashover is occurred at the two phase A and B.

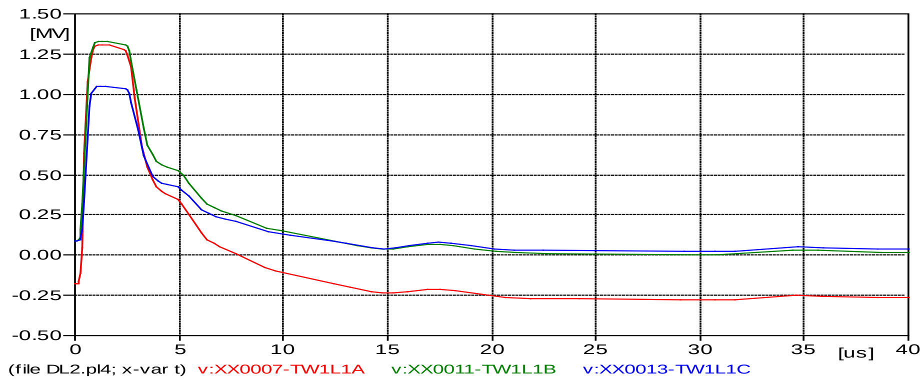

Figure (17) Voltage across insulator strings, for 15kA lightning-strike current

4-Effect of Tower-Footing Resistance on Voltage across insulator strings

The effect of the tower-footing resistance on the induced voltage across string insulator is shown in Figure (18). The figure indicates that the higher the tower footing resistance, the higher the possibility for damage to transmission-line equipment through induced higher back-flashover voltage across insulator strings

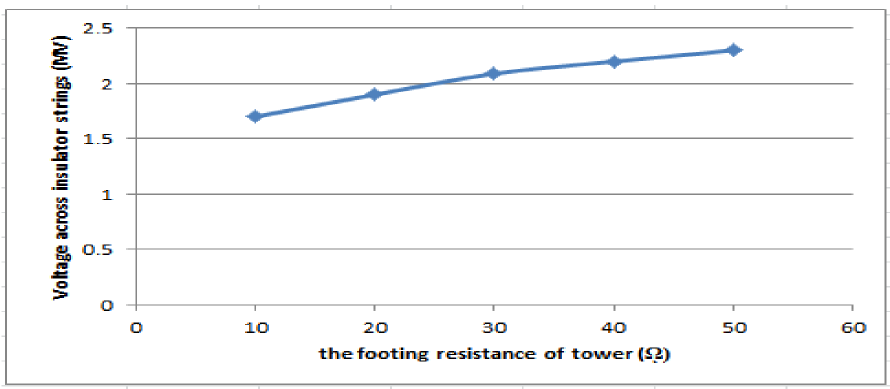

Figure (18) Effect of Tower-Footing Resistance on Voltage across insulator strings

V. CONCLUSION

The main conclusions derived from this study can be summarized in the following main points:

For 500 kV transmission tower,

1. The maximum value of the voltage across insulator string is increased by about 6%, when the tail time is increased from 20μs to 60μs.
2. The magnitude of the voltage across insulator increases with increasing the lightning current.
3. As the front time of lightning current decreases, the voltage across the insulators string of phase conductor is increased, and as the tail time of lightning current increases, the voltage across insulator string of phase conductor is increased.

For 220 kV transmission tower

1. The peak value of the voltage across the insulator string is decreased to about 57% from its value at 400m from the struck tower, to about 31% at 800m, to about 13% at 1200m, and to about 9% at 1600m from the struck tower.
2. The voltage across the insulator string is increased by about 263% from its value as the peak value of the lightning current increases from 20 to 50kA.
3. The voltage across the insulator string decreases to about 86.5%, as the front time of lightning current increases from 1.2μs to 6μs and increased by 35%, as the footing resistance increases from 10Ω to 50Ω.

REFERENCES

[1] G. Radhika, M. Suryakalavathi, "Back flashover Analysis Improvement of a 220KV Transmission Line", International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622, Vol. 3, Issue 1, Jan-Feb.2013, pp.533-536.

[2] Swati Agrawal, Prema Daigawane and J. .B. Helonde, "Comparison of Induced Voltages in Different Cases Describing the Effect of High Voltage on Transmission Line", International Journal of Emerging Trends in Electrical and Electronics (IJETEE), ISSN: 2320-9569, Vol. 8, Issue. 1, Oct. 2013.

[3] M. H..Shwehdi, S. Raja Mohammad, "Computation of Lightning Impulse Backflashover Outages Rates on High Voltage Transmission Lines", International Journal of Automation and Power Engineering (IJAPE), Vol. 3, Issue 1, Jan. 2014.

[4] M. H. Shwehdi, “Computation of Lightning Flashovers& Backflashover Voltage Levels on 230KV Transmission Lines”, 2nd IEEE International Conference on Power and Energy (PECon 08), Dec. 1-3, 2008, Johor Baharu, Malaysia.

[5] C.A. Christodoulou, et. al., “Evaluation of lightning performance of transmission lines protected by metal oxide surge arresters intelligence using artificial techniques”, Journal of Energy Systems, Dec. 2012, Vol.3, Issue 4, pp 379-399.

[6] Saeedollah Talaei Mobarakei, Taghi Sami, Babak Porkar, “Back Flashover Phenomenon Analysis in Power Transmission Substation for Insulation Coordination”, 11th International Conference on Environment and Electrical Engineering (EEEIC), pp. 170 – 174, Venice, DOI:10.1109/EEEIC.2012.6221567, 18-25 May 2012.

[7] C. J. Coelho Teixeira, J. A. Dias Pinto, “back flashover analysis of overhead transmission line for different tower and lightning models”, 39th International Universities Power Engineering Conference 2004 (UPEC 2004), Vol.1, Sept. 2004, pp. 238 – 241, Bristol, UK

[8] M. Kizilcay, C. Neumann, “Back flashover Analysis for 110-kV Lines at Multi-Circuit Overhead Line Towers”, International Conference on Power Systems Transients (IPST’07) in Lyon, France on June 4-7, 2007.

[9] B. Marungsri, et. al., “Study of Tower Grounding Resistance Effected Back Flashover to 500 kV Transmission Line in Thailand by using ATP/EMTP”, International Scholarly and Scientific Research & Innovation, 2008.

[10] Andrew R. Hileman, “Insulation Coordination for Power Systems”, CRC Press, 1999, ISBN:978-0-8247-9957-1.

[11] IEEE Power Engineering Society, “IEEE Guide for the Application of Insulation Coordination”, 1999, DOI:10.1109/IEEESTD.1999.90576.

AUTHORS

First Author– M. A. Abd-Allah, Electrical Engineering Department, Faculty of Engineering at Shoubra, Benha University and E.mail mousa_abdulah@yahoo.com

Second Author- T. Elyan, Electrical Engineering Department, Faculty of Engineering at Shoubra, Benha University and E-mail tamerhamama@yahoo.com

Correspondence Author– Eman Belal, Faculty of Engineering at Shoubra, and E-mail ms_tota2009@yahoo.com.