Analyzing and Modeling the Separation Distance of Lightning Arresters For A 400KV Substation Protection Against the Lightning Strokes

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Abstract **–The aim of this paper is to study the effect of separation distance of lightning arresters to protect the 400KV substation against the direct lightning strikes. Hence this study, the performed analysis for assessing single phase ignition and back flash over, The testing system consists of four towers and a substation, The paper illustrates the benefit of Alternative Transient Program / Electromagnetic (ATP / EMTP) to finding the best type of arrester against the lightning. This circuit where exposed to the 260 KA lightning current after change the arrester separation distance at transformer from 5m to 30m. The results showed that if the increased separation distance at 15m for arrester of the type (Zinc Oxide-porcelain EXLIM Q1) is going to happen breakdown of the substation. Whereas find that if the increased distance from 5 to 30 m for arrester type (Zinc Oxide-silicone polymer PEXLIM Q2) be a good transformer protection, Also results of this study show that silicone polymer arrester is better and more acceptable than the porcelain arrester for the studied line. To avoid the problem of transient waves change the transmission lines system protection and of which choosing good lightning arrester as well as reduce the separation distance between the arrester and transformer.**

***Index Terms*— lighting currents, lightning arresters, separation distance, ATP/EMTP, BIL insulation level.**

I. Introduction

Exposed electrical network to traveling impulse waves, as a result, the system voltage rises to very high values may ultimately lead to the destruction of one of the components of electrical network, For this reason it is important to study the impact of these high voltages, And also methods the protection of them to improving the performance of the network under this circumstances,

This traveling impulse waves produced from a number of external factors such as the phenomenon of lightning and the phenomenon of electrostatic friction that results from sand storms. It produces waves of traveling also from several internal factors such operations as closing and opening of the circuit breakers, or a sudden cutting for line the result of a faults incidence, all of these problems have been hurt to the destruction of insulators and substations, If there is no good protection for the system [1,2].

On this basis, it is very important to identify phenomenon of lightning and calculate density of lightning in different regions in order to take necessary measures for protecting power network equipment. 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 earth and causes an increase of voltage and this issue causes back flash over [3].

There are two approaches of overhead lines' behavior at lightning strokes. Some analytical models determine the pulse voltages` time evolution, considering the repeated reflections, even at the towers' level [4,5], others analytical models asses, only in a quantitative way, the lines` performance at lightning over voltages on basis on specific number of outages indicator, These often used models in estimation calculations operate with the voltages' and currents' peak values, having no interest for their time evolution [6,7].

The stress of the lines' insulators is analyzed on basis on parameters like: towers' surge impedance, pulse surge impedance of the grounding grid, 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 [8].

To design insulator of power systems, study of lightning behavior and overvoltage resulting from it is an important factor in protection of different tools of substations and power plants. Lightning seldom directly collides with a transmission line. Lightning almost collides on top of tower of transmission line or shield wires and lightning currents flow on top of tower downward. This major current increases its voltage considering impedance of the tower. With increase of tower voltage, ignition may be created between the arms of the tower and earth and between two arms of the tower [9,10].

There are several studies conducted on this subject of which: in [11]. Study the voltage of lightning strikes on a number of transmission lines in the Libyan network (200kV, 400kV), It was the annual hangouts these lines rate calculation resulting from lightning strikes and using the program ATP/EMTP, It was also hangouts rate is calculated by mathematical equations and comparing the results of the program, In [12] it was given about the phenomenon of lightning and it is effect on the electrical network, after reaching the results showed a clear picture of the importance of lightning arresters using the program ATP / EMTP simulation of lightning strike hit the sub-station and transmission line with no arrester again with use.

In the present paper, the characteristics of the Separation Distance of Lightning Arresters For A 400KV Substation Protection Against the Lightning Strokes have been presented based on lightning simulation with ATP / EMTP with negative polarity. The paper is organized as follows: in section II, the system model is presented. Two different models of arrester including (Zinc Oxide-porcelain EXLIM Q1) and (Zinc Oxide-silicone polymer PEXLIM Q2) arrester are evaluated in section III. Result of two models included in the paper is mentioned in section IV and finally the most important results are elaborated in section V**.**

II. SYSTEM MODEL

This part introduces single line diagrams of the 400kV network composed of four towers and the substation. The 400kv single circuit transmission line has triplet bundle conductors. Tower footing resistance of this system is 10 ohms, and the distance of the arrester at transformer changes from 5 m to 30 m, and the range of lighting current is 260 KA with negative peak and the following figure 1. shows model for a 400 kV network using a program ATP. The figure 2. Shows the structure of the studied tower, Physical specifications of conductors and geometrical parameters of tower are given in tables 1 – 3 [13,14].

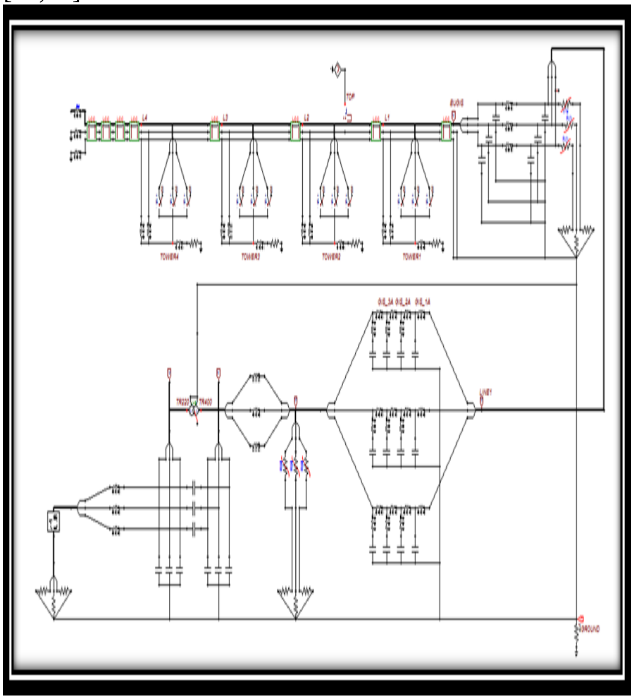

Figure 1. Shows the structure of 400kv studied system

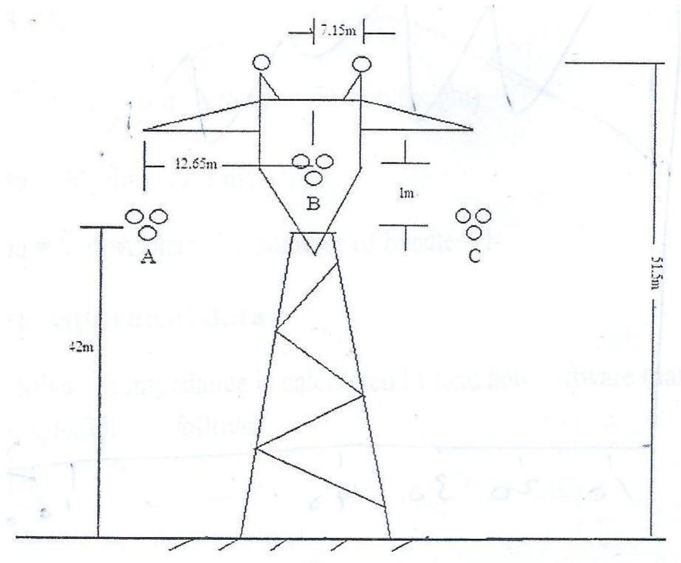

Figure 2. Tower configuration

Table 1. Conductor characteristics

Ph no	R_{in} cm	R_{out} cm	R_{ho} Ω/km DC	H_{oriz} m	V_{tow} m	V_{mid} m	*Alpha* Deg	*No bundl*
1	0	1.32	0.079	-11.38	41.7	27.4	30	3
2	0	1.32	0.079	0	42.7	28.4	30	3
3	0	1.32	0.079	11.38	41.7	27.4	30	3

Table 2. Ground wire characteristics

Ph no	**R_{in}**	**R_{out}**	**R_{ho} DC**	**H_{oriz}**	**V_{tow}**	**V_{mid}**
	Cm	**cm**	**Ω/km**	**m**	**m**	**m**
4	0.48	0.87	0.3	-6.28	51.27	39.07
5	0.48	0.87	0.3	6.28	51.27	39.07

Table 3. Conductor arrangement of overhead transmission line

Number.ph	**Vertical**	**Horizontal**
1	41.7 m	-11.38m
2	42.7 m	0
3	41.7 m	11.38m
Ground wire	**Vertical**	**Horizontal**
4	51.27 m	0 m
5	51.27 m	0 m

III. EVALUATION OF LIGHTNING ARRESTER.

Lightning arresters are devices used at substations and at line terminations to discharge the lightning over voltages and short duration switching surges. These are usually mounted at the line end at the nearest point to the substation. They have a flashover voltage power than that of any other insulation or apparatus at the substation. These are capable of discharging 10 to 20 kA of long duration surges (8/20 µsec) and 100 to 300 kA of the short duration surge currents (1/5 μsec) [15].
The following are the basic requirements of a Lightning Arrester:

i. It should not pass any current at normal or abnormal (normally 5% more than the normal voltage) power frequency voltage.
ii. It should breakdown as quickly as possible after the abnormal high frequency voltage arrives.
iii. It should interrupt the power frequency follow current after the surge is discharged to ground.

In this paper will study two types of surge arresters.

A. First arrester of type (Zinc Oxide EXLIM-Q1):

Protection of switchgears, transformers and other equipment in high voltage systems against atmospheric and switching overvoltages.
The design is based on successful experience of over 60 years, first as gapped arresters, in all climates and conditions all over the world. EXLIM arresters live up to their name: EXcellent voltage LIMiters. The design is robust and well-matched with the other apparatus in substations, It is made from Porcelain [16].

B. Second arrester of type (Zinc Oxide PEXLIM –Q2):

Protection of switchgear, transformers and other equipment in high voltage systems against atmospheric and switching overvoltages.
PEXLIM arresters, using the same ZnO blocks as the EXLIM arresters, match their electrical performance. Silicone rubber as outer insulation material has been used for over 25 years with good results and has been chosen by ABB for arresters as well. It confers the additional benefits of low weight, improved pollution performance, increased personnel safety and flexibility in erection, It is made from silicone polymer [16,17].
Table 4. shows the arrester characteristics for the voltage and current for tow arresters, and Table 5. Shows brief performance data for tow arresters and .

Table 4. The relationship between voltage and current

Arrester type	Zinc Oxide EXLIM-Q1	Zinc Oxide PEXLIM-Q2
I(A)	V1(v)	V2(v)
1500	783000	654000
3000	821000	680000
5000	856000	737000
10000	914000	776000
20000	991000	854000
40000	1102000	954000

Table 5. Brief performance data for tow arresters

Arrester type	Zinc Oxide EXLIM-Q1	Zinc Oxide PEXLIM-Q2
System voltage	170 -420 kv	52 - 420kv
Rated voltage	132 -420 kv	42 - 360kv
Nominal discharge current	10 KA	10 KA
Line discharge class	Class 3	Class 3
Short-circuit	65kA	50kA
Mechanical Strength	18000Nm	2500Nm
Design altitude	max 1000m	max 1800m
Ambient temperature	-50 C° to +45 C°	-50 C° to +45 C°
Frequency	15 – 62 Hz	15 – 62 Hz

V. ATP ANALYSIS OF 400KV CIRUIT DIAGRAM

In this paper will study the resulting voltage from a blow by lightning current has a rang 260KA on ground wire with changing the arrester separation distance at transformer, which ranging between 5 m to 30 m, With using two types of arresters, 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.

A. First Case:

In this case, results of study are based on ATP / EMTP software. lightning current has a range of 260 kilo amperes, with a changing of arrester separation distance at the transformer from 5 m to 30 m, increase the distance 5m in each step, by using the arrester of type **(Zinc Oxide EXLIM-Q1)**

Figures 3,4 Show the values of the internal voltages of the transformer on the primary side 400KV when distance 5m and 10m Respectively result of lightning current 260 kA by using (**Zinc Oxide EXLIM – Q1**).

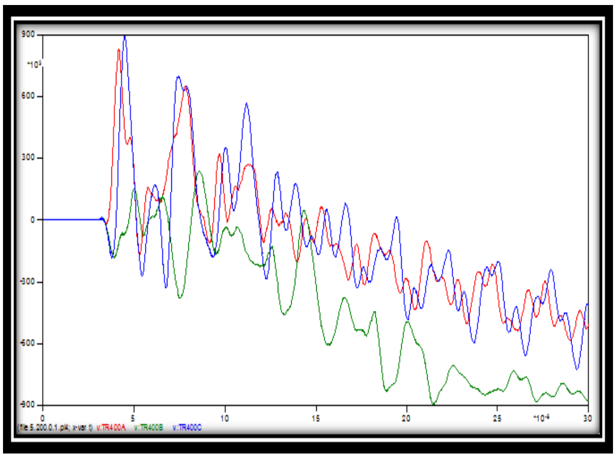

Figure 3. The inside voltage of the transformer when distance 5m

of lightning current 260KA

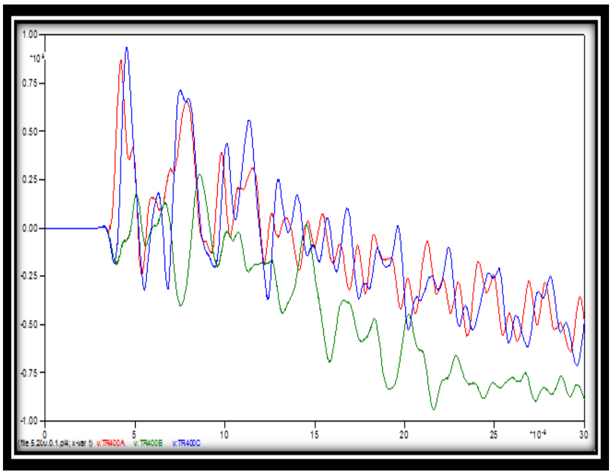

Figure 4. The inside voltage of the transformer when distance 10m of lightning current 260kA

Thus, it increase the arrester separation distance at the transformer width by 5m and test the system. In each step, it calculate the basic insulation level of the transformer BIL using the following formula:

$$\%BIL = \frac{BIL - \max overvoltage}{\max overvoltage} \times 100 \quad (1)$$

Where: (BIL) equal 1300kV [18-20].

(max overvoltage) Is the maximum voltage on the primary side 400kV 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 [19-22].

-When be arrester separation distance at the transformer is 5m be BIL:

Then:

$$BIL = \frac{1300 - 894.17}{894.17} \times 100 = 45.23\%$$

the rest of results have been listed in the table 6.

B. Second Case :

In this case will study the resulting voltage from a stroke by lightning current has a rang 260 kilo amperes with a changing of arrester separation distance at the transformer from 5 m to 30 m, increase the distance 5m in each step, using the arresters (Zinc Oxide PEXLIM-Q2).

Figures 5,6 Show the values of the internal voltages of the transformer on the primary side 400kV when distance 5m, 10m Respectively result of lightning current 260 kA by using (**Zinc Oxide PEXLIM –Q2**).

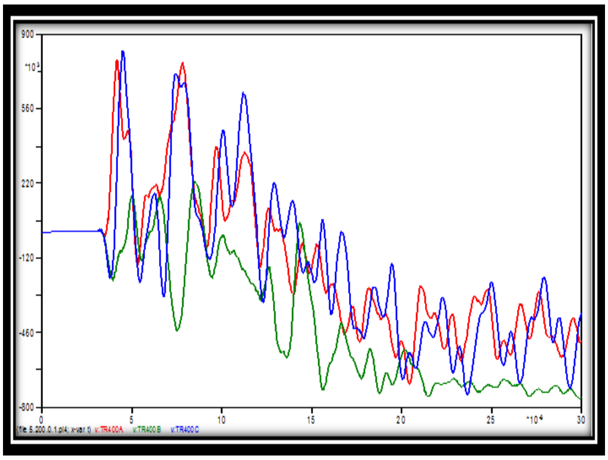

Figure 5 . The inside voltage of the transformer when distance 5m of lightning current 260kA

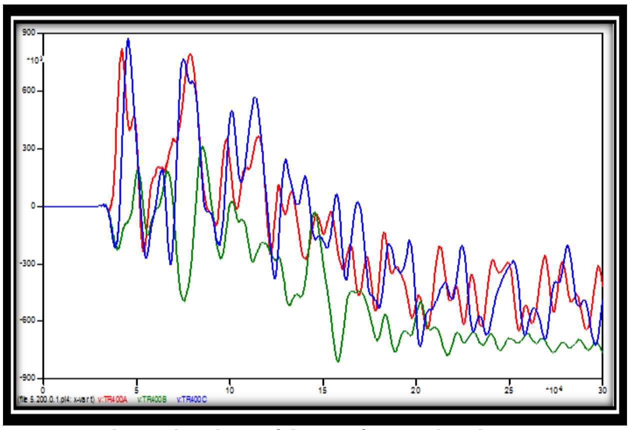

Figure 6. The inside voltage of the transformer when distance 10m of lightning current 260KA

Thus, it increase the arrester separation distance of the transformer width by 5m and test the system. In each case, it calculate the basic insulation level of the transformer BIL using the last law.

The table 6. and the figure 7. show the change extent of insulation level (BIL) for the transformer by 260kA lightning current on the primary side 400Kv of the transformer when arrester distance ranging from 5m to 30m for both two types of surge arresters

Table 6. Effect of the arrester distance on inside voltage of transformer when be 260KA lightning current.

Distance m	**Zinc Oxide EXLIM – Q1**		**Zinc Oxide PEXLIM – Q2**	
	Overvoltage kV	BIL %	Overvoltage (kV)	BIL %
5	894.17	45.23%	824.66	57.64%
10	994.88	30.66%	874.29	48.69%
15	1054.8	23.24%	904.08	43.79%
20	1097.9	18.42%	927.47	40.16%
25	1112.2	16.88%	940.02	38.29%
30	1134.7	14.56%	955.08	

				36.11%

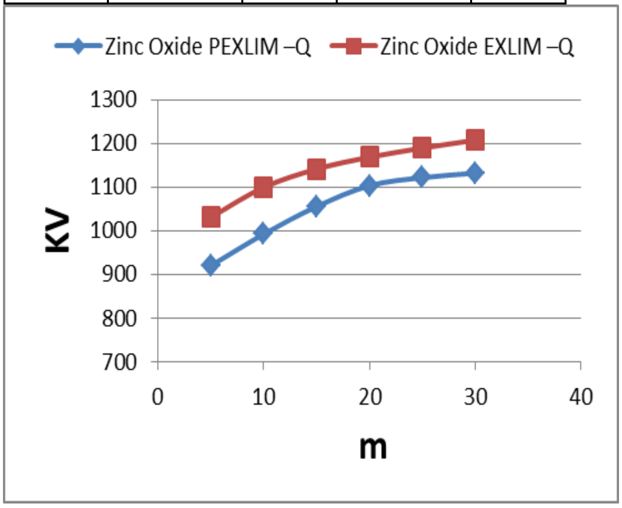

Figure 7. Effect of the arrester distance on inside voltage of transformer when be 260KA lightning current.

VI. CONCLUSION

The purpose of this paper was to study the extent of the impact of arresters separation distance at transformer for protection against lightning strokes. Using the ATP program, the study reached a number of important conclusions :

- The results showed that when using arrester the type (**Zinc Oxide EXLIM- Q1**), and by using the lightning current 260KA when be distance 15m and less be BIL good, But when be distance 20m and above will break down the insulation level of the transformer in front of the lightning wave destroying transformer
- When using arrester the type (**Zinc Oxide PEXLIM Q2**) with distance ranging from 5m to 30m and by using the lightning current 260 KA it is good protection for system.
- Better value for the arrester distance at the transformer helps protect the network from lightning strikes are 5m and less.
- Arrester of type (Zinc Oxide-Silicone Polymer PEXLIM Q2) best insulation from arrester of type (Zinc Oxide-Porcelain EXLIM Q1).
- Calculating the basic insulation level (BIL) of the transformers shows the extent of the impact of voltages rises duo to increasing the separation distance of arresters at transformer.
- Occurs exit the substation if the value of BIL is less than 20%.

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