Computational Study of 400 kV Transmission Lines Against Lightning with Line Terminating Matrix

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Abstract-*The main object of this paper is to analyse the impact of tower type (geometry of the tower) against lightning by studying one of its major factors, self and mutual impedances by taking geometry of the practical 400 kV, D/c, 2 ground wire tower in Hyderabad, Telangana, India.This paper also focuses to present PSCAD/EMTDC based transient multi-conductor modelling of a three phase double circuit for analysing transmission line performance during lightning of say 100 kA, 8/20µs as well as recovery of the string voltage at the tower with the placement of transmission line arresters, when back flashover was triggered into one of the phases of a chosen tower. A comparison was made with respect to tower footing resistance ranging from 10Ω to 100Ω by varying arc horn gap length which is considered to be an important factor in this model as arrester can perform well in a high tower footing resistance area.*
Keywords - Back flashover, Double Circuit*,* *Transmission Line Arrester, Transmission line Geometry, Ground Wire and PSCAD/EMTDC.*

I.INTRODUCTION

Electricity became oxygen for all of the present day inventions and technologies. Electricity is the greatest gift of science to mankind. The principle objective is supplying electric power as per load requirements and maintaining a very high level of continuity without unanticipated power outages. The power system is evolving to a smart, super, and clean grid, accompanied by interior diversified and budding threats [3]. Power system keeps on expanding in terms of geographical areas, assets additions, and penetration of new technologies in generation, transmission and distribution. This makes the electric power system complex, heavily stressed and thereby vulnerable to cascade outages. The conventional methods in solving the power system design, planning, operation and control problems have been very extensively used for different applications but these methods suffer from several difficulties due to necessities of derivative existence, providing suboptimal solutions, etc. [10]. The only solution is to find new computational techniques which can overcome the problems of conventional methods. Even technological accidents and disasters occurring in critical infrastructure facilities have drastic impacts on the society, economy and environment [1]. Hence

a robust technique has to be introduced. It was observed that natural factors cause more than 70 percent of all "blackouts", where lightning is one of such serious transient fault on the transmission line, where a powerful sudden flow of electricity (an electrostatic discharge) accompanied by thunder, creates a power outage. The lightning performance of overhead transmission lines is measured by the probability of back flashover whose probability is affected by (a) tower type, (b) grounding arrangement, (c) soil resistivity and (d) lightning activity and lightning parameters of that particular area.

The amount of power on any electric line at any given moment depends on generation and load end, customer use, the status of other transmission lines and their associated equipment, and even prominently the weather conditions and there are no questions about the danger posed by lightning strikes and their associated effects. Lightning strokes have a much unpredicted behaviour, their elimination or total reduction on TLs is impossible, thus at this moment it is the most important disturbing phenomenon for the functioning of EPS [14]. Lightning occurs when some region of the atmosphere attains an electric charge sufficiently large that the electric fields associated with the charge cause electrical breakdown of the air. The most common producer of lightning is thundercloud (cumulonimbus) [8]. When a tower is struck by lightning, voltage at the tower top results from a surge traveling through the tower surge impedance, and this voltage is enforced upon line insulation because the conductor is capacitively tied to ground [11].

It is a matter of great surprise to know that over the whole world, more than 40,000 lightning strokes per day and not less than 100 lightning strokes per second takes place. Hence, it is vital to control power outages in the existing system, because the frequency of transmission line faults resulting in power loss has decreased year by year yet the trouble due to natural cause is not yet reduced (for instance, the recent drastic calamity created by Hudhud cyclone to coast of Andhra Pradesh). Fig. 1 also depicts the emerging need of research in this particular natural disaster effects on Power lines. On the other hand, since the intensity and frequency of storms worldwide increased due to global warming, there is a very high probability that lightning impacts on TLs. The number of strokes

contacting a tower or ground wire along the span can only depend on the number of thunderstorm days in a year which is called as 'Keraunic level' or also called 'Isokeraunic level' [7].
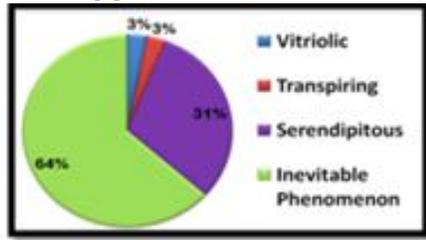

Fig.1 Causes of Power Blackouts

Due to high frequency range associated with lightning transient phenomena, adequate electrical models are required. For these reasons, simulation studies require detailed modelling of the lightning phenomena and of the network components, including towers and insulators which are not usually considered in the other models. The method used to analyse the increase in voltage due to lightning was done by using the powerful and flexible graphical user interface to the world renowned electrical tool called PSCAD/ EMTDC which enables the users to schematically construct a circuit, run a simulation, analyse the results as well in managing the data in a completely integrated graphical environment [16].

The overhead ground wires or shield wires are located at the top of the tower so as to minimize the number of lightning strokes that will terminate on the phase conductor. The remaining and vast majority of the strokes and flashes now terminate on the overhead ground wires. The tower with one OHGW leads to high overvoltage across insulator comparing with two OHGW [19]. Any stroke that forces current to flow down the tower and out on the ground wires, thus voltage is built up across the line insulation. If this voltage equals or exceeds the line basic insulation level (BIL) flashover over occurs and this event is said to be back flashover. Back flashover accounts for a large ratio of the faults experienced by high voltage transmission lines and that to prediction of back flashover is renewed as a complex task because of the interaction of random multi parameter lightning phenomenon with all the components of the transmission lines. The reasons for installing transmission line arresters are, to reduce or eliminate lightning induced outages due to flashover of insulators, and less common purposed is to eliminate insulator flashover due to switching surges. Lightning impulse withstand voltage level of the insulator string is not a unique number. The insulator string may withstand a high magnitude impulse voltage which has a short duration even it has failed to withstand a lower magnitude impulse voltage with longer duration [12].

The lightning performance of overhead transmission lines is measured by the probability of back flashover whose probability is substantially affected by different factors like tower type, grounding arrangement, soil resistivity, lightning activity and lightning parameters of that particular area [2]. We here are dealing with foremost (tower type) factor. Electromagnetic transient simulations from an atmospheric impulse show that the tall transmission line has a major transient overvoltage than a conventional line [9]. As the voltage rating increases the height of the transmission tower also increases. This factor increases the complexity of calculations.

II.SELF AND MUTUAL IMPEDANCES

A. *Self impedance*

The equations assume infinitely long and perfectly horizontal conductors above a homogeneous conducting earth, having a uniform resistivity ρ_c (Ω m) and a unit relative permeability. Proximity effect between conductors is neglected. Using the series voltage drop in V of each conductor due to current flowing in the conductor itself and currents flowing in all other conductors in the same direction is given by

$$V_i^N = \sum_{j=1}^N Z_{ij} I_j \quad V/k \tag{1}$$

where *Z* is the impedance expressed in Ω/km and *I* is the current in amps. The self-impedance of conductor '*i*' is given by

$$Z_{ii} = [R_{i(c)} + jX_{i(c)}] + jX_{i(g)} + [R_{i(e)} + jX_{i(e)}]\frac{\Omega}{km} \tag{2}$$

where subscript *c* represents the contribution of conductor '*i*' resistance and internal reactance, *g* represents a reactance contribution to conductor '*i*' due to its geometry, i.e. an external reactance contribution and '*e*' represents correction terms to conductor '*i*' resistance and reactance due to the contribution of the earth return path. If skin effect is neglected, i.e. assuming a direct current (DC) condition or zero frequency, the internal DC impedance of a solid magnetic round conductor, is given by

$$Z_{i(c)} = R_{i(c)} + jX_{i(c)} = \frac{1000\rho_c}{\pi r_c^2} + j4\pi 10^{-4} f\left(\frac{\mu_r}{4}\right)\Omega/km \tag{3}$$

where μ_r and ρ_c are the relative permeability and resistivity of the conductor, respectively, and r_c is the conductor's radius.

B. *Mutual Impedance*

The mutual impedance between conductor 'i' and conductor 'j' is given by

$$Z_{ij} = jX_{ij(g)} + [R_{ij(e)} + jX_{ij(e)}]\Omega/km \tag{4}$$

Where $X_{ij(g)}$ is the external reactance of conductor i due to its geometry and the simplified Self and Mutual impedances after simplification are

$$Z_{ii} = R_{i(c)} + \pi^2 10^{-4} f + j4\pi10^{-4}f\left[\frac{1}{4n} + \ln\frac{D_{erc}}{r_o}\right]\Omega/km \quad (5)$$

$$Z_{ij} = \pi^2 10^{-4} f + j4\pi10^{-4}f\left[\ln\frac{D_{erc}}{d_{ij}}\right]\Omega/km \quad (6)$$

The soil resistivity (or conductivity) may influence the characteristics of cloud-to-ground lightning flashes [13]. TABLE I shows the typical values of earth resistivity.

Type of Soil	Earth resistivity values
Garden and marshy soil	1–20 Ω m
Loam and clay	10–100 Ω m
Farmland	60–200 Ω m
Sand	250–500 Ωm
Pebbles,	300–1,000 Ωm
Rock	1,000–10,000 Ωm
Sandstone.	10^9 Ωm

TABLE I: TYPICAL VALUES OF EARTH RESISTIVITY.

III. 400 kV TRANSMISSION TOWER IMPEDANCE MATRIX

A line is a static power plant that has electrical parameters distributed along its length [4]. The basic parameters of the line are conductor series impedance and shunt admittance. Each conductor has self-impedance and there is mutual impedance between any two conductors. The impedance generally consists of a resistance and a reactance.

The transient impedance varies mainly with effective wire height over ground and with earth resistivity [6]. Inductance and capacitance are said to be varying quantities according to their relative distances to the ground, consequently the impedance will be as well. Thus, to the extent that an outbreak pervades the extension of the tower, from the top to the ground, this current wave is the subject of variable impedance and, by the travelling wave theory, reflected waves will be present. The computation of overvoltage that the tower is subjected to must be taken into consideration in this aspect. The sub conductor spacing in Fig. 2 show the chosen configuration for the proposed model. In Table. II, the parameters representing the geometry of 400 kV, D/c, and double ground wire transmission towers was given for the chosen tower from Mamidipally substation.
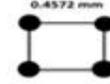

Fig. 2: Sub-conductor spacing

TABLE II: PARAMETERS OF 400 KV, 2-G D/C TOWER

Tower Parameters	1-Ground wire
Sub-conductor spacing	0.4572 m
Earth wire AC resistance	0.0643 Ω/km
M	3.4 m
A	6.5 m
B	6.9 m
C	7.5 m
D	40.4 m
E	32.4 m
F	24.4 m
G	46.2 m
H_4	28.20 m
H_3	8.00 m
H_2	8.00 m
H_1	5.8 m
H	50 m

Where

GMR_c = conductor outer radius x stranding factor

GMR_{equ2} = (4 x 20.3454 x $(323.289)^3$) $^{1/4}$ = 228.994 mm

R_{qb2} = 457.2 x $(2)^{1/2}$ = 323.289 mm

D_{erc} = 658.87 x (Earth resistivity/ Nominal frequency)$^{1/2}$

D_{erc2}= 658.87 x $(30/50)^{1/2}$ = 510.3585 m

AC resistance per phase = resistance of conductor/4

R_{AC2} = 0.0513 /4 = 0.013 Ω/km

For a 400 kV D/c overhead line with two ground wires, the conductors are numbered 1–8 and their spacing, including average conductor sag relative to the centre of the tower and earth shown in Fig.3. However 50% of the lightning strokes contain more than one stroke, which is also known as multiple strokes lightning (MSL) [20], but in this proposed model single stroke lightning (SSL) current magnitude was considered.
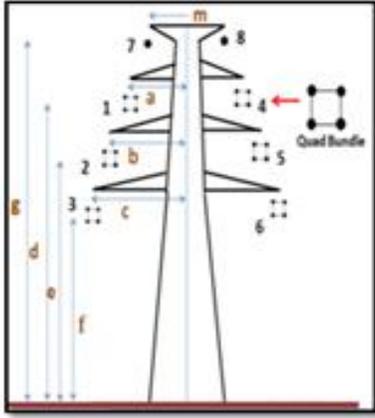
Fig. 3: 400kV Transmission Tower with Double Ground Wire

For every 3Φ, D/c lines with two earth wires suspended on the same tower, there exists mutual coupling between the conductors of the two circuits as well between the conductors and within each circuit. Herein the self-circuit and inter-circuit mutual coupling needs to be defined, together with its significance, in sequence component terms, for its use in large-scale power frequency steady state analysis. Here are the conductors spacing with respect to each other and with respect to ground for a chosen 400kV, D/c, two ground wire tower configuration.

$d_{11}=d_{22}=d_{33}=d_{44}=d_{55}=d_{66}$

$d_{77}=d_{88}$

$d_{12}=d_{21}=d_{45}=d_{54} = \sqrt{(d-e)^2 + (b-a)^2}$

$d_{13}=d_{31}=d_{46}=d_{64} = \sqrt{(d-f)^2 + (c-a)^2}$

$d_{15}=d_{51}=d_{42}=d_{24} = \sqrt{(a+b)^2 + (d-e)^2}$

$d_{16}=d_{61}=d_{43}=d_{34} = \sqrt{(c+a)^2 + (d-f)^2}$

$d_{17}=d_{71}=d_{48}=d_{84} = \sqrt{(a-m)^2 + (g-d)^2}$

$d_{18}=d_{81}=d_{47}=d_{74} = \sqrt{(a+m)^2 + (g-d)^2}$

$d_{26}=d_{62}=d_{53}=d_{35} = \sqrt{(e-f)^2 + (c+b)^2}$

$d_{27}=d_{72}=d_{58}=d_{85} = \sqrt{(g-e)^2 + (b-m)^2}$

$d_{28}=d_{82}=d_{57}=d_{75} = \sqrt{(g-e)^2 + (b+m)^2}$

$d_{32}=d_{32}=d_{65}=d_{56} = \sqrt{(e-f)^2 + (c-b)^2}$

$d_{37}=d_{73}=d_{68}=d_{86} = \sqrt{(g-f)^2 + (c-m)^2}$

$d_{38}=d_{83}=d_{76}=d_{67} = \sqrt{(g-f)^2 + (c+m)^2}$

$d_{14}=d_{41}= 2a$

$d_{25}=d_{52}= 2b$

$d_{36}=d_{63}= 2c$

$d_{78}=d_{87}= 2m$

Figure. 3 exemplifies a quintessential 3Φ, D/c line with two earth wires. For circuit A, the phase conductors are numbered 1, 2 and 3 and for circuit B, the phase

$Z_{11}=Z_{22}=Z_{33}=Z_{44}=Z_{55}=Z_{66} = 0.0623+j0.4883$

$Z_{77}=Z_{88}=0.1136+j0.6826$

$Z_{12}=Z_{21}=Z_{45}=Z_{54} = 0.0493+j0.2610$

$Z_{13}=Z_{31}=Z_{46}=Z_{64}=0.0493+j0.2174$

$Z_{15}=Z_{51}=Z_{42}=Z_{24}=0.0493+j0.2157$

$Z_{16}=Z_{61}=Z_{43}=Z_{34}=0.0493+j0.1997$

$Z_{17}=Z_{71}=Z_{48}=Z_{84} = 0.0493+j0.2734$

$Z_{18}=Z_{81}=Z_{47}=Z_{74} = 0.0493+j0.2384$

$Z_{26}=Z_{62}=Z_{53}=Z_{35}=0.0493+j0.2157$

$Z_{27}=Z_{72}=Z_{58}=Z_{85}=0.0493+j0.2249$

$Z_{28}=Z_{82}=Z_{57}=Z_{75}=0.0493+j0.2129$

$Z_{32}=Z_{32}=Z_{65}=Z_{56}=0.0493+j0.2609$

$Z_{38}=Z_{83}=Z_{67}=Z_{76}=0.0493+j0.1911$

$Z_{37}=Z_{73}=Z_{68}=Z_{86}=0.0493+j0.1970$

$Z_{14}=Z_{41}=2a=0.0493+j0.2306$

$Z_{25}=Z_{52}= 2b=0.0493+j0.2268$

$Z_{36}=Z_{63}= 2c=0.0493+j0.2216$

Hence, the line terminating impedance matrix of 400 KV, D/c lines with earth wires is given in Matrix [1].

$$
\begin{bmatrix}
0.0623{+}j0.4883 & 0.0493{+}j0.2610 & 0.0493{+}j0.2174 & 0.0493{+}j0.2306 & 0.0493{+}j0.2191 & 0.0493{+}j0.1997 & 0.0493{+}j0.2734 & 0.0493{+}j0.2384 \\
0.0493{+}j0.2610 & 0.0623{+}j0.4883 & 0.0493{+}j0.2609 & 0.0493{+}j0.2191 & 0.0493{+}j0.2268 & 0.0493{+}j0.2157 & 0.0493{+}j0.2249 & 0.0493{+}j0.2129 \\
0.0493{+}j0.2174 & 0.0493{+}j0.2609 & 0.0623{+}j0.4883 & 0.0493{+}j0.1997 & 0.0493{+}j0.2157 & 0.0493{+}j0.2216 & 0.0493{+}j0.1970 & 0.0493{+}j0.1911 \\
0.0493{+}j0.2306 & 0.0493{+}j0.2191 & 0.0493{+}j0.1997 & 0.0623{+}j0.4883 & 0.0493{+}j0.2610 & 0.0493{+}j0.2174 & 0.0493{+}j0.2384 & 0.0493{+}j0.2734 \\
0.0493{+}j0.2191 & 0.0493{+}j0.2268 & 0.0493{+}j0.2157 & 0.0493{+}j0.2610 & 0.0623{+}j0.4883 & 0.0493{+}j0.2609 & 0.0493{+}j0.2129 & 0.0493{+}j0.2249 \\
0.0493{+}j0.1997 & 0.0493{+}j0.2157 & 0.0493{+}j0.2216 & 0.0493{+}j0.2174 & 0.0493{+}j0.2609 & 0.0623{+}j0.4883 & 0.0493{+}j0.1911 & 0.0493{+}j0.1970 \\
0.0493{+}j0.2734 & 0.0493{+}j0.2249 & 0.0493{+}j0.1970 & 0.0493{+}j0.2384 & 0.0493{+}j0.2129 & 0.0493{+}j0.1911 & 0.1136{+}j0.6826 & 0.0493{+}j0.2713 \\
0.0493{+}j0.2384 & 0.0493{+}j0.2129 & 0.0493{+}j0.1911 & 0.0493{+}j0.2734 & 0.0493{+}j0.2249 & 0.0493{+}j0.1970 & 0.0493{+}j0.2713 & 0.1136{+}j0.6826
\end{bmatrix}
$$

Matrix (1): 8x8 Line Terminating Matrix of 400 kV D/C Double Ground Wire (Conventional Calculation)

IV.8X8 LINE TERMINATING MATRIX OUTPUT

A large variety of tower structures with many different geometric forms makes the creation of a generic method for the calculations which were very complex, with every structure format having a different set of equations to perform any calculation. This can be overcome in case of MATLAB code for calculating LTM, the same program could be used for any tower configuration with appropriate changes which was given in Appendix.

Fig. 4 shows the so modelled 8X8 line terminating matrix in PSCAD/EMTDC which was ever done for a D/c, double ground wire configuration. The above calculated conventional impedance matrix values were used as inputs to build up the line terminator which will be used as a source to the proposed model.
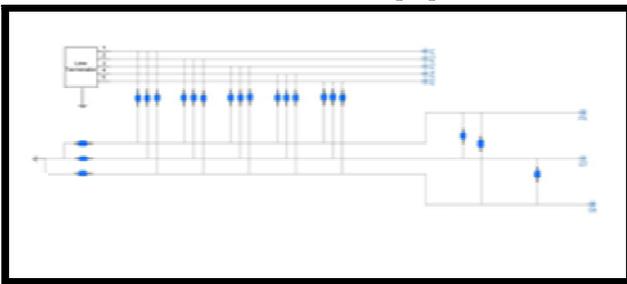

Fig. 4: Line Terminator

V.PROPOSED MODEL

The proposed model selected in this paper is given in Fig. 5 , that consists of 5 nos. of double circuit steel lattice towers with two galvanized steel overhead ground wires for a span of 5Km and which stepped down by 400/220 KV T/F. The tower geometry calculations and line terminator given above and the same geometry was used to the proposed model.
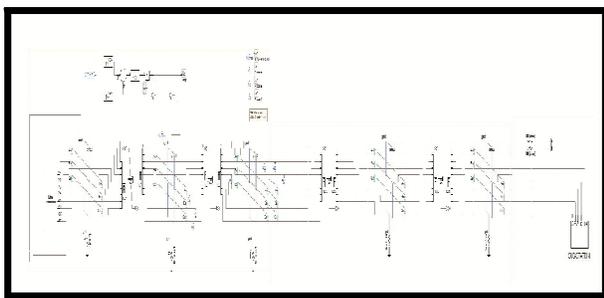

Fig. 5: Proposed model

A transmission line arrester is a line arrester applied on a transmission line. The selection of transmission line arrester firstly includes, identical the electrical characteristics of the arrester to the system's demand [15], and secondly matching the mechanical characteristics of the arrestors to the system's mechanical and environmental requirements. From [20] the arrester rating shall not be less than the product of system's highest voltage and coefficient earthing. Thus the arrester voltage rating for an effectively earthed system could be 354 kV by taking the rated lightning impulse withstand voltage (peak) as 1425 kV. The proposed model is interfaced with 400/220 kV substation with two incoming feeders and simulation was carried by collecting data from Mamidipally substation, Hyderabad with which calculations were carried out. The construction of twelve sub-circuits that includes six insulator strings, six cross arms each with each 22 discs was already done as per IEC recommendations for a 400 kV system. Hence over the proposed model, lightning of 100 KA, 8/20 μs was induced on the first tower and back flashover was triggered and then transmission line arresters were kept in operation respectively. Thus the corresponding tower insulator flashes off and string voltage drops to zero, which is highly undesirable for the electrical power world. Now transmission line arresters of that particular tower circuit were kept in operation and then the successive recovery of the string voltage could be observed.

With reference to [17], the modelling was done with supply voltage of 400 kV in this paper, the system was modelled with line terminator of 8X8 matrix.

With practical scenario, decreasing tower footing resistance is not practically possible, because of which study was done with tower footing resistance ranging from (10-90) Ω. Transmission line arresters been developed and are already in successful service, however tower with high footing resistance has been studied. The lightning stroke to the power conductor is the decisive factor in the design of the line arrester for the application of reasonably low footing resistance area [18]. This is also the case for the tower footing resistance of up to 100Ω [19] as the tolerable energy for the normal duty arrester is approximately 300 KJ. Hence, for the proposed model, Table III give the validation of high tower footing resistance with the impact of string recovery voltage with their respective arc horn gap length.

VOLTAGES	A21			A22		
	With Surge	With BFO	With TLA	With Surge	With BFO	With TLA
Phase Voltage(kV)	3.582	2.34	2.732	3.232	2.556	2.765
Tower Voltage(kV)	2.518	2.34	2.551	2.556	2.556	2.555
String voltage(kV)	2.827	0	0.6297	1.795	0	0.62631
	B21			B22		
Phase Voltage(kV)	3.16	2.553	2.832	2.43	2.52	2.417
Tower Voltage(kV)	2.513	2.553	2.518	2.544	2.52	2.559
String voltage(kV)	2.269	0	0.690	1.664	0	0.66365
	C21			C22		
Phase Voltage(kV)	2.985	2.568	2.334	2.283	2.558	2.277
Tower Voltage(kV)	2.542	2.568	2.543	2.558	2.558	2.565
String voltage(kV)	1.913	0	0.6879	1.375	0	0.6633

TABLE III: VALIDATION FOR HIGH TOWER FOOTING RESISTANCE

S.No	Tower footing resistance in Ω (R_{tf})	Arc horn gap length (m)	Recovery voltage in P.U (V_{recvry})
1	10	1.4	2.544
2	20	1.4	2.571
3	30	1.4	2.60
4	40	1.6	2.81
5	50	1.6	2.88
6	60	1.6	2.942
7	70	1.8	2.9417
8	80	2	2.9435
9	90	2	2.96
10	100	2	2.967

TABLE IV: 400 KV D/C INSULATOR STRING RECOVERY VOLTAGES

Also Table IV, shows the phase voltage, tower voltage and string voltage when lightning of 100 KA , 8/20 µs was induced into the system using line terminator as a source of supply and the consecutive towers of the same configuration. By triggering back flashover on one of the circuit respectively, the corresponding drop out in string voltage was observed. As transmission line arrester when applied on the lines will reduce the risk of insulator flashover during surge events, the same could be seen, i.e. with TLA's placement in all lines, the insulator string voltage could be recovered. Thus the recovery in the string voltage could be observed accordingly in both the circuits. The electrical system is constantly tested relating to its continuity in service, and its competence to endure and minimize fault phenomena [5].

VI.SIMULATION RESULTS

During the simulation process, a scaled down standard lightning impulse current generator was fabricated and developed, that can generate an impulse current waveform of 8/20 Ωs with tolerance of ±1% at wave front and ±2% at wave tail. Fig. 6 shows the experimental output of so developed impulse current generator that could generated an impulse current of 6.08 KA with 9.23 kV charging voltage.
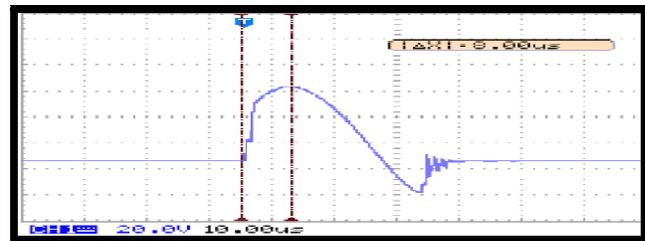

Fig. 6: Impulse Current as per IEC Standards, 8/10µs

Thus the 3kV, MO blocks was also tested for any physical punctures or cracking after being tested for 10 times with a time gap of 20 sec and found to be fair. Below Fig. 7 shows the non linear V-I characteristics of 3kV MO block drawn on experimental work, where measuring , testing were discussed in detailed in [ieema].
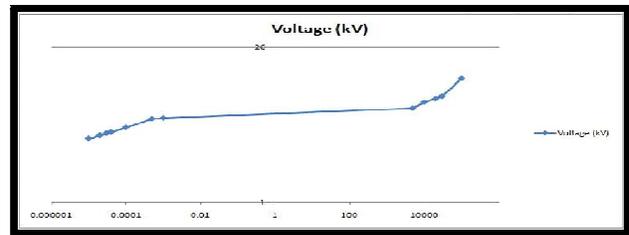

Fig. 7: V-I Characteristics of 3kV block

The below simulation results shown in Fig.8, Fig.9 and Fig.10 shows the Phase voltage, String voltage and Tower voltage when back flashover was triggered.
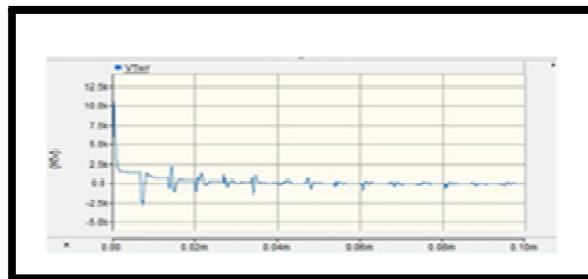
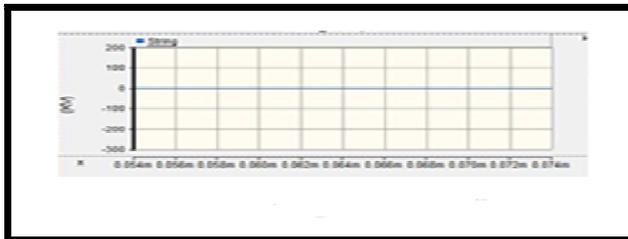Fig. 8: Phase Voltage with Back Flashover
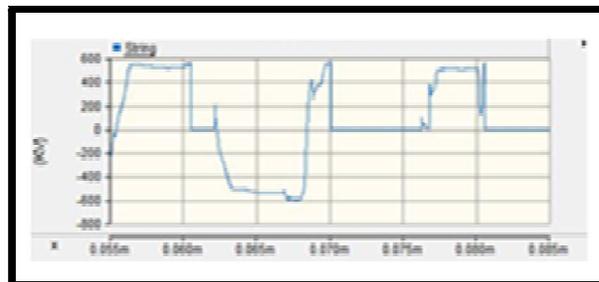

Fig. 9: String Voltage with Back Flashover

Fig. 10: Tower Voltage with Back Flashover

So, herein Fig.10 the string voltage was dropped to zero which is highly undesirable for the transmission line arrester was placed and successive results were drawn , where Fig.11, Fig.12 and Fig.13 shows the phase voltage, String Voltage and Tower Voltage when TLA was placed.
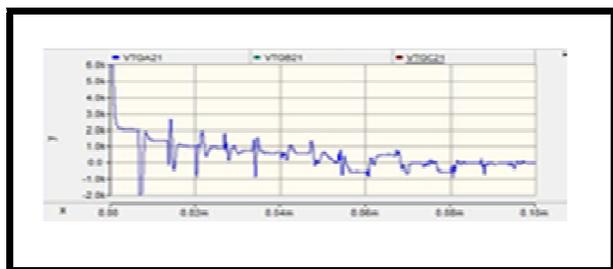

Fig. 11: Phase Voltage with TLA

Fig. 12: Tower Voltage with TLA

Fig.13: String Voltage with TLA

Wherein Fig. 13 the string recovery voltage was recovered as well without disturbing the continuity of the power supply to the substation.

VII. CONCLUSION

In view of a typical 400 kV D/c route of a vertical conductor arrangement with two ground wires, the following conclusions can be made from this analysis.

(1) The mathematical calculations and simulation output, hence shows an excellent similarity by which it is proved that the impedance calculation has been reduced the complexity by using programming technique. Hence the same program could be used for any tower configuration.

(2) The string voltage can be recovered by installing transmission line arresters per phase against back flashover, as well analysis with footing resistance of 10 - 100Ω and with varying arc horn gap length of 1.4 – 2m was also tabulated.

Therefore, we conclude that the line design influences more on insulation coordination and also in minimizing the effects of lightning flashovers.

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