Study and Analysis of Dynamic Behavior of Surge Arrester in 132/11 kV Power System

Nikhil Menon[1], Bhavik Prajapati[2], Viral Patel[3], Bhavik Patel[4]

[1]*ME student, Electrical Department, Sigma Institute of Engineering*
[2]*Assistant Professor, Electrical Department, Sigma Institute of Engineering*
[3]*Assistant Professor, Electrical Department, Sigma Institute of Engineering*
[4]*Assistant Professor, Electrical Department, Sigma Institute of Engineering*

Abstract — *Surge Arresters are used as protective device against lightning strokes and high voltage switching surges in power system. Dynamic behavior of various surge arrester are analyzed by modelling in ATP Draw and by selecting various system parameters. By analyzing the simulation results mainly the peak of residual voltage and the quenching time for each model is calculated. The metal oxide surge arresters cannot be modeled by only a non-linear resistance, since its response depends on the magnitude and the rate of rise of the surge pulse because the residual voltage increases as the current front time descends and the residual voltage reaches its maximum before the arrester current reaches its peak. Simulation of 132/11 kV system is done with the help of three models i.e. IEEE, Pinceti, Fernandez and Diaz and the analysis of the result is done with the help of ATP draw software and best model is selected on the basis of residual voltage and quenching time which shows the dynamic behavior of surge arrester in the power system.*

Keywords-*ATP, MOSA, Residual voltage, Dynamic behavior, Lightning stroke*

I. INTRODUCTION

Metal oxide surge arrester is the basic element to protect equipment from overvoltage. The main purpose of the paper is to study and analyze the dynamic behavior of various surge arrester models like IEEE, Pinceti, Fernandez and Diaz with the help of software like ATP/EMTP.The parameters of the models are calculated from the manufacturer datasheet. The dynamic behavior is important for the surge arrester location and insulation coordination study. Generally, cause of damage in electrical equipment and the network occurs when lightning strike happens. The overvoltage is very dangerous for any equipment and it may cause damage or failure, unless some protective steps against this overvoltage are being taken. The overvoltage may cause many interruptions like: supply interruption, or even equipment damage.

When equipment damage cause waste of money with time. To make certain convenience with safety, we required some device which can protect devices against overvoltage in the system. Metal oxide surge arrester is fundamental crucial part of protecting device that can protect against overvoltage. Some of the important to be count into account is dynamic behavior of metal oxide surge arrester while in progressing models to represent the performance of a metal oxide surge arrester to lightning current. It is called accurate non-linear V-I curve.[9]

Different types of surge arrester like gapped silicon carbide (SiC), gapped or non-gapped metal oxide surge arrester are also used. Gapped surge arresters with silicon carbide are still in use in several countries. However, surge arresters used today are generally gapless metal oxide surge arresters (MOSA) and it has a very simple structure. It has a series connection of ZnO elements with high nonlinear resistance.

The elements are in cylindrical blocks with single or multiple columns. The cylindrical block type metal oxide varistor are shown in figure 2.2. The energy absorption was calculated based on the block diameter. Generally, in distribution a system, the diameter has varies in a range within 30 mm to 100 mm in high or ultra-high voltage system or in special applications.

Metal oxide resistors have a height from 20 mm to 45 mm. During a lightning surge (e.g. current 10kA), the residual voltage per millimeter of height are 450 V/mm for distribution surge arresters down to 270 V/mm for arrester in 420kV system. The elements are stack on top of each other for metal oxide surge arrester has to be mechanically fixed in the housing. It is sure that the active part cannot be moved from original position during arrester installation. Moreover, contact pressure for a certain axis is necessary to make current stress easy to handle.

II. 132/11 kV TEST SYSTEM

For analysis the effect of lighting strike on distribution power system, a 132/11kV substation modelled and simulations are done by ATP Draw version 5.7. Figure 5.1 equivalents to the 132/11kV system in which 11kV feed from the 132kV network via T1 transformer. In this model main transformer “line 1” is around 60 km long and the length of lateral branches of main l is shown on figure 5.1. The modelling of lighting flash was done by using three sequential spikes of different value of magnitude. This contains first stoke duration of 0.6ms with about 10 kA lighting current and the second ,third subsequent lighting stoke has duration of 0.3ms with 5 kA and 3 kA lighting current magnitude respectively.

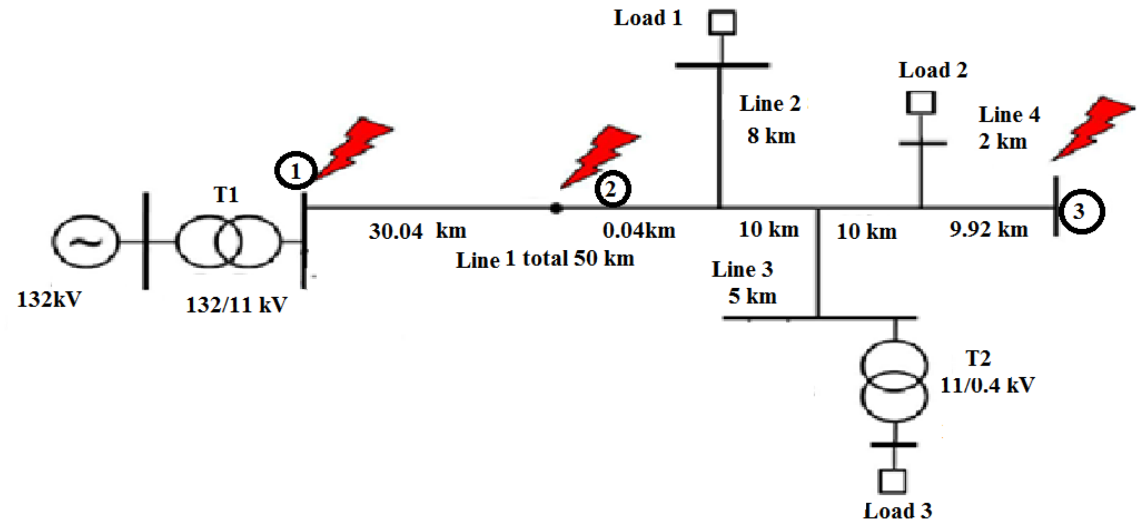


Figure 1 Scheme of the Power Network

The source of voltage is introduced by supply network and equation 5.1 gives amplitude of source voltage. Short circuit power can be used to calculate internal impedance. AC3ph-Type 14 ((cosine's) Steady-state function 3 phase) model was used to represent supply network in ATP Draw. (R =974.5, L =0.00693 mH).

$$U_{amp} = \frac{\sqrt{2}}{\sqrt{3}} * 132 = 107.905 \text{ kV} \qquad (1)$$

III. 132/11 KV 20 MVA AND 11/0.4 KV 0.4 MVA SPECIFICATIONS

The BCTRAN model is used to represent transformer in ATP and parameters used for transformer are provided in table 1.

Table 1: Parameters used for BCTRAN in ATP

Transformer Names	**T1**	**T2**
Power in MVA	20	0.4
Primary Voltage in kV	132	11
Secondary Voltage in kV	11	0.415
Leakage Impedance in %	10	4
Open-Circuit Current in %	0.22	1.1
Short-Circuit Losses in kW	78.2	4.6
Open-Circuit Losses in kW	15.5	0.65

No of Windings of Transformer = 2

The other required values are: number of phases: 3, test frequency 50 Hz, Core type: shell Core and the transformer connection is Y_{nyn} (volt- age divided by $\sqrt{3}$).

IV. LIGHTNING STROKE SPECIFICATIONS

By using ATP Draw three shunt connected ideal current sources introduced as lighting flash in simulation. Figure 2 represented first stroke of lighting and it was simulated by using. The lightning flash is simulated in ATP-Draw using three shunt connected ideal current sources. The Type 15 surge function [1] which is given as follow:

Surge value of 10 kA for duration of 0.6ms can be achieved by selecting constant amplitude of A and B. Table 2 suggests constant value.

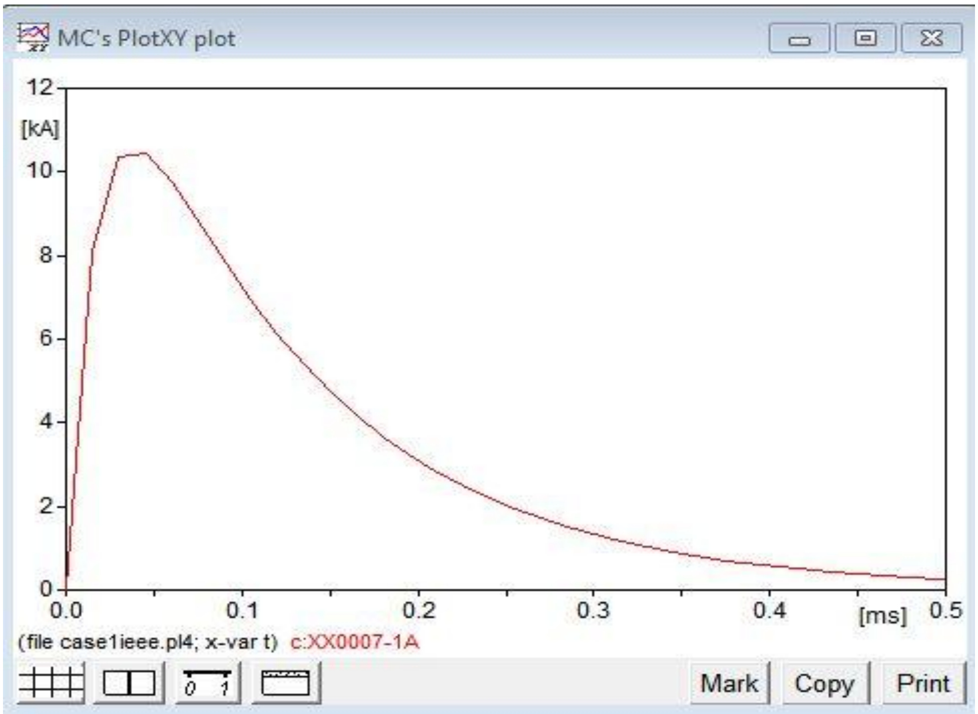


Figure 2: The first lightning stroke (10 kA, 0.6ms)

Table 2: The surge function values for 10 kA

Amplitude [A]	**A [ ]**	**B [ ]**	**T-start [s]**	**T-stop [s]**
15000	-8500	-60000	0	0.0006

Type-13 ramp functions model used for second and third stroke magnitude of 5 kA and 3 kA respectively with duration of 0.3ms. Table 3 listed the values which are required to generate ramp function. Lighting flash simulated in ATP Draw shown in Figure 3.[1]

Table 3: The 5 kA and 3 kA ramp function values.

Stroke	**1**	**2**
Amplitude in A	5000	3000
T_0 in sec	0	0
A_1	0	0
T_1 in sec	0.0003	0.0003
T-start in sec	0.06	0.12
T-stop in sec	0.0603	0.1203

Figure 3: The lightning flash as simulated in ATP-Draw.

V. SURGE ARRESTER CHARACTERISTICS

MOV-Type 92 component model represents lighting arrester [1]. In our test system we used Crompton Greaves ZLA2007 Surge arrester, with heavy duty distribution class, tested and design according to IEC 60099-4. High current impulse and operating duty test used to prove thermal stability of metal oxide surge arrester. Table 4 shows the characteristics which were taken from manufacturer data [32].

Table 4: Crompton Greaves ZLA2007 Arrester characteristics

Max. continuous operating voltage U_c (kVcrest)	7.65				
Rated Voltage Ur kV (rms)	9				
Residual voltage (U_{res}) in kV(crest) at specified discharge current (crest) wave 8/20 µs	1.5 kA	2.5 kA	5 kA	10 kA	20 kA
	21.5	22.5	23.2	24.5	27.4

In this chapter analysis & study of three cases are done;

1. When lightning strikes at 132/11 kV substation secondary side on phase A.

2. When lightning strikes on the phase A around 30.04 km far away from secondary side of transformer at 132/11 kV substation.

3. When lightning strikes at the end of main transmission line1on phase A.

In all the three cases simulation of all the three models i.e. IEEE, Pinceti and Fernandez and Diaz model are done and the results of all the three are compared at different points in each cases.

VI. CALCULATION FOR THE MOV BLOCK IN DIFFERENT MODELS

Selected current was chosen from non-linear resistor V-I characteristics point with reading of IR in per-unit (p.u). Then, this value was multiplied with (V_{10} /1.6) to calculate the discharge voltage of the arrester. Conversion from p.u to actual voltage can be done by following formula (6.1,6.2) is shown in table 5 show nonlinear V-I characteristic in the ATP-EMTP software.

For A0, voltage kV= (Voltage in p.u) *(V_{10} /1.6) (2)

Same with A1, voltage kV= (Voltage in p.u*(V_{10} /1.6) (3)

Table 5 Voltage Current (V-I) values for nonlinear resistor A0 and A1 in IEEE, Pinceti and Fernandez & Diaz model

Curve A0			Curve A1		
I (kA)	**V (PU)**	**V (kV)**	**I (kA)**	**V (PU)**	**V (kV)**
0.01	**1.40**	**21.437**	**0.1**	**1.23**	**18.83**
0.1	**1.54**	**23.881**	**1**	**1.36**	**20.82**
1	**1.67**	**25.571**	**2**	**1.43**	**21.89**
2	**1.74**	**26.643**	**4**	**1.47**	**22.50**
4	**1.70**	**26.031**	**6**	**1.50**	**22.96**
6	**1.72**	**26.337**	**7**	**1.53**	**23.42**
7	**1.77**	**27.101**	**10**	**1.55**	**23.73**
10	**1.90**	**29.093**	**12**	**1.56**	**23.88**
12	**1.93**	**29.550**	**14**	**1.57**	**24.04**
14	**1.97**	**30.160**	**16**	**1.59**	**24.34**
16	**2.00**	**30.625**	**17**	**1.60**	**24.50**
17	**2.05**	**31.390**	**20**	**1.61**	**24.65**
20	**2.10**	**32.156**			

Table 6 Parameters of each model

Model	**L0(µH)**	**L1(µH)**	**R0(Ω)**	**R1(Ω)**	**C(pF)**
IEEE	0.094	7.05	47	30.55	212.76
Pinceti	0.088	0.266	100000	30.55	-
Fernandez and Diaz	-	0.808	100000	-	0.0360

VII. SIMULATION MODEL OF IEEE PINCETI AND FERNANDEZ DIAZ MODEL FOR CASE I

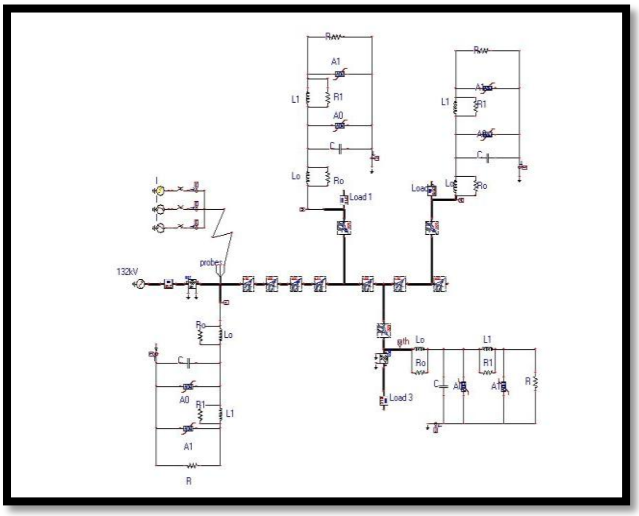


Figure 4 Simulation model when lightning strikes at at transformer for IEEE model

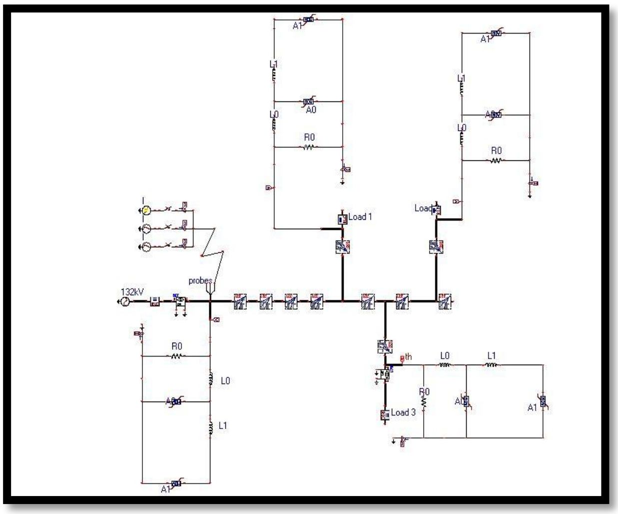


Figure 5 Simulation model when lightning strikes transformer for Pinceti model

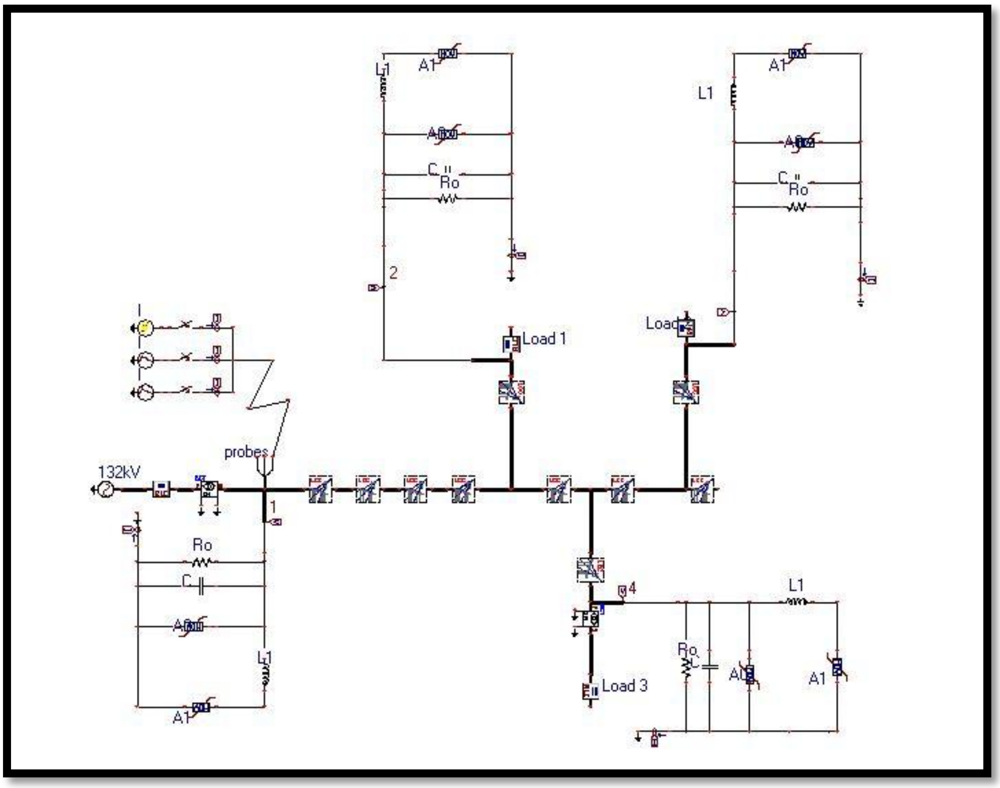


Figure 6 Simulation model when lightning strikes at transformer for Fernandez and Diaz model

VIII. SIMULATION MODEL OF IEEE PINCETI AND FERNANDEZ DIAZ MODEL FOR CASE II

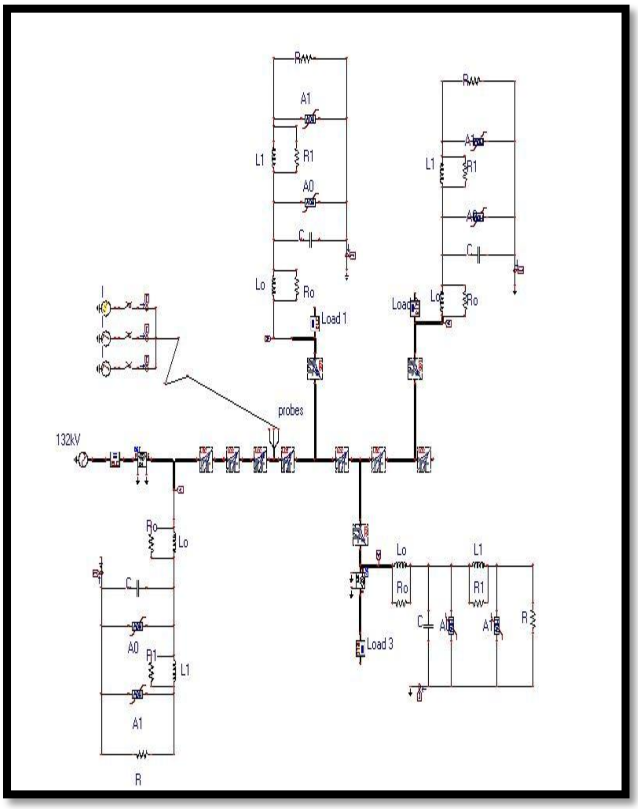


Figure 7 Simulation model when lightning strikes midpoint for IEEE model

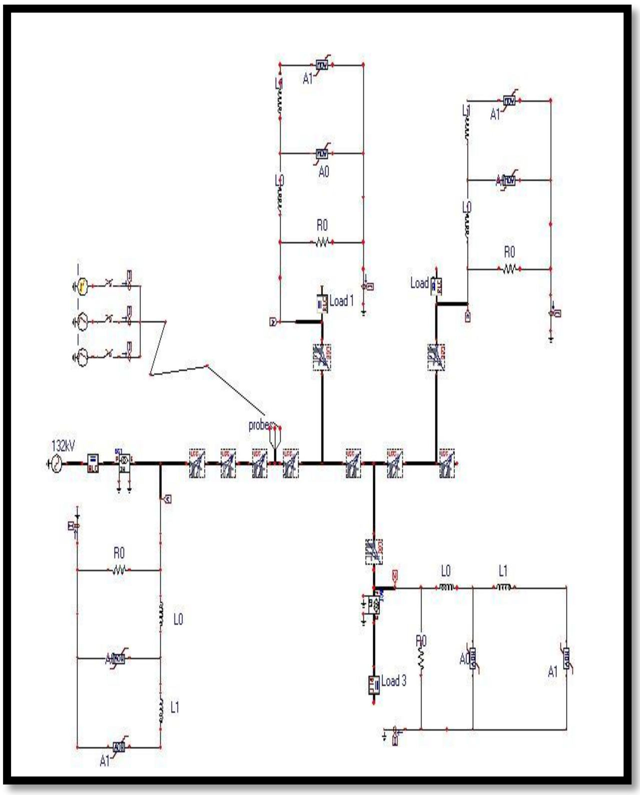


Figure 8 Simulation model when lightning at strikes at midpoint for Pinceti model

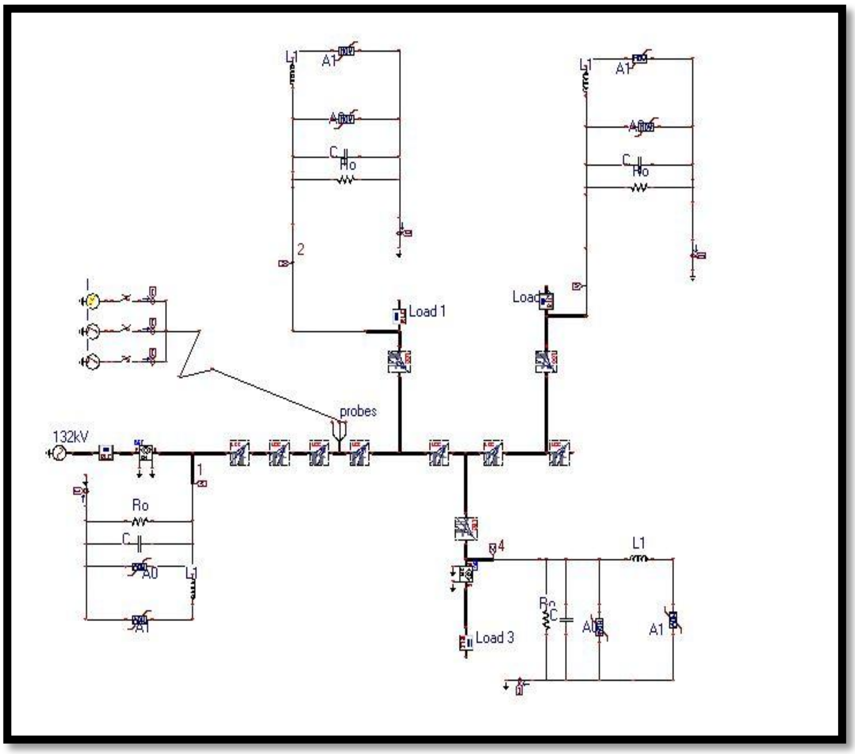
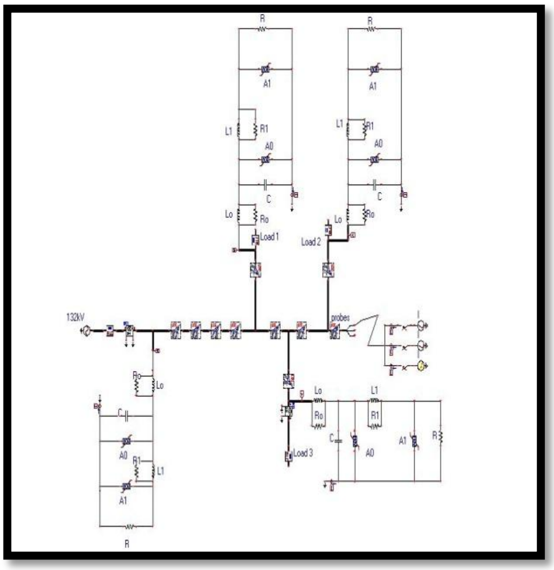


Figure 9 Simulation model when lightning strikes At midpoint for Fernandez and Diaz model

IX. SIMULATION MODEL OF IEEE PINCETI AND FERNANDEZ DIAZ MODEL FOR CASE III



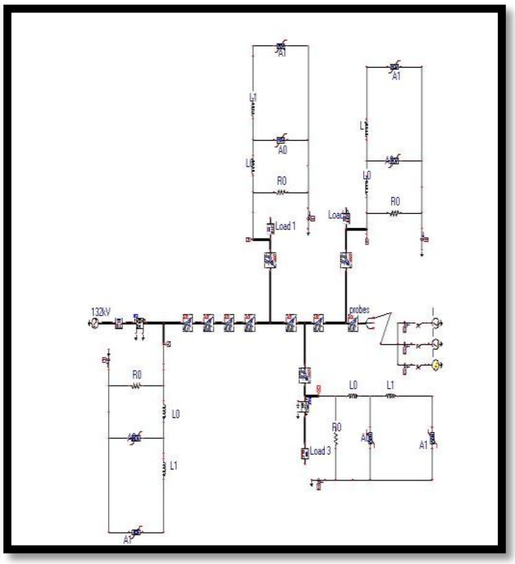


Figure 6 Simulation model when lightning of strikes at end of transmission line for IEEE model

Figure 7 Simulation model when lightning strikes at end strikes at end of transmission line for Pinceti model

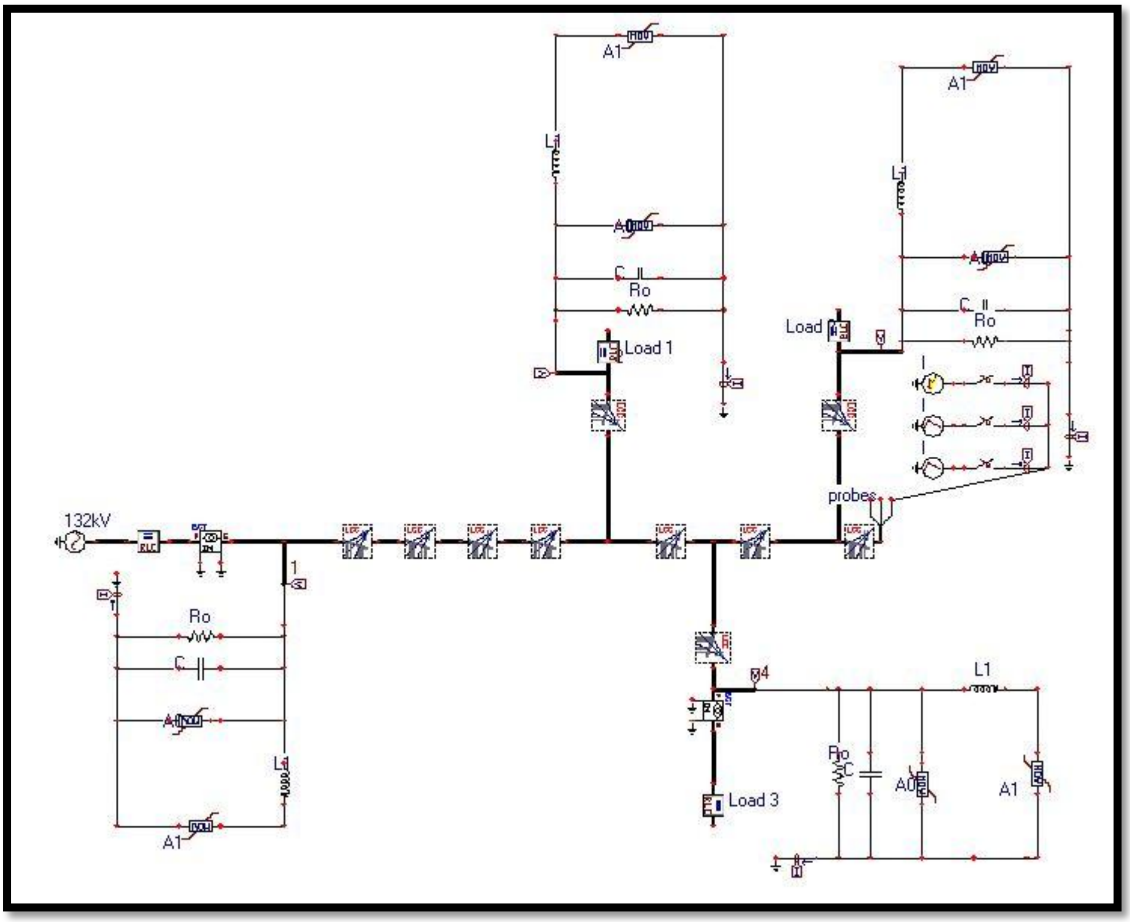


Figure 8 Simulation model when lightning strikes at end of transmission line for Fernandez and Diaz model

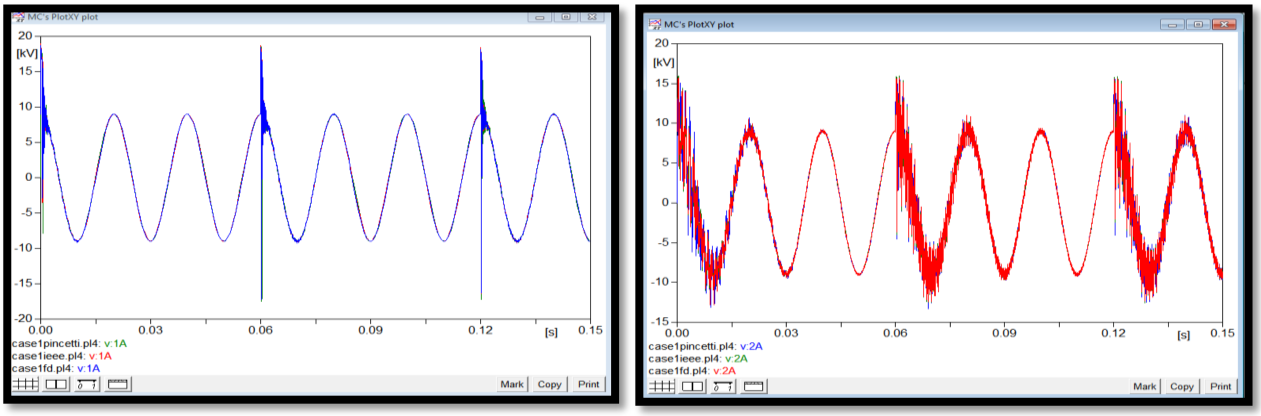


Fig 9&10 Residual Voltage of IEEE Pinceti and Fernandez and Diaz near transformer &near Load 1

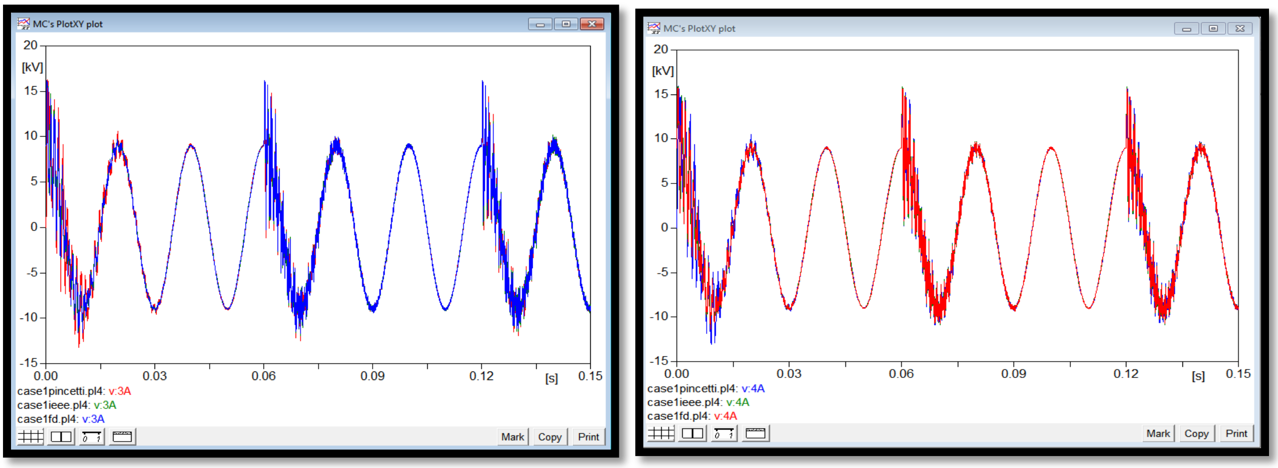


Fig 11&12 Residual Voltage of IEEE Pinceti and Fernandez and Diaz near Load 2 & near Load 3

X. SIMULATION COMPARISON OF IEEE PINCETI AND FERNANDEZ DIAZ FOR CASE II

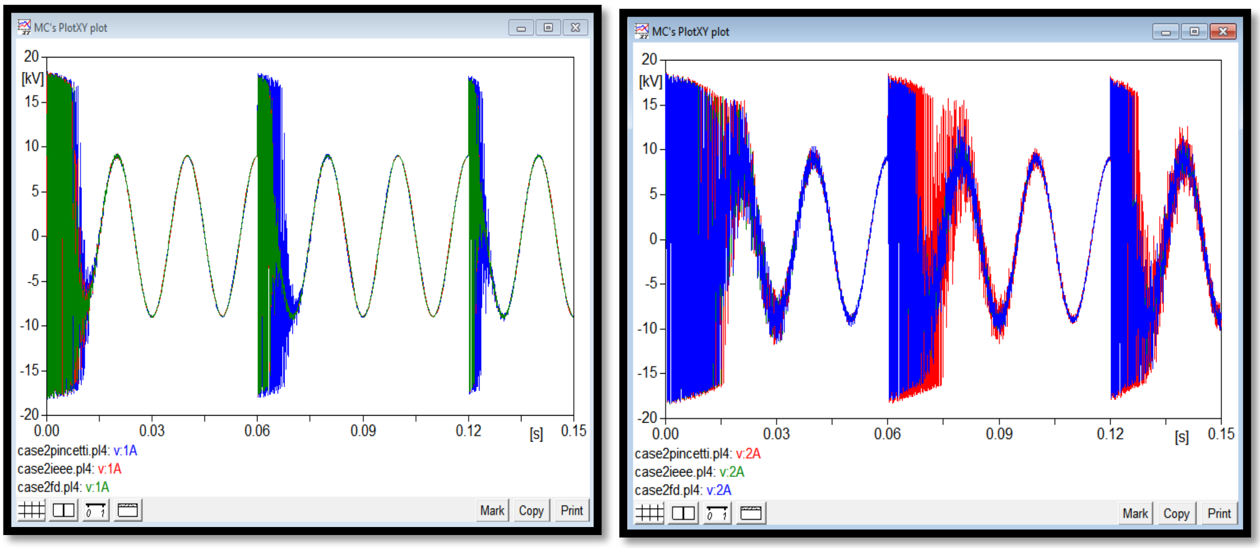


Fig 13&14 Residual Voltage of IEEE Pinceti and Fernandez and Diaz near transformer& near Load 1

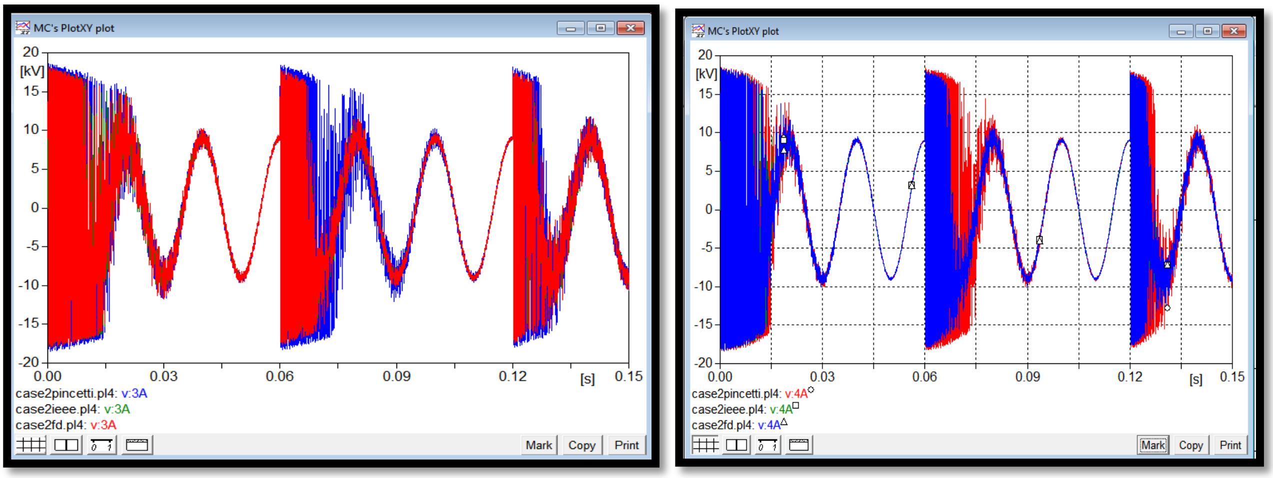


Figure 14&15 Residual Voltage of IEEE Pinceti and Fernandez and Diaz near Load 2 & near Load 3

XI. SIMULATION COMPARISON OF IEEE PINCETI AND FERNANDEZ DIAZ FOR CASE III

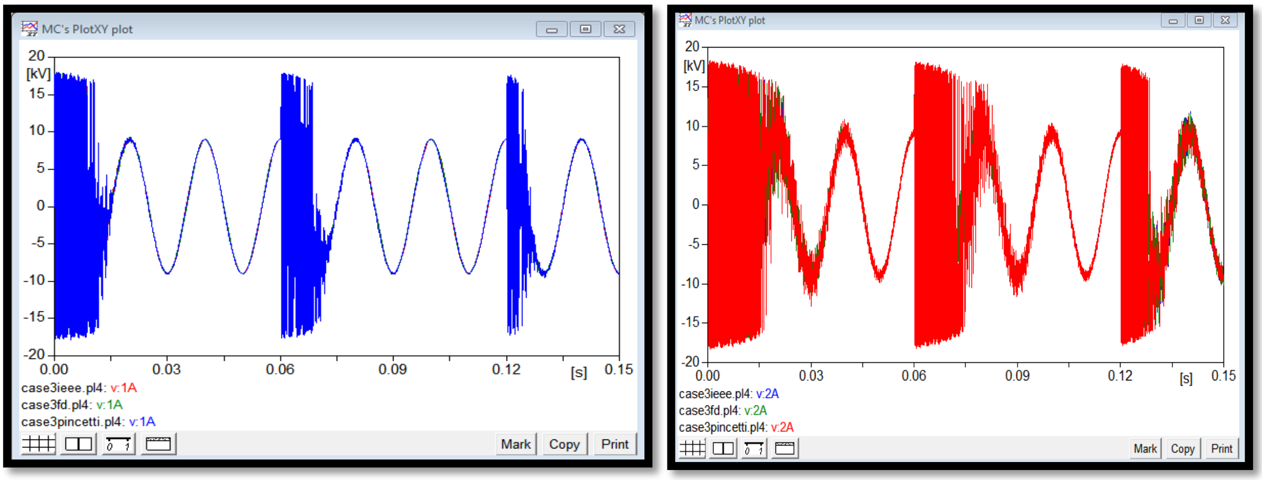


Fig 16&17 Residual Voltage of IEEE Pinceti and Fernandez and Diaz near transformer & near Load 1

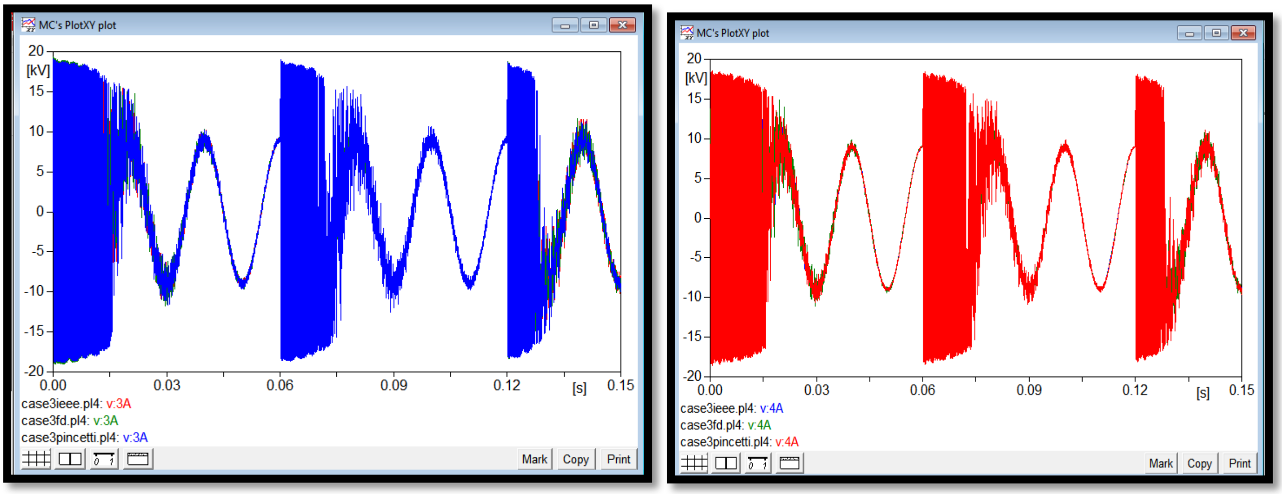


Fig 18&19 Residual Voltage of IEEE Pinceti and Fernandez and Diaz near Load 2 & near Load 3

XII. COMPARISON OF THE RESULTS FOR CASE I, II, III FOR DIFFERENT MODELS

Table 7 Comparison of residual voltages of three models for case I at different points

MODEL	Secondary side of transform(kV)	At Load 1 (kV)	At Load 2 (kV)	At Load 3 (kV)
IEEE	19.10	16.00	15.97	15.91
Pinceti	18.87	15.9	16.28	15.92
Fernandez and Diaz	18.71	15.71	16.21	15.72

Table 8 Comparison of residual voltages of three models for case II at different points

MODEL	Secondary side of transform(kV)	At Load 1 (kV)	At Load 2 (kV)	At Load 3 (kV)
IEEE	18.31	18.57	18.16	18.43
Pinceti	18.38	18.64	18.23	18.50
Fernandez and Diaz	18.18	18.53	18.14	18.40

Table 9 Comparison of residual voltages of three models for case III at different points

MODEL	Secondary side of transform(kV)	At Load 1 (kV)	At Load 2 (kV)	At Load 3 (kV)
IEEE	17.80	18.21	19.07	18.45
Pinceti	17.92`	18.29	19.14	18.53
Fernandez and Diaz	17.89	18.21	19.38	18.42

XIII. CONCLUSION

From the figure 9 to 19 we can conclude that if lightning strikes at the secondary side of the transformer then the system stabilizes in less time as compared to the other cases in which lightning strikes at midpoint and at the end of the transmission line. When the lightning strikes at the end of the transmission line then it causes adverse effect on the system and it takes time to stabilize the system. The dynamic behavior of the surge arrester is tested and all the models show fairly good results. All simulated models seem to be efficient and produce almost same residual voltage for the multiple lightning stroke.

XIV FUTURE SCOPE

Simulation of the model with lightning stroke of single stroke and with different intensity and wave front is to be done. Analysis of the quenching time is to be done and the comparison of all the models will be done and will deduce that which model is best for the testing of dynamic behavior of surge arrester.

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