INVESTIGATION OF LIGHTNING PERFORMANCE ON TRANSMISSION LINES

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Abstract— **This study presents a comparative of lightning performance study conducted on transmission lines by using Electromagnetic Transient Program that is Power System Computer Aided Design (PSCAD) software. The line performance is investigated by injecting the surge current to the transmission line acting as a direct strike from lightning to a line phase conductor. In order to improve the lightning performance of the line, Metal Oxide Surge Arresters (MOSA) is introduced using different voltage rating based on the Typical Arrester Ratings for System Voltages Table. Results are investigated and the influence of arrester voltage rating to transmission lines metal oxide surge arrester at different conductor tower of transmission line is discussed. Findings from this investigation can be significant as a modeling guideline to the transmission line designers or other researchers to improve the performance of transmission line in term of reducing the rate of switching surge overvoltage by implementing suitable arrester voltage rating to their system.**

Keywords-Ligtning performance, PSCAD, Metal Oxide Surge Arrester, Arrester Voltage Rating.

I. INTRODUCTION

Lightning is one of the natural occurrence phenomenon's that cannot predict and stop when it was happen. Lightning is an electric discharge between cloud and earth or between the charge centers of the same cloud [1].

Lightning is a major cause of overhead line faults. It has been a problem since the earliest day of electricity supply industry. "Between" 5% to 10% of the lightning caused fault are thought to result in permanent damage to power system equipment. Therefore, the investigation of lightning performance is fundamental when designing new lines and for up rating existing lines to higher voltage [2].

Metal oxide surge arrester is one of the mitigation techniques that can be used to mitigate lightning surge overvoltage on transmission lines. The objective of the arrester application is to select the lowest rated surge arrester which will provide adequate overall protection of the equipment insulation and have a satisfactory service life when connected to the power system [3]. The arrester with the minimum rating is preferred because it provides the greatest margin of protection for the insulation. A higher rated arrester increases the ability of the arrester to survive on the power system, but reduces the protective margin it provides for a specific insulation level. Both arrester survival and equipment protection must be considered in arrester selection. By the way, it is difficult to select the most suitable arrester voltage rating that can be implemented to the system.

Modeling of ±500kV transmission system has been developed by using PSCAD/EMTDC software packages in the paper and the lightning performance has been discussed to identify the lower of the arrester voltage rating that will gives the lower the discharge voltage, and the better the protection of the insulation system .

II. SURGE ARRESTER PARAMETERS

A. *Types of Surge Arrester*

Originally, there were three types of surge arresters which are Expulsion Type, Nonlinear Resistor Type with gaps (currently silicone-carbide gap type) and Gapless Metal-Oxide Type. One of the three types noted above, the expulsion types are no longer being used. The nonlinear resistor type with gaps was utilized through the middle of the 1970s and is currently being phased out. The conventional gap type with silicone-carbide blocks/discs are still being used and the gapless metal-oxide type are the most widely used today [3].

B. *Classification of Surge Arrester*

There are four classification of surge arrester which is Station Class, Intermediate Class, Distribution Class (Heavy, Normal and Light Duty) and Secondary Class. With respect to the four classes of surge arresters, the station class surge arrester is the best because of its cost and overall protective quality and durability. It has the lowest (best) available protection level and energy discharging capability with successively higher (poorer) protection levels for the other classifications. As noted above, the distribution class has several duty ratings, which are dependent upon the test severity. Heavy-duty arresters are more durable and have lower protective characteristics. The housing/enclosure construction of surge arresters can be of either polymer or porcelain [3]. Gapless metal-oxide surge arrester (MOSA) is the main focus in this paper due to the best performance and reliability that it can provide.

C. *Arrester Selection*

The proper selection and application of lightning arresters in a system involve decisions in three areas which are:

i. Selecting the arrester voltage rating. This decision is based on whether or not the system is grounded and the method of system grounding.
ii. Selecting the class of arrester which are describing in above.
iii. Determine where the arrester should be physically located [3].

D. *Arrester Voltage Rating*

The lower the arrester voltage rating will gives the lower the discharge voltage, and the better the protection of the insulation system. The challenge of selecting the arrester voltage rating is primarily one of determining the maximum sustained line-to-ground voltage that can occur at a given system location .This maximum sustained voltage to ground is usually considered to be the maximum voltage on the unfaulted phases during a single line-to-ground fault. Hence, the appropriate arrester ratings are dependent upon the manner of system grounding.

Table 1 shows the lists of arrester ratings that would normally be applied on systems of various line-to-line voltages. The rating of the arrester is defined as the RMS voltage at which the arrester passes the duty cycle test as defined by the referenced standard [3].

Table 1: Typical Arrester Ratings for System Voltages [3].

Table 1 Typical Arrester Ratings for System Voltages					
	Arrester Rating (kV)			Arrester Rating (kV)	
Nominal Sytem L-L Voltage (kV)	Grounded Neutral Circuits	High Impedance Grounded, Ungrounded, or Temporarily Ungrounded	Nominal System L-L Voltage (kV)	Grounded Neutral Circuits	High Impedance Grounded, Ungrounded, or Temporarily Ungrounded
2.4	2.7	3.0	69	54	--
				60	--
4.16	3.0	--		--	66
	4.5	4.5		--	72
		5.1	115	90	--
4.8	4.5	--		96	--
	5.1	5.1		108	108
	--	6.0		--	120
			138	108	--
6.9	6.0	--		120	--
	--	7.5		--	132
	--	8.5		--	144
12.47	9.0	--	161	120	--
	10	--		132	--
	--	12		144	144
	--	15		--	168
13.2,13.8	10	--	230	172	--
	12	--		180	--
	--	15		192	--
	--	18		--	228
23, 24.94	18	--		--	240
	21	--	345	258	--
	24	24		264	--
	--	27		276	--
34.5	27	--		288	288
	30	--		294	294
	--	36		300	300
	--	39		312	312
46	39	--	400	300	--
	--	48		312	--
				336	--
				360	--

III. MODELLING DEVELOPMENT

To carry out the study, PSCAD version 4.2 is used to model the transmission lines, surge arresters and surge characteristics.

A. *Overhead Transmission Lines*

Overhead Transmission Lines is modeled using Frequency Dependent (Phase) Model which uses curve fitting to duplicate the frequency response of a line. It is the most advanced time domain model available as it represents the full frequency dependence of all parameters (including the effect of a frequency dependent transform).

B. *Tower Model*

Tower is modeled by using several segments of single conductor distributed parameter model or Bergeron model .The surge impedance of the transmission line tower and the tower travel time of wave propagation down the tower are required. For each case of tower structures, the travel time from top to ground can be estimated using equation (1) [4].

$$\tau = \frac{h}{c} \qquad (1)$$

Where h is height of the tower, m and c is the speed of light, $3 \times 10^{8}\ ms^{-1}$

C. *Lightning Model*

Lightning strokes is represented by a current sources of negative polarity which includes steepness. In this model, the steepness and front time increase as the peak current increases.

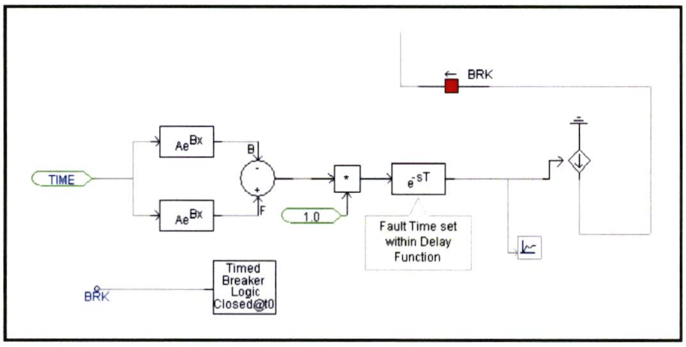

Figure 1: Module of lightning current

D. *Surge Arrester Model*

Metal oxide surge arresters (MOSA) are widely used as a protective device against switching and lightning overvoltage in power electrical systems. Surge arrester is defined as a protective device for limiting surge voltages by discharging or bypassing surge current, and it also prevents the flow of lightning current while remaining capable of repeating these functions.

A simplified lightning model for distribution-class metal oxide surge arrester is derived from the IEEE Working Group (WG) 3.4.11(1992) and the effectiveness of the model was tested and compared with the residual voltage test results for typical lightning surges of 8/20ms. The selected model of surge arrester is constructed as recommended by IEEE. This model includes two non-linear resistances which are A0 and A1 as shown in Figure 2. These resistances are separated by an R-L filter [5].

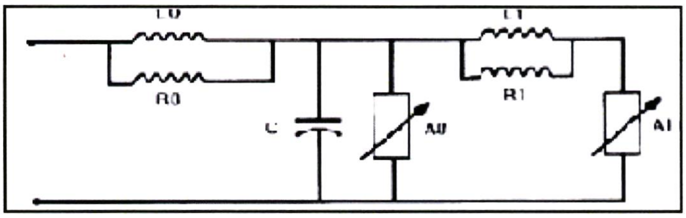

Figure 2: IEEE Frequency Dependent Surge Arrester Model [5]

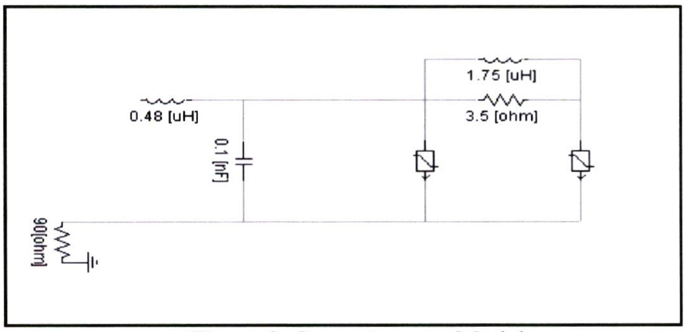

Figure 3: Surge Arrester Model

E. Total Harmonic Distortion Model

The total harmonic distortion (THD), of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. In this research, THD Model is one of the important measurement in term of investigate the most accurate arrester voltage rating for the system.

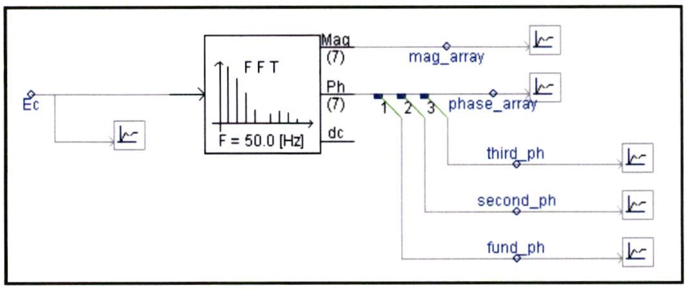

Figure 4: THD Model

For applications in the high voltage transmission lines, the general system limits are most appropriate. This means that the design of MOSA model should be less < 5% VTHD and with no single harmonic greater than 3%. These generally will be met at the PCC provided the current harmonic limits are met [6].

Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user

Figure 5: Voltage Distortion Limits [6]

Table 10.2, p77
Low-Voltage System Classification and Distortion Limits

	Special Applications[1]	General System	Dedicated System[2]
Notch Depth	10%	20%	50%
THD (voltage)	**3%**	**5%**	10%
Notch Area (A_N)[3]	16 400	22 800	36 500

NOTE: The Value A_N for other than 480 V systems should be multiplied by V/480

1 **Special applications include hospitals and airports**

2 A dedicated system is exclusively dedicated to the converter load

3 In volt-microseconds at rated voltage and current

Figure 6: IEEE STD 519 [6]

IV. RESULTS AND DISCUSSION

The circuit is consisting of Overhead Transmission Lines, Transmission Tower, Lightning Model, and Load. The simulation is done when the current of lightning, 80kA is injected to the transmission tower, and the output, Ec will produce.

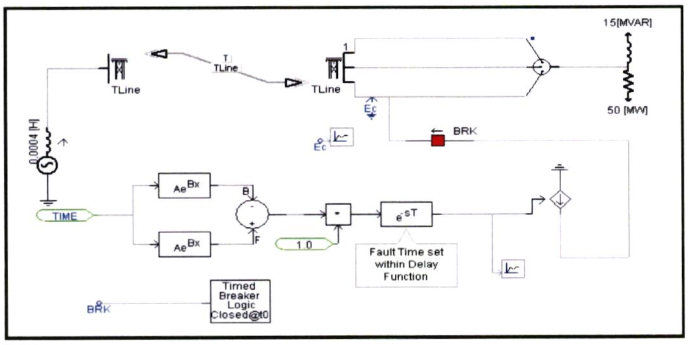

Figure 7.0: Schematic Diagram Without insertion MOSA

The output, EC produces:

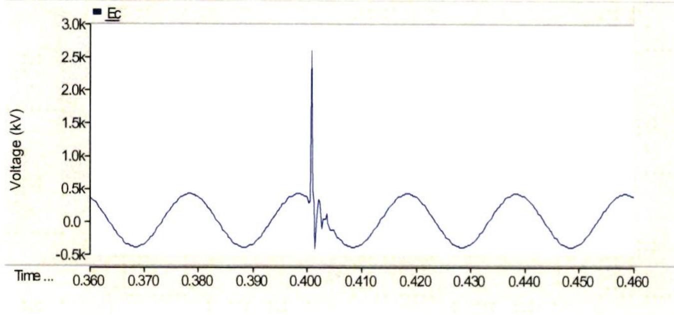

Figure 7.1: Without insertion MOSA

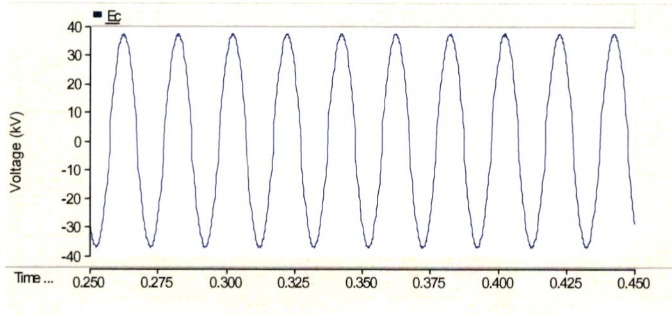

Figure 8.1: With insertion MOSA

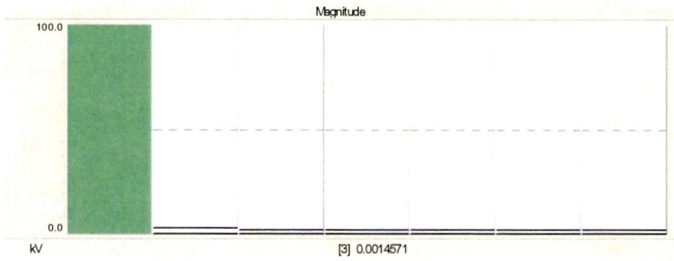

Figure 7.2: FFT Diagram for without insertion MOSA

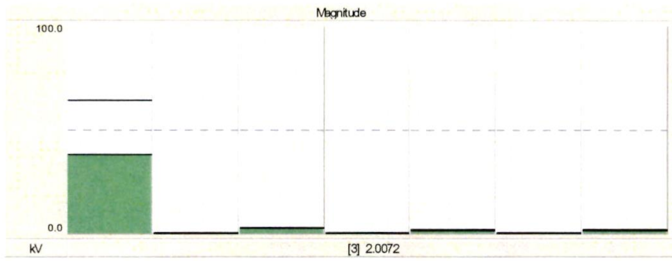

Figure 8.2: FFT Diagram for with insertion MOSA

The switching surge overvoltage occurs very high when the MOSA is not installed in the circuit.

The simulation is continued by applying the Metal Oxide Surge Arrester (MOSA) Model with the lowest arrester voltage rating from the Table 1 which is 2.4kV, 5.7Ω to the schematic diagram.

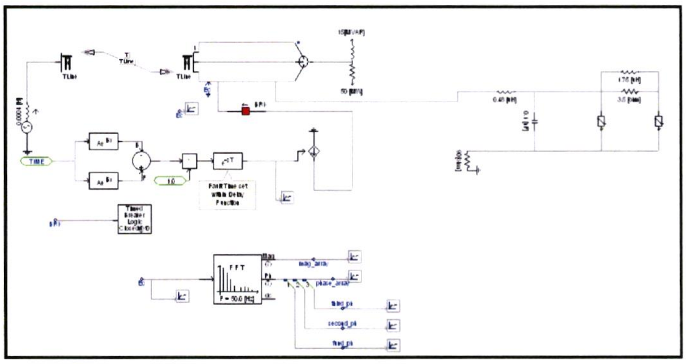

Figure 8.0: Schematic Diagram With insertion MOSA

The output, Ec produces:

With insertion MOSA, the switching surge overvoltage is extremely reduced as compared to the switching surge overvoltage experienced without insertion MOSA. So, it proven that the installed of MOSA is the most suitable mitigation technique in term of reducing the switching surge overvoltage. Below is the result when the different arrester voltage rating has been applied to the MOSA model.

A. The result when the different arrester voltage rating applied to the ±500kV system with one of the conductor tower has been connected to the surge arrester model.

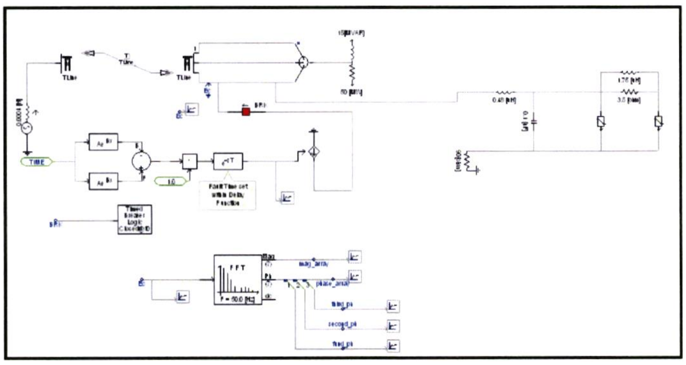

Figure 9.0: Schematic Diagram With one conductor connected to MOSA model

i. 400kV with 300Ω grounded system

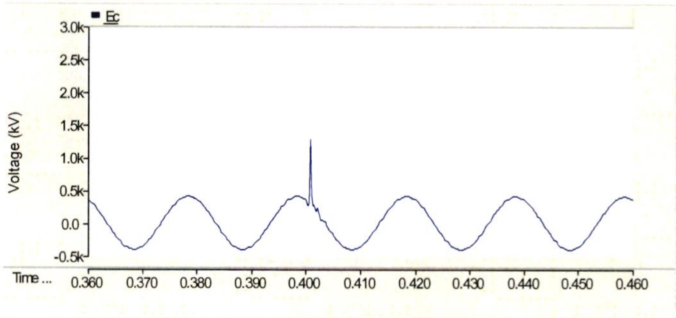

Figure 9.1: Output Ec produced by 400kV with 300Ω grounded system

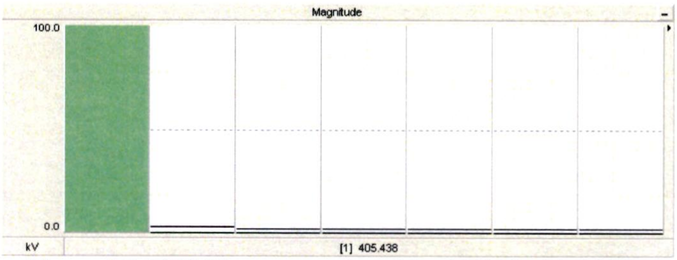

Figure 9.2: FFT Diagram produced by 400kV with 300Ω grounded system

ii. 345kV with 258Ω grounded system

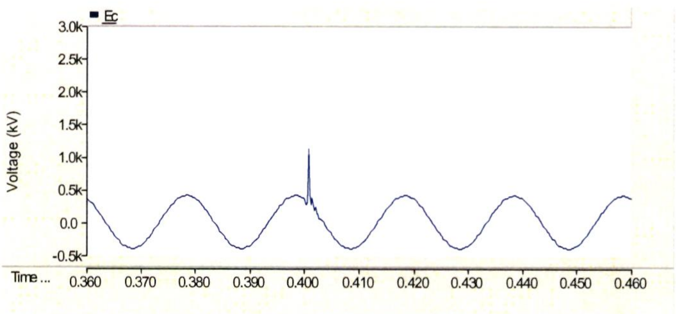

Figure 9.3: Output Ec produced by 345kV with 258Ω grounded system

iii. 230kV with 172Ω grounded system

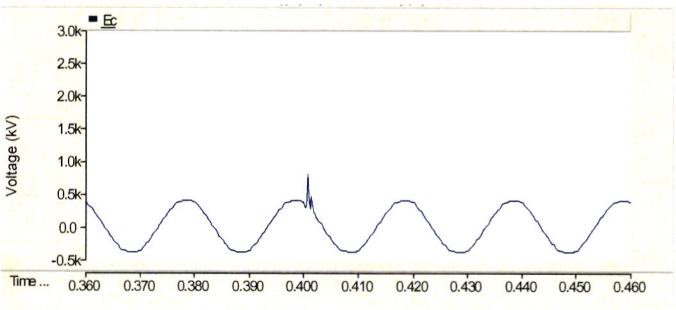

Figure 9.4: Output Ec produced by 230kV with 172Ω grounded system

iv. 161kV with 120Ω grounded system

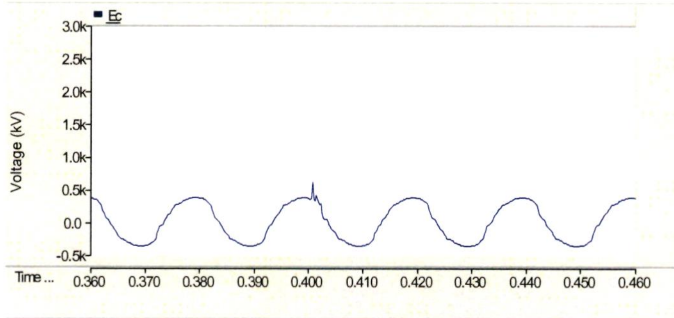

Figure 9.5: Output Ec produced by 161kV with 120Ω grounded system

v. 138kV with 108Ω grounded system

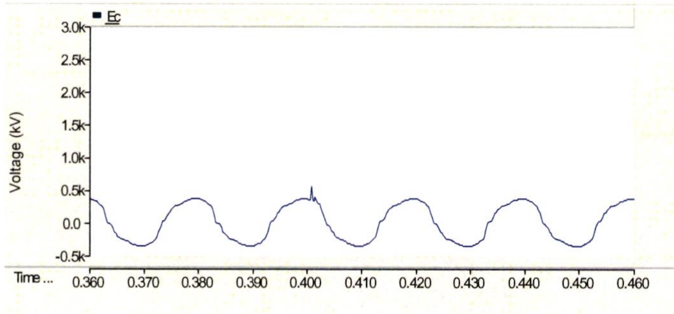

Figure 9.6: Output Ec produced by 138kV with 108Ω grounded system

vi. 115kV with 90Ω grounded system

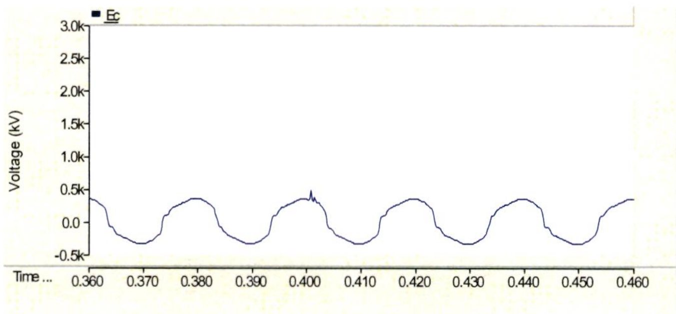

Figure 9.7: Output Ec produced by 115kV with 90Ω grounded system

From the waveform, it shows that the switching surge overvoltage reduced when the lower arrester rating voltage applied to the ±500kV system.

Table 2: Percentages of Reduction and THD Table.

Arrester Voltage Rating(kV,Ω)	Percentages of Reduction (%)	THD (%)
400kV,300Ω	50.76	0.003
345kV,258Ω	56.30	0.025
230kV,172Ω	69.26	2.560
161kV,120Ω	76.76	9.861
138kV,108Ω	78.70	13.970
115kV,90Ω	81.17	20.240

From Table 2, it shows that the highest arrester voltage rating 400kV, 300Ω grounded system gives the lowest value percentages of reduction but it is too small of reduction even though the THD value is less < 5% so the rating is not suitable. While the lower arrester voltage rating 115kV, 90Ω grounded system gives the highest value percentages of reduction and THD but the value of THD is more than >5%, so it is also not suitable. From this it can be conclude that the most suitable arrester voltage rating for ±500kV transmission lines system is 230kV,172Ω grounded system due to the higher percentages of reduction and the less from <5% of THD.

B. The result when the different arrester voltage rating applied to the ±500kV system with the entire conductor tower has been connected to the surge arrester model.

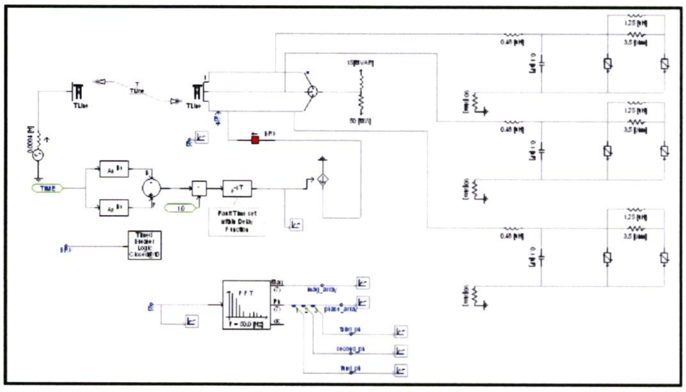

Figure 10.0: Schematic Diagram With the entire conductor connected to MOSA model

i. 400kV with 300Ω grounded system

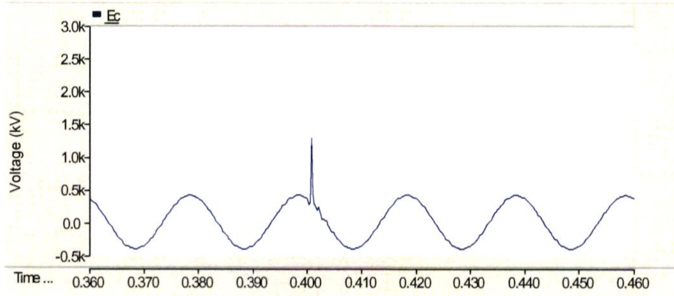

Figure 10.1: Output Ec produced by 400kV with 300Ω grounded system

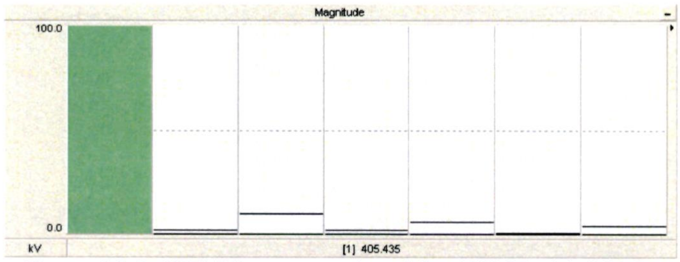

Figure 10.2: FFT Diagram produced by 400kV with 300Ω grounded system

ii. 345kV with 258Ω grounded system

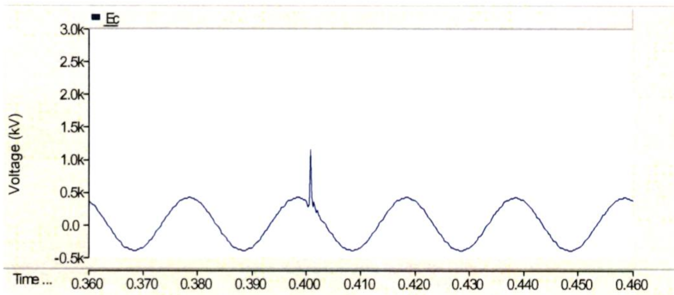

Figure 10.3: Output Ec produced by 345kV with 258Ω grounded system

iii. 230kV with 172Ω grounded system

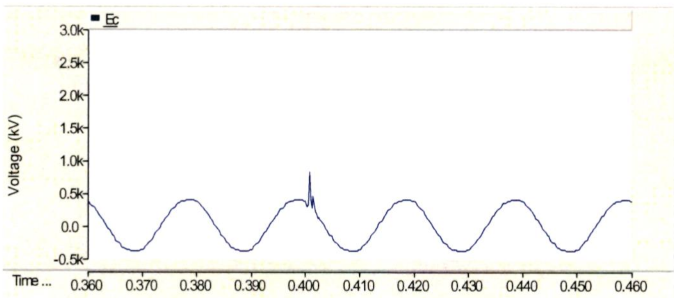

Figure 10.4: Output Ec produced by 230kV with 172Ω grounded system

iv. 161kV with 120Ω grounded system

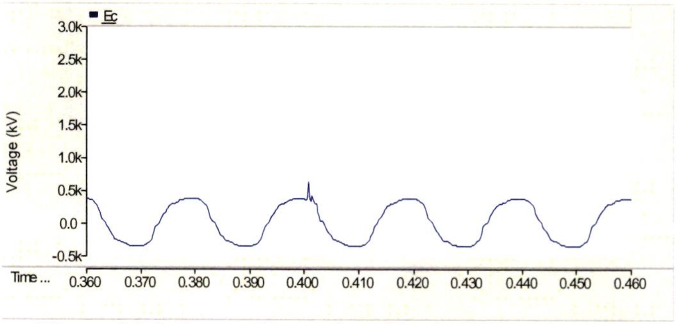

Figure 10.5: Output Ec produced by 161kV with 120Ω grounded system

v. 138kV with 108Ω grounded system

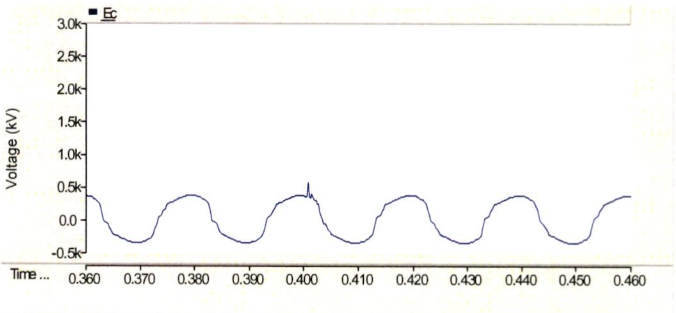

Figure 10.6: Output Ec produced by 138kV with 108Ω grounded system

vi. 115kV with 90Ω grounded system

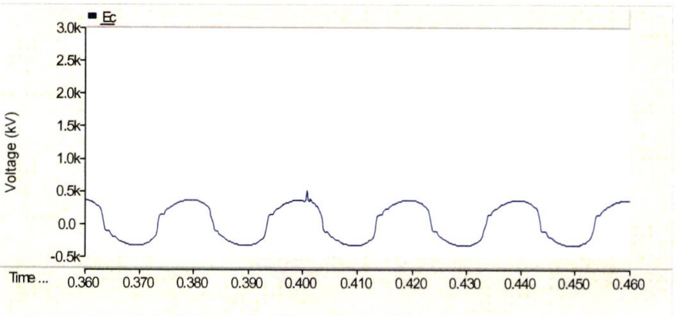

Figure 10.7: Output Ec produced by 115kV with 90Ω grounded system

From the waveform, it still shows that the switching surge overvoltage reduced when the lower arrester rating voltage applied to the ±500kV system but the calculation of Total Harmonic Distortion was increased as the arrester voltage rating is lower.

Table 3: Percentages of Reduction and THD Table

Arrester Voltage Rating(kV,Ω)	Percentages of Reduction (%)	THD (%)
400kV,300Ω	50.55	0.004
345kV,258Ω	56.01	0.029
230kV,172Ω	68.53	2.510
161kV,120Ω	76.01	12.050
138kV,108Ω	77.96	17.620
115kV,90Ω	80.49	22.390

From Table 3, it still shows that the highest arrester voltage rating 400kV, 300Ω grounded system gives the lowest value percentages of reduction but it is too small of reduction even though the THD value is less < 5% so the rating is not suitable. While the lower arrester voltage rating 115kV, 90Ω grounded system gives the highest value percentages of reduction and THD but the value of THD is more than >5%, so it is also not suitable. From this it can be conclude that the most suitable arrester voltage rating for ±500kV transmission lines system with the entire conductor tower connected to the MOSA is still 230kV,172Ω grounded system due to the higher percentages of reduction and the less from <5% of THD.

V. CONCLUSION

The proper selection of the arrester voltage rating is an extremely important parameter in reducing the switching surge overvoltage. The lower the arrester voltage rating will give the lower the discharge voltage and the better the protection of the insulation system. From the results discussed above, it shows that when the lower arrester voltage rating applied to the ±500kV system the peak of the switching surge voltage has been reduced but the percentages of THD is increased more than > 5%. So, it is not suitable because the rating is more than IEEE limits which is should be less than <5%. However, the most appropriate arrester voltage rating that can be applied to the ±500kV transmission lines system is 230kV with 172Ω grounded system due to the best performance that has been shown above in term of higher percentages of reduction and lower percentages of THD for both of one and entire conductor tower connected to the Metal Oxide Surge Arrester (MOSA) model.

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