Transient Overvoltage Suppression Techniques against Lightning

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Abstract—**This paper presents transient overvoltage suppression techniques against lightning at UiTM Shah Alam. It involved the development of a simulator model that can be used to analyze several transient overvoltage mitigation techniques. Power system computer aided design (PSCAD) software is used as it is user friendly and efficient in conduct power system simulations. This project used metal oxide surge arrester (MOSA) to mitigate the effect due to lightning strikes. The effect is mitigated by using three types of (MOSA) model, which are IEEE, Pincenti Giannettoni and Fernandez Diaz models. Using PSCAD software, the performance of the MOSA models were evaluated and compared. It was found that IEEE model can reduce the transient overvoltage better than Picenti Giannettoni, and Fernandez Diaz models.**

Keywords-Metal Oxide Surge Arrester (MOSA), Power System Computer Aided Design(PSCAD), transient overvoltage.

I. INTRODUCTION

The phenomenon of lightning has been the subject of intensity study by many people. The consequences and the behavior of lightning are unpredictable but in general term it is fairly predictable. Lightning is an electrical discharge in the air between the clouds; it is carried by warm air rising into a developing cloud. Discharge may occur from cloud to cloud or from cloud to ground [1]. Four type of lightning illustrated in Figure 1 [2].

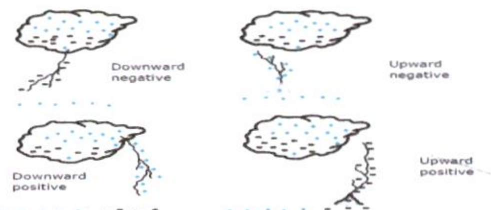

Figure 1. Four types of lightning.

Lightning can strike directly to the phase conductors of overhead power lines. Lightning also can strike the overhead earth wire (shielded wire) that is sometimes installed above the phase conductors to protect them from a direct lightning strike.

When lightning strike the electricity distribution system, surge current is generated and conducted through power system into the facilities. Large impulsive transient overvoltage is produced due to this surge current.

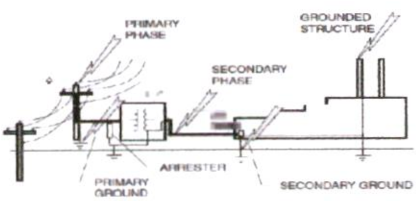

Figure 2. Lightning strikes in power line system.

The Institute of Electrical and Electronics Engineers (IEEE) Standard 1313.1-1996 defines transient overvoltage as "a short-duration highly damped, oscillatory or non oscillatory overvoltage, having duration of a few milliseconds or less [3]. Voltage transients normally last only about 50 microseconds and current transients last typically 20 microseconds [4].

An impulsive transient is a sudden change in the steady state condition of voltage, current or both, that is unidirectional in polarity, either positive or negative [5]. Standard lightning impulse voltage specifies a rise time of 1.2 microseconds and decay to half the peak value in 50 microseconds [5]. Figure 3 illustrated impulsive transient caused by lightning.

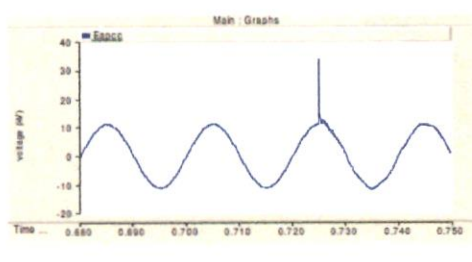

Figure 3. Example impulsive transient due to lightning.

The appropriate mitigation technique is important in order to mitigate the impulsive transient overvoltage. Metal oxide surge arresters (MOSA) are widely used as protective devices against switching and lightning overvoltage in power electrical systems [6]. The main function of surge arrester is to limit the voltage that can appear between two points in the circuit [7]. Three types of circuit that represent metal oxide surge arrester in this project are circuit proposed by IEEE, Picenti Giannettoni, and Fernandez Diaz.

This paper present the mitigation technique for transient overvoltage based on metal oxide surge arrester .In order to determine the best metal oxide surge arrester model, the simulation was done using PSCAD software. Metal oxide surge arrester model with the best performance was selected as the best design.

II. METHODOLOGY

In general, this project is to simulate the effect of lightning strike at three phase cable at intake of power supply at UiTM Shah Alam by using PSCAD software. The flowchart of this project is shown below.

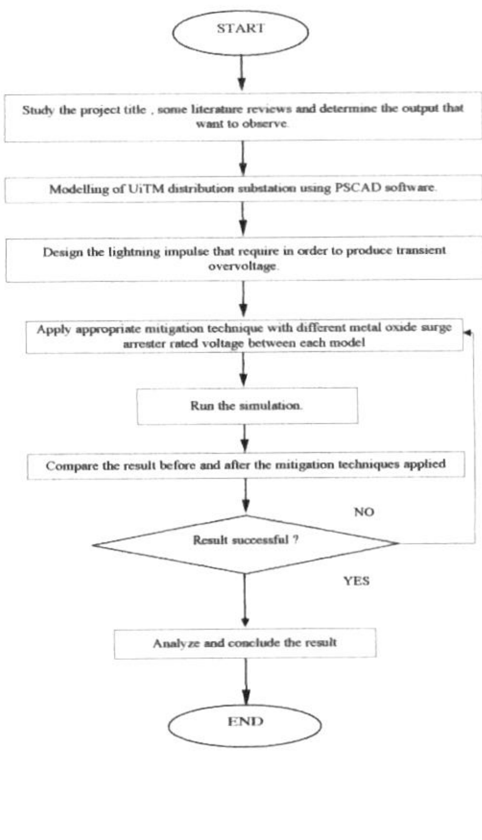

Figure 4. Flow chart of project.

A. UiTM Shah Alam Distribution System

The UiTM Shah Alam distribution system was modeled using PSCAD software. This circuit focused only on distribution system of Science and Technology (S&T) building.

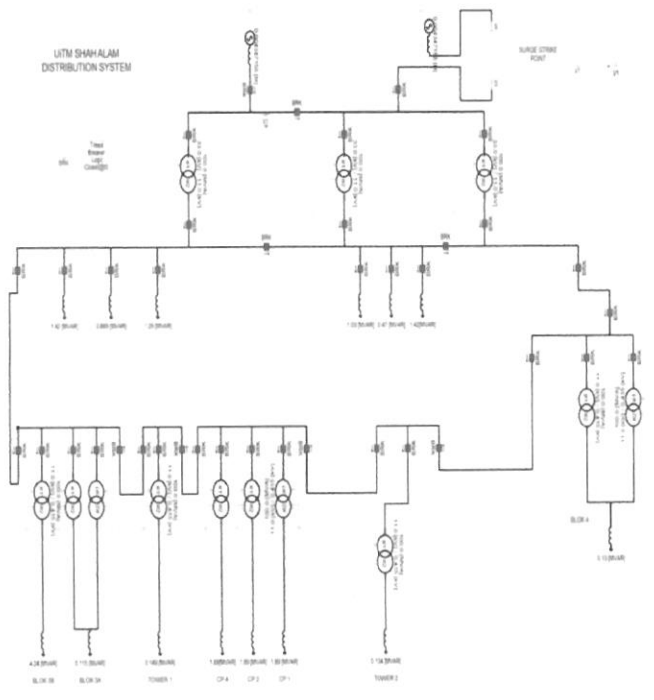

Figure 5. UiTM distribution systems at Science and Technology building.

B. Lightning Impulse Design.

In order to get or observe transient overvoltage, 10kA lightning impulse (8/20us) is generated using double exponential function equation in PSCAD. The equation is stated as below:

$$I(t) = e^{-\alpha t} - e^{-\beta t} \quad \ldots (1.0)$$

I (t) = peak current magnitude
α & β = constant value that will determine the rise time and the decay time of current impulse curve.

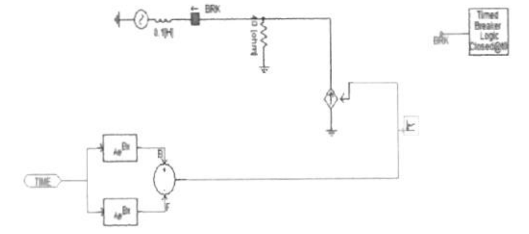

Figure 6. Lightning impulse circuit designs.

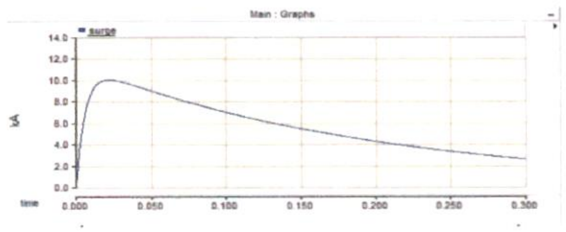

Figure 7. Lightning impulse waveform.

The circuit that generated this lightning impulse will then be injected to the three phase cables at the UiTM Shah Alam distribution system. The lightning strike at one of the three phase cables is shown in Figure 8.This circuit will create transient overvoltage.

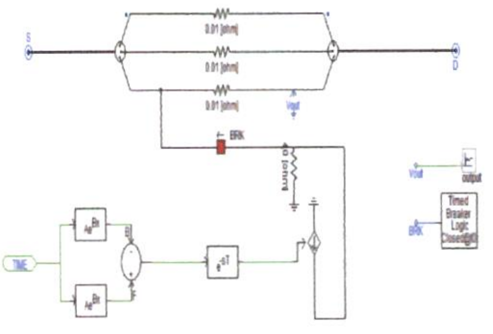

Figure 8. Lightning strike at three phase cable.

C. Surge Arrester Model.

In this project, there were three types of surge arrester models were constructed. They were IEEE surge arrester model, Picenti Giannettoni surge arrester model and also Fernandez Diaz surge model.

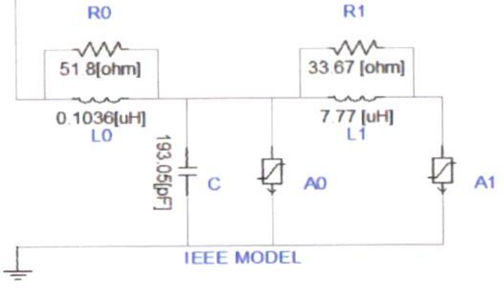

Figure 9. IEEE surge arrester model.

IEEE metal oxide surge arrester models also known as a frequency dependent model. This is because it depends on the frequency that will divert the over current to the ground through this circuit. This model has non-linear resistance A_0 and A_1, separated by an R-L filter. For slow surges, the filter impedance is extremely low and A_0 and A_1 are practically connected in parallel [8].For fast front surge, filter impedance becomes high and current flows through the non linear resistance, A_0. The equation for IEEE parameters is shown below:

$$L_1 = \frac{15d}{n}(\mu H) \qquad \text{... (1.1)}$$

$$R_1 = \frac{65d}{n}(\Omega) \qquad \text{... (1.2)}$$

$$L_0 = \frac{0.2d}{n}(\mu H) \qquad \text{... (1.3)}$$

$$R_1 = \frac{100d}{n}(\Omega) \qquad \text{... (1.4)}$$

$$C = \frac{100n}{d}(\rho F) \qquad \text{... (1.5)}$$

R_1& L_1 = Low pass filter.
C = External capacitor to attenuate the transient at high frequency.
R_0 = Resistor that placed to avoid numerical oscillation and effect that create by capacitor.
L_0 = Inductance of magnetic field around arrester.
d = Estimated height of arrester in meters.
n = Number of parallel columns of metal oxide in the arrester.

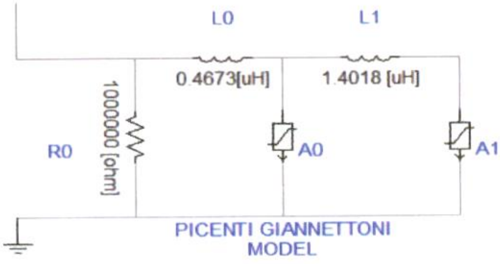

Figure 10. Picenti.Giannettoni surge arrester model.

Picenti Giannettoni surge arrester model is a modified version of IEEE model .Operating principle for Picenti Giannettoni model is quite similar to IEEE frequency-dependent model. For this model, the capacitance is eliminated, since its effects on model behaviour is negligible and two resistances in parallel with the inductances are replaced by one resistance R (about 1 MΩ) between the input terminals, with the only scope to avoid numerical troubles [9]. The equation for Pincenti Giannettoni is shown below:

$$L_1 = \frac{1}{4} \times \frac{Vx - Vr_{8/20}}{Vr_{8/20}} \times Vn\ (\mu H) \qquad \text{... (1.6)}$$

$$L_0 = \frac{1}{12} \times \frac{Vx - Vr_{8/20}}{Vr_{8/20}} \times Vn\ (\mu H) \qquad \text{...(1.7)}$$

L_1& L_0 = Filtering high frequency during transient and to reduce the response time during fast front transient.

Vn = Arrester rated voltage.

Vx = The residual voltage at 10kA fast front current surge (kV).

$Vr_{8/20}$ = The residual voltage at 10kA current surge with $8/20\,\mu s$ shape (kV).

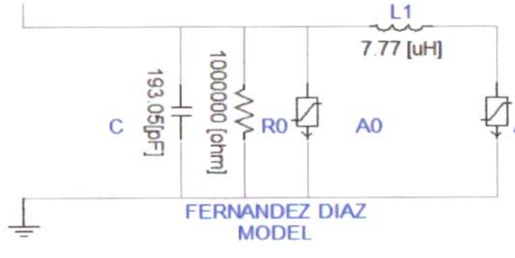

Figure 11. Fernandez Diaz surge arrester model

Fernandez Diaz surge arrester model is also based on IEEE model. In this model, A_0 and A_1 are separated by L_1, while Lo is neglected Figure 11. C is added in arrester terminals. This model does not require iterative calculations since the required data are obtained from the manufacturer's datasheet [10]. However, for parameter L_1 and C the equation is :

$$L_1 = nL_{1*} \qquad \text{... (1.8)}$$

$$C = \frac{100}{d} \qquad \text{...(1.9)}$$

n = scale factor

C = External capacitor to attenuate the transient at high frequency.

D. Final Mitigation Circuit.

In order to determine the best design to mitigate transient overvoltage, each metal oxide surge arrester model is constructed and then connected to the lightning impulse circuit Figure 8. The connection for each types of metal oxide surge arrester model is shown in Figure 12, 13, and 14.

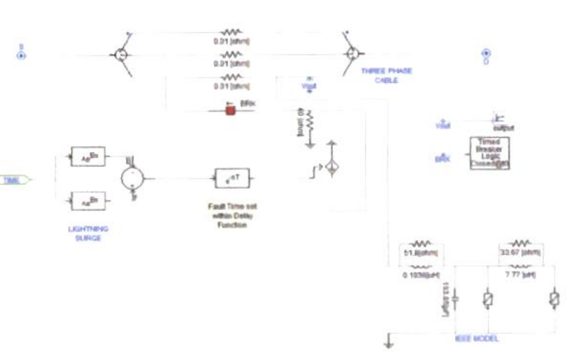

Figure 12. Mitigation circuit for IEEE surge arrester model.

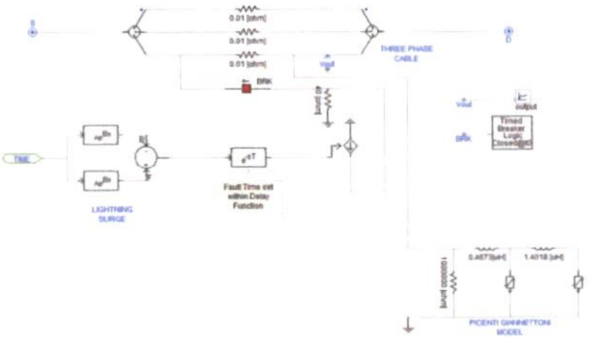

Figure 13. Mitigation circuit for Picenti Giannettoni surge arrester model.

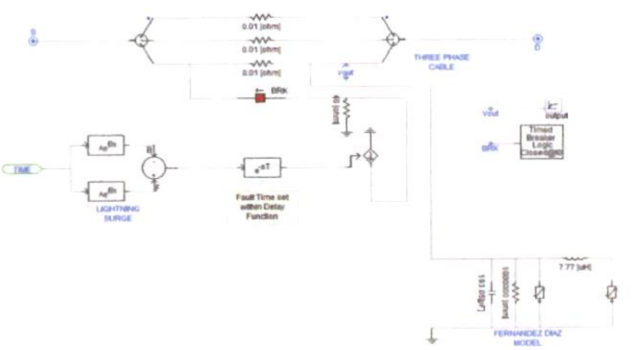

Figure 14. Mitigation circuit for Fernandez Diaz surge arrester model.

E. Surge Arrester Parameters.

The parameter value for each of MOSA was calculated and tabulated as shown below.

TABLE 1. IEEE ARRESTER MODEL

Arrester rating (kV)		Parameters				
A_0	A_1	L_1(μH)	R_1(Ω)	L_0(μH)	R_0(Ω)	C(pF)
40	40	7.77	33.67	0.1036	51.8	193.05
40	30	6.435	27.89	0.1036	51.8	193.05
30	30	6.435	27.89	0.0858	42.9	233.1
20	20	4.29	18.59	0.0572	28.6	349.6
15	15	3.585	15.535	0.0478	23.9	418.4

TABLE 2. PICENTI GIANNETTONI ARRESTER MODEL

Arrester rating (kV)		Parameters		
A_0	A_1	$L_1(\mu H)$	$R_1(M\Omega)$	$L_0(\mu H)$
40	40	1.4018	1	0.4673
40	30	1.0536	1	0.4673
30	30	1.0536	1	0.3512
20	20	0.7054	1	0.2351
15	15	0.5268	1	0.1756

TABLE 3. FERNANDEZ DIAZ ARRESTER MODEL

Arrester rating (kV)		Parameters		
A_0	A_1	$L_1(\mu H)$	$R_1(M\Omega)$	C(pF)
40	40	2.018	1	193.05
40	30	1.5138	1	193.05
30	30	1.5138	1	233.1
20	20	1.009	1	349.6
15	15	0.7567	1	418.4

III. RESULT AND DISCUSSION

Simulations for each model were performed using PSCAD software. The results were evaluated and compare as shown below:

A. Initial State

At initial state the three phase cable circuit is connected to the lightning circuit that performed waveform as Figure 15.

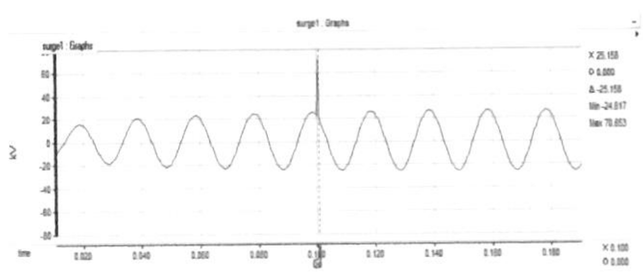

Figure 15. Transient overvoltage occur at initial state after lightning strike

From the result, it can be seen that transient overvoltage is obtained after lightning strike at one of three phase cable. At 0.1 microseconds where the transient occur, the nominal voltage increased from 24.617kV to 70.653kV.

B. Mitigation Technique Using IEEE Model

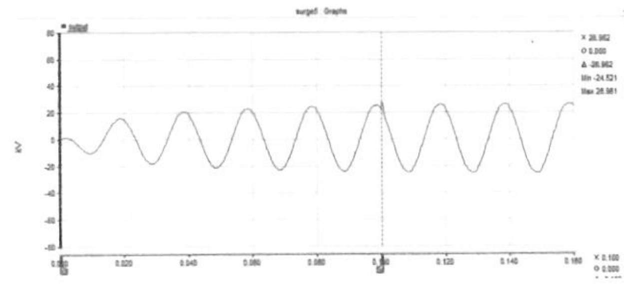

Figure 16. Transient overvoltages due to lightning strike for (A0=15kV and A1=15kV) arrester rating.

From the result, it can be seen that after IEEE model is applied with rated voltage for both arrester set at 15kV, the nominal voltage at transient overvoltage reduced from initial 70.653kV to 26.961kV. At this state, voltage has been clamped. The voltage that been reduced is about 43.692kV.

C. Mitigation Technique Using Picenti Giannettoni Model

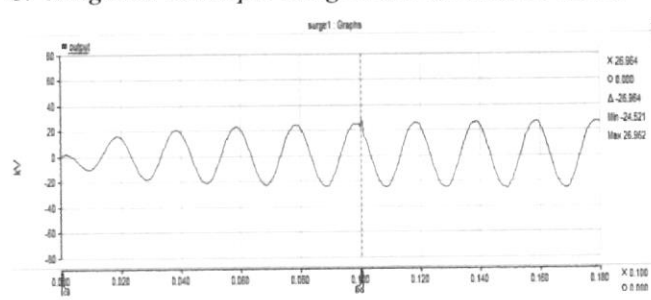

Figure 17. Transient overvoltage due to lightning strike for (A0=15kV and A1=15kV) arrester rating.

From the result, it can be seen that after Picenti Giannettoni model is applied with rated voltage for both arrester set at 15kV, the nominal voltage at transient overvoltage reduced from initial 70.653kV to 26.962kV. At this state, voltage has been clamped. The voltage that been reduced is about 43.691kV.

E. Mitigation Technique Using Fernandez Diaz Model

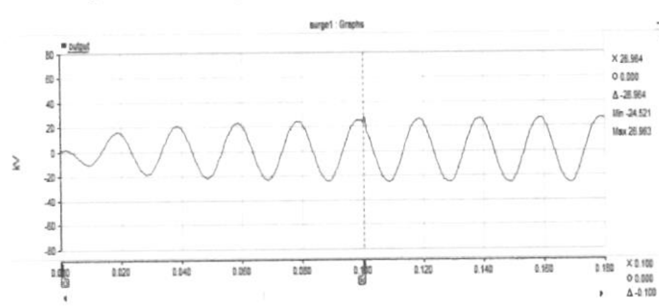

Figure 18. Transient overvoltages due to lightning strike for (A0=15kV and A1=15kV) arrester rating

From the result, it can be seen that after Fernandez Diaz model is applied with rated voltage for both arrester set at 15kV, the nominal voltage at transient overvoltage reduced from initial 70.653kV to 26.963kV.At this state, voltage has been clamped. The voltage that been reduced is about 43.690kV.

After the simulation of metal oxide surge arrester models proposed by IEEE, Picenti Giannettoni, and Fernandez Diaz, all the data was tabulated in order to analyze the differences between each of metal oxide surge arrester model. Table 4 shows the differences of clamping voltage for the three types of metal oxide surge arrester.

TABLE 4: REDUCTION IN TRANSIENT OVERVOLTAGE WITH DIFFERENT RATED OF VOLTAGE FOR THE THREE TYPE OF ARRESTER.

Arrester rating (kV)		IEEE model (kV)	Picenti Giannettoni model (kV)	Fernandez Diaz model (kV)
A_0	A_1			
40	40	69.859	69.880	69.886
40	30	54.468	54.538	54.538
30	30	53.144	53.157	53.160
20	20	35.780	35.784	35.785
15	15	26.961	26.962	26.963

IV. CONCLUSION

In this project, it shows the consequences in the actual condition when lightning strike an electrical distribution system by using simulation software. This project has successful mitigate transient overvoltage by each of the metal oxide surge arrester model. The differences of transient over voltages before and after the mitigation techniques that been applied was successfully observed and analyzed. Outputs from simulation were analyzed and the results were compared between the models and between the different rated voltages used. Comparison between the results shows that IEEE surge arrester model produce better result than Picenti Giannettoni, and Fernandez Diaz model Table (4).

V. FUTURE RECOMMENDATION

For future recommendation, it is strongly recommended to do a simulation of lightning strike at different location at the distribution system in order to see the effect, and also regarding to parameter for each metal oxide surge arrester model, more accurate calculation is required in order to obtain good result in mitigate transient overvoltage.

VI. ACKNOWLEDGEMENT

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