Effect of indirect lightning strike to 66kV transmission line in Java-Bali system

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Abstract. Based on Java-Bali grid disturbance data, the 66kV transmission lines that is close to or intersect with 150kV or 500kV transmission line is often experienced earth fault due to insulator flashover. The insulator flashover can be caused by indirect lightning strike since lightning strikes tend to strike higher structure. Therefore, this paper will determine the effect of indirect lightning strike on 150kV or 500kV transmission line to 66kV transmission line by modeling and simulation using application of transient analysis. Variation of lightning peak current magnitude and gap between 66kV transmission line and transmission line with higher voltage is performed during simulation. The range of peak current magnitude follows the data from lightning detection systems, while the value of gap follows the data from actual condition. It is found that higher current peak and closer gap will cause higher transient overvoltage on insulator of 66kV transmission line thus insulator flashover may occur more frequent. Addition of earth wire on 66kV transmission line and gap between each transmission by organizing the sag of conductor can be performed to minimize the insulator flashover.

1 Introduction

In Indonesia power system, especially Java-Bali grid, use 66kV, 150kV, and 500kV as the voltage level for transmission line. The development process of those transmission lines is usually constrained by land for the transmission line right of way. Therefore, it is often found that transmission line with different voltage level in the Java-Bali grid is either adjacent to each other or intersected with each other as given in Figure 1. Based on disturbance data, it is known that 66kV transmission lines that is close to or intersect with 150kV or 500kV transmission line is often experienced earth fault due to insulator flashover. Because lightning strike tend to strike higher structure [1,2], so the insulator flashover on this 66kV transmission line can be caused by induced voltage due to lightning strike to 150kV or 500kV transmission line. This phenomenon can be called as indirect lightning strike.

Fig. 1. Illustration of existing transmission in Java-Bali grid.

Generally, direct lightning strike will cause higher voltage magnitude than induced voltage caused by indirect lightning strike. However, this induced voltage might be occurred more frequently so it also can cause disturbance on the transmission line. The induced voltage generation mechanism is explained on [3]. The model has been validated by many comparisons between calculations and experimental results [4]. Induced voltage due to indirect lightning strike is influenced by lightning current, ground resistivity, height of transmission line, and the distance between the transmission line and the location of the lightning strike [5]. However, some of the references have not explained about the effect of indirect lightning strike on higher transmission line to lower transmission line.

Therefore, this paper will determine the induced voltage magnitude perceived by 66kV transmission line due to indirect lightning strike on 150kV or 500kV transmission line. The case reviewed in this paper is the 66kV transmission line in Java-Bali grid, because it is the transmission line that frequently suffer insulator flashover. In addition, it is also expected to obtain the method that can be used to minimize the occurrence of insulator flashover due to indirect lightning strike.

2 Methodology

In this paper, the magnitude of induced voltage will be determined by modeling and simulation using application of transient analysis. During simulation, multistory tower model will be used for 500kV transmission line while 66kV and 150kV transmission

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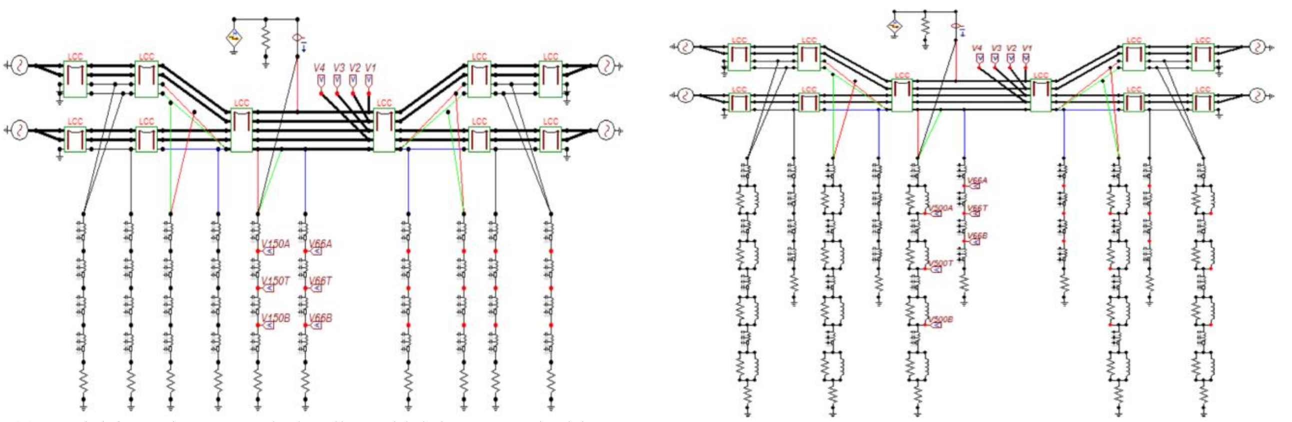
lines will use distributed line tower model. Selection of tower model for each voltage level is referring to [6-9]. The multistory tower model is the first tower model proposed for lightning strike analysis and is built based on the measurement of arcing horn voltage on 500kV transmission line with double circuit [6,7]. While in [8-9], it is explained that the distributed line tower model can be used for voltage level from 66kV to 275kV because this tower model will give simulation results that is similar to the conditions in the field.

It is assumed to use only one typical geometry for each transmission voltage level in this paper, where it is given in Table 1. From the typical geometry then the magnitude of surge impedance, resistance, and inductance for multistory tower model and distributed line tower model is calculated based on [7,8]. Furthermore, the model as given in Figure 2 is built in the application of transient analysis. During the simulation process, it is also assumed to use 300m as the span for each tower and 100Ωm as the magnitude of soil resistivity.

Table 1. Parameter for typical transmission tower geometry.

Parameter	66kV tower	150kV tower	500kV tower
Radius of tower top section [m]	1.1	1.6	2.6
Radius of tower mid-section [m]	1.1	1.6	3.5
Radius of tower base section [m]	4.465	5.4	19.503
Length of crossarm for bottom phase [m]	4.7	8.6	24.2
Length of crossarm for middle phase [m]	4.7	8.2	21.6
Length of crossarm for top phase [m]	4.7	7.8	20.6
Length of crossarm for ground wire [m]	-	7.4	24.2
Height from base to crossarm for bottom phase [m]	19.5	26.5	36.325
Height from base to crossarm for middle phase [m]	22.4	31.2	47.825
Height from base to crossarm for top phase [m]	25.3	35.9	59.275
Height of tower [m]	28.2	38.8	72.105



(a) Model for 66kV transmission line which intersected with or close to 150kV transmission line

(b) Model for 66kV transmission line which intersected with or close to 500kV transmission line

Fig. 2. Model in application of transient analysis.

From the model shown in Figure 2, then simulation for several scenarios is performed. The scenarios simulated in this paper consist of five scenarios and described as follows.

2.1 Scenario 1

Variation of lightning strike location which either on the ground wires or on the upper phase conductor of 150kV or 500kV transmission line. From the typical tower geometry in Table 1, it can be calculated that the magnitude of lightning peak current that will start to strike the ground wire is 9.241kA for 150kV transmission line and 20.89kA for 500kV transmission line. The current magnitude is obtained using electrogeometric model on [1], where it is calculated from the magnitude of shielding angle for each tower. Therefore, it is assumed that the magnitude of lightning peak current that strike the upper phase conductor is 9kA for 150kV transmission line and 20kA for 500kV transmission line, while the magnitude of lightning current peak that strike the ground wire of both transmission line is 50kA.

2.2 Scenario 2

Variation of lightning current polarity, that either strikes the ground wire or upper phase conductor of 150kV or 500kV transmission line. Based on lightning detection system that have already installed on western Java and central Java system, it is known that 91.4% of the lightning incidence is lightning with negative polarity while the 8.56% is lightning with positive polarity. Figure 3 shows the distribution of lightning current magnitude and polarity from the lightning detection system.

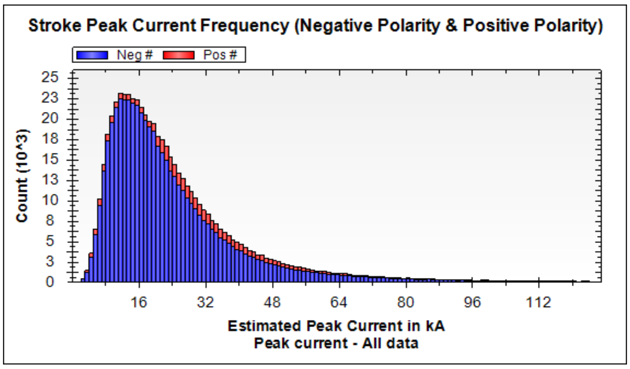


Fig. 3. The distribution of lightning current magnitude and polarity.

2.3 Scenario 3

Variation the magnitude of lightning peak current that strike 150kV or 500kV transmission line. The range of lightning peak current magnitude follows the data from lightning detection system. In this scenario, only one location of lightning strike from two possible location is performed during simulation. In addition, only one lightning polarity is also performed during the simulation. The selection of location and polarity is based on the condition that tend to cause higher induced voltage which perceived by insulator of 66kV transmission line.

2.4 Scenario 4

Variation the gap between the ground wire of 66kV transmission line and the bottom phase conductor of 150kV or 500kV transmission line. This scenario is only used for 66kV transmission line that intersected with 150kV or 500kV transmission line. Variation of the gap is performed by modifying the basic sag of each transmission line. The lower gap limitation follows the clearance magnitude on [10]. The clearance for inter-phase and phase to ground of 500kV transmission line is 7.84m and 5.01m, while the clearance for inter-phase and phase to ground of 150kV transmission line is 1.57m and 1.325m. This scenario is also only performed on one location of lightning strike and one lightning current polarity as described in scenario 3.

2.5 Scenario 5

Variation the gap between the outermost phase conductor of 66kV transmission line and the outermost of 150kV or 500kV transmission line. This scenario is only used for 66kV transmission line that adjacent to 150kV or 500kV transmission line, where the gap variation is adjusted to the condition in the field. The lower gap limitation also follows the clearance magnitude which stated on scenario 4. This scenario is also only performed on one location of lightning strike and one lightning current polarity as described in scenario 3.

3 Simulation and analysis

First, the simulation results of scenario 1 and scenario 2 are given in Table 2 and Table 3. The voltage magnitude for each phase and condition is the maximum induced voltage magnitude perceived by insulator of 66kV transmission line. This maximum induced voltage magnitude is selected from several voltage magnitudes which generated during simulation of lightning strike between 0ms to 10ms. Comparison of both tables indicate that lightning strike to the ground wire of 150kV or 500kV transmission line would be more likely to cause higher induced voltage than lightning strike to the top phase of 150kV or 500kV transmission line. In addition, it is also known that lightning current with positive polarity will tend to produce higher induced voltage than lightning current with negative polarity. Therefore, the probability of insulator flashover on 66kV transmission line due to this induced voltage will be higher. From the above explanation, it can be stated that lightning current with positive polarity which strike the ground wire of 150kV or 500kV transmission line will produce higher induced voltage that perceived by insulator of 66kV transmission line. Consequently, selection of location and polarity of lightning strike during simulation of scenario 3 to scenario 5 will follow those results.

Table 2. Induced voltage of insulator on 66kV transmission line due to indirect lightning strike with positive polarity.

Parameter	Ground wire of		Top conductor of	
	150kV	500kV	150kV	500kV
Top phase; circuit 1 [kV]	462.03	246.56	157.03	189.97
Middle phase; circuit 1 [kV]	486.86	311.25	117.93	178.01
Bottom phase; circuit 1 [kV]	448.7	296.89	121.7	143.48
Top phase; circuit 2 [kV]	395.81	228.83	139.98	176.96
Middle phase; circuit 2 [kV]	438.54	297.21	105.98	167.33
Bottom phase; circuit 2 [kV]	412.7	284.62	123.86	143.57

Table 3. Induced voltage of insulator on 66kV transmission line due to indirect lightning strike with negative polarity.

Parameter	Ground wire of		Top conductor of	
	150kV	500kV	150kV	500kV
Top phase; circuit 1 [kV]	340.8	191.12	91.453	120.15
Middle phase; circuit 1 [kV]	288	118.57	99.943	110.24
Bottom phase; circuit 1 [kV]	305.8	177.67	78.96	106.14
Top phase; circuit 2 [kV]	300.1	179.91	81.173	111.91
Middle phase; circuit 2 [kV]	265.2	118.31	101.54	105.01
Bottom phase; circuit 2 [kV]	289.2	169.64	73.786	104.48

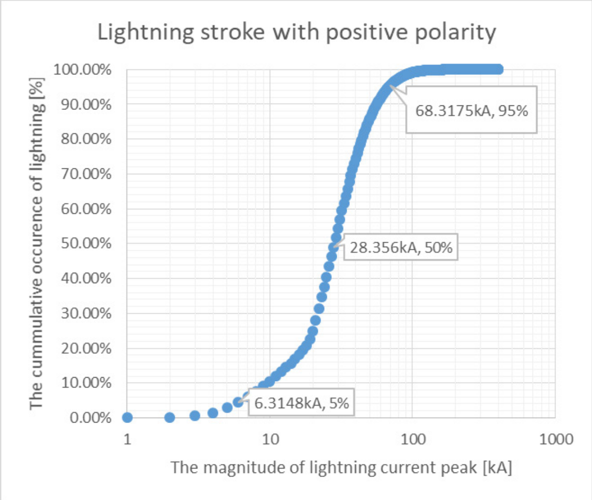


Fig. 4. The cummulative occurrence probability of lightning strike with positive polarity.

Before discussing about the simulation results of scenario 3, it is necessary to know the peak current magnitude range of lightning with positive polarity. Figure 4 shows the probability of the cumulative occurrence for lightning with positive polarity. The probability is obtained from the lightning detection system. Based on Figure 4, it is assumed that the magnitude range of lightning peak current is 10kA to 70kA for 150kV transmission line and 25kA to 70kA for 500kV transmission line. The lower limit of current is determined by the magnitude of lightning peak current that start to strike the ground wire of transmission line. While the upper limit of current is determined to know the probability of insulator flashover for 95% cumulative occurrence of lightning.

The simulation results of scenario 3 are given in Figure 5 to Figure 8. The induced voltage magnitude of insulator on each condition is obtained from lightning strike at t = 0ms. This simulation time is chosen because it give the highest induced voltage magnitude on insulator in the top phase for lightning strike at t = 0ms to t = 10ms. Based on Figure 5 through Figure 8, it is known that lightning strike to 150kV or 500kV transmission line with higher peak current magnitude will lead to higher induced voltage magnitude on the insulator of 66kV transmission line. If the simulation results of scenario 3 are compared to the cumulative occurrence of lightning in Figure 4, it can be seen that the utilization of insulator with basic insulation level (BIL) 325kV for 66kV transmission line, which intersected with 150kV transmission line, will reduce the probability of insulator flashover up to 50%. While the probability of insulator flashover will be lower than 50% for the other cases such as 66kV transmission line which is close to 150kV or 500kV transmission line and 66kV transmission line which is intersected with 500kV transmission line.

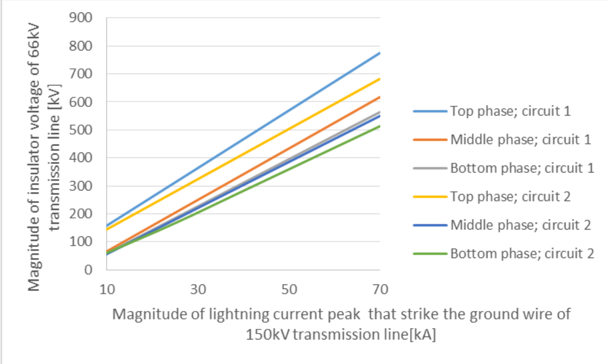


Fig. 5. 66kV transmission line intersected with 150kV transmission line with 4.3m separation gap.

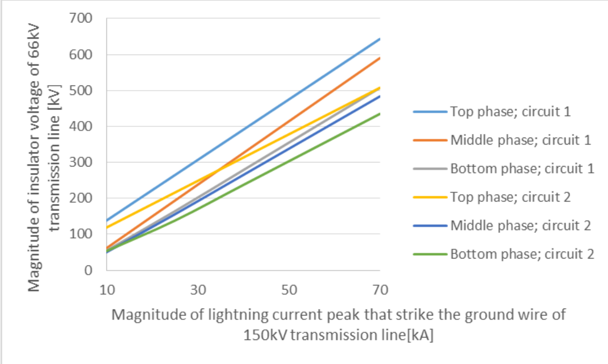


Fig. 6. 66kV transmission line adjacent to 150kV transmission line with 4.3m vertical gap and 2.5m horizontal gap.

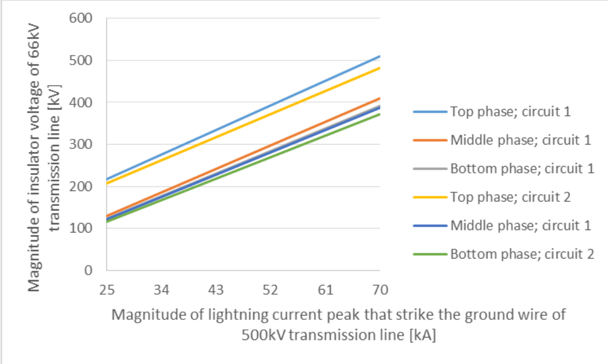


Fig. 7. 66kV transmission line intersected with 500kV transmission line with 8.125m separation gap.

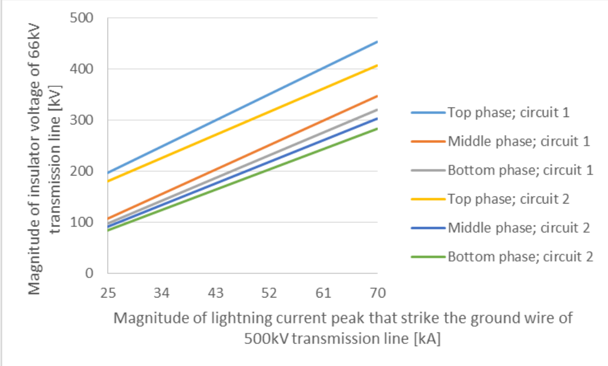


Fig. 8. 66kV transmission line adjacent to 500kV transmission line with 8.125m vertical gap and 2.5m horizontal gap.

Next is discussion about scenario 4 and 5. The simulation results of scenario 4 are given in Figure 9 and Figure 10, while the simulation results of scenario 5 are given in Figure 11 and Figure 12. Based on Figure 9 through Figure 12, it is known that wider gap between 66kV transmission line and 150kV or 500kV transmission line will cause the induced voltage perceived by insulator becomes lower. The insulator voltage on 66kV transmission line will have higher magnitude if the 66kV transmission line is intersected with or adjacent to 150kV transmission line. Therefore, the probability of insulator flashover on 66kV transmission line will also higher for this case.

From Figure 9 through Figure 12, it is also known that transmission line which is intersected with each other will have higher induced voltage magnitude than transmission line which is close to each other. It is because each of intersected transmission line is only separated by a small gap. During planning stage of transmission line, this problem can be solved easily by separating the transmission line with a big gap. While in the case of existing transmission line, one method that can be used is by modifying the basic sag of each transmission line. Increasing the gap of the intersected transmission line with this method is performed by using higher basic sag for 66kV transmission line and using lower basic sag for 150kV or 500kV transmission line. However, the vertical clearance of 66kV transmission line and the tension strength of 150kV or 500kV transmission tower are needs to be considered during the application of this method.

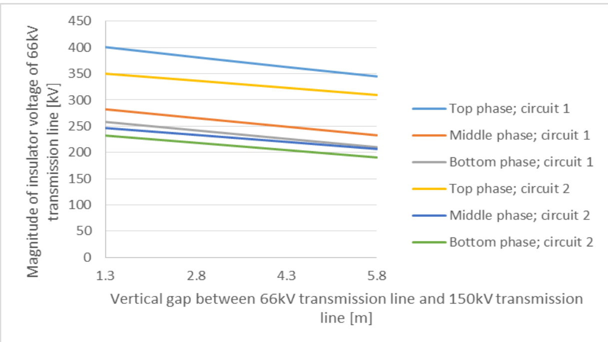


Fig. 9. 66kV transmission line intersected with 150kV transmission line during 30kA lightning strike with positive polarity

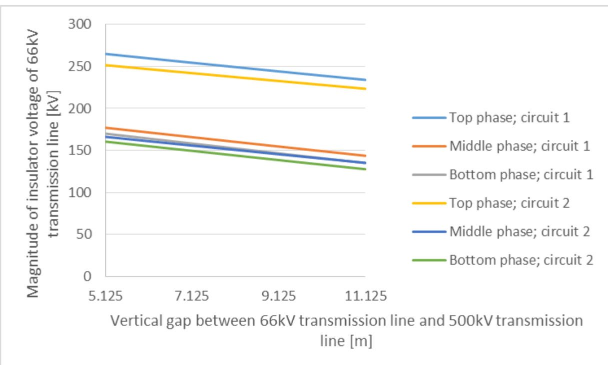


Fig. 10. 66kV transmission line intersected with 500kV transmission line during 30kA lightning strike with positive polarity

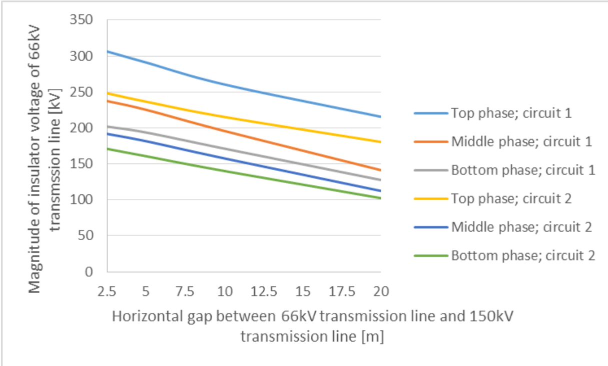


Fig. 11. 66kV transmission line adjacent to 150kV transmission line with 4.3m vertical gap during 30kA lightning strike with positive polarity.

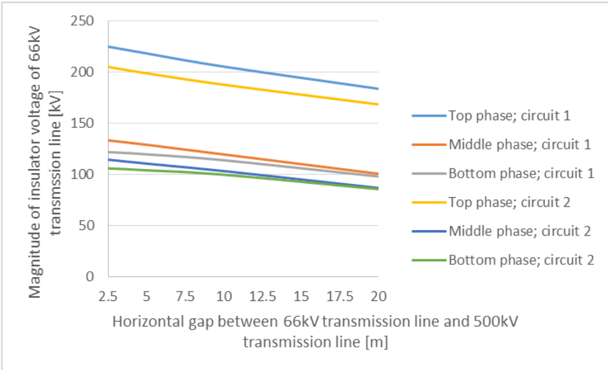


Fig. 12. 66kV transmission line adjacent to 500kV transmission line with 8.125m vertical gap during 30kA lightning strike with positive polarity.

4 Discussion

Based on Figure 5 and Figure 7, it is known that the insulator voltage on the top phase of transmission line will have the highest voltage magnitude in the case of intersected transmission line. This is because the top phase insulator felt the highest induced voltage due to indirect lightning strike, which is only reduced by the ground wire. The middle phase or bottom phase insulator will feel induced voltage, which has been reduced by ground wire and phase conductor above it. In the case of transmission line which close to each other, the insulator voltage of 66kV transmission line tends to have higher magnitude on the circuit closer to the 150kV or 500kV transmission line. The other circuit is induced by voltage, which has been reduced by closer circuit and body tower. The highest induced voltage magnitude also perceived by the top phase insulator in this case. Therefore, another method that can be used to reduce the insulator voltage on 66kV transmission line due to indirect lightning strike is by adding the number of ground wire used on 66kV transmission line. Addition of ground wire will reduce the induced voltage felt by insulator on all of three phases as shown in Figure 13 and Figure 14.

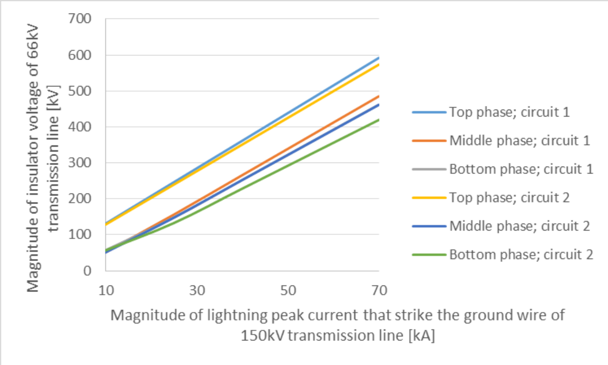


Fig. 13. 66kV transmission line with two ground wire intersected with 150kV transmission line with 4.3m separation gap

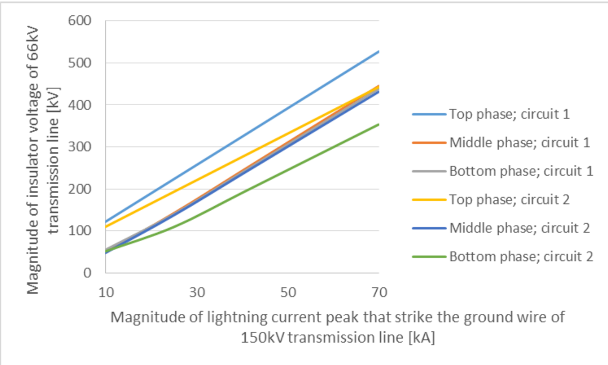


Fig. 14. 66kV transmission line with two ground wire adjacent to 150kV transmission line with 4.3m vertical gap and 2.5m horizontal gap

Comparison between Figure 5 and Figure 13 and also between Figure 6 and Figure 14 indicate that the use of two ground wires on 66kV transmission line will decrease the magnitude of insulator induced voltage on 66kV transmission line due to lightning strike at 150kV transmission line. The reduction of insulator induced voltage is almost 24% after ground wire addition in the case of intersected transmission line, while almost 26% in the case of transmission line which is close to each other. Consequently, ground wire addition can be used to reduce the probability of insulator flashover on 66kV transmission line due to indirect lightning strike. In addition, it should also be considered to use unbalance insulation of insulator on double circuit transmission line to avoid widespread disturbance due to insulation flashover. During utilization of unbalance insulation, it is necessary to ensure the insulation level difference meet the requirement on [11] and also ensure the loading of each circuit is not exceeding 50% of the transmission line ampacity.

5 Conclusions

From the simulation results, it is known that the induced voltage perceived by insulator of 66kV transmission line will have high magnitude, if the lightning current have positive polarity and strike the ground wire of 150kV or 500kV transmission line. Higher magnitude of lightning peak current and lower gap between 66kV transmission line and 150kV or 500kV transmission line will cause higher magnitude of induced voltage either in the case of intersecting or adjacent transmission line. In addition, comparison of each simulation results shows that 66kV transmission line which is intersected with or close to 150kV transmission line tends to have higher induced voltage. Furthermore, it is also known that intersected transmission line will have higher induced voltage magnitude. Generally for both intersecting and adjacent transmission line, the highest induced voltage is experienced by the top phase insulator of the circuit closer to the location of lightning strike. Reduction of the insulator induced voltage due to indirect lightning strike can be achieved by combining the usage of larger basic sag percentage for 66kV transmission line and lower basic sag percentage for 150kV or 500kV transmission line. Besides that, adding the number of ground wire into two on 66kV transmission line can also reduce the magnitude of insulator induced voltage until 24% for intersecting case or 26% for adjacent transmission line case.

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