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Short Communication

Distribution Voltage of Quadruple Circuit Dual Voltage Tower Model During Lightning Strike

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ABSTRACT

Lightning strikes on transmission lines often triggers electrical blackout. A direct lightning strike to the ground wire or the structure of tower makes voltage rise along the tower and the voltage stress appear along the installed string insulators at the tower. A back flashover occurs as the voltage along the string insulator exceeds the maximum insulator withstand. Most of previous works carried out the impact of lightning strike for conventional tower with single voltage and maximum two circuits. In this report, the assignment was carried out by modelling the quadruple circuit dual voltage tower model. The tower carries two circuits with 500kV and other two circuits with 150kV working voltage. In this work, an approach to estimate passive element of tower impedance surge was implemented and then it is followed by several experiments through a simulations program to investigate to determine voltage stress of each stage of tower and the string insulations.

Keywords: Tower Transmission, Lightning Strike, Impulse Voltage Stress

INTRODUCTION

As an equatorial country with a tropical climate, Indonesia has a high-density lightning strike. The level of lightning density in Indonesia is 12 / km2 / year which means that an area of 1 km2 will have the possibility of a lightning strike 12 times each year [1]. This condition has become because lightning strikes can trigger massive blackout to the electrical supply.

In the 500/150 kV transmission line the frequent disturbance is direct lightning strikes that can cause back flashover [2]. Back flashover occurs when a direct lightning strike on the ground wire or tower, and when the voltage that arises on the string isolator equals or exceeds Critical Flashover Voltage (CFO). This phenomenon causes a return strike from the tower to the phase wire [3].

This lightning disturbance causes the rise of electrical voltage and current flowing in the electrical network in the form of impulse waveform. The wave travels along the line transmission to the end of network. The travelling wave with high voltage amplitude may reach the substation and cause many damages to electrical equipment [5,6].

To indicate the possibility of backflash over, it is important to know voltage distribution along the tower of transmission. However, the prediction cannot be obtained without the model of tower in the form of equivalent circuit consisting the impedance of tower.

In this work an approach to model the quadruple circuit dual voltage tower was carried out to investigate the stress voltage on every phase of insulator string as the lightning surge travelled. The result shows significant influence to get the behaviour to avoid the occurrence of back flash.

LITERATURE REVIEW

The conventional transmission line has single working voltage and maximum two circuits [2,4]. To increase the capacity of power delivery and provide better efficiency in transmitting power with different working voltage, then transmission line uses a quadruple circuit transmission line on the same tower with dual voltages of 500 kV and 150 kV is introduced [7]. However, there are several potential shortages in the tower with dual voltage for example: the shielding performance of the protection line has the potential to deteriorate, and the lightning resistance level decreases, when compared to the single circuit transmission line operating at the same voltage. Another risk is the simultaneous failure of two or more circuit transmission cables. For the protection of the secure and reliable functioning of the power system, it is crucial to calculate and evaluate the lightning withstanding level and lightning outage rate of multi-circuit transmission line in one tower [5,6].

Many previous research focused on single circuit transmission line and its tower [2,4,5]. Several researchers investigate the efficiency, and transmission parameters of quadruple circuit transmission line during steady state condition. In this paper, the equivalent circuit for surge impedance model of tower for quadruple circuit transmission line is proposed. The impact of lightning which stroke directly on ground wire the transmission line is considered to investigated.

The lightning current is a exponential wave of 1.2/50μs following The IEC 61000-4-5 standard of lightning waveform model. The lightning wave form has front wave to rise within 1.2 micro seconds and the tail is 50 micro-second to reach half of maximum amplitude of the waveform [8].

Construction of tower transmission for quadruple circuits dual voltage is shown in Fig.1[7]. On the top of the tower, there are two ground wire on the right and left arm. The length of ground wire arm is wider than the arm of phase conductor for 500 kV, so it gives more protection zone against lightning strike. The ground wire is expected to be an effective shield protection, as the lightning has a bigger chance to make a direct strike to the ground wire rather than phase conductor. The lower stage is dedicated for two circuit 150 kV. As there are 3 phases for each circuit, so the tower has 4 circuits i.e., 2 circuits for 500kV and 2 circuit for 150kV. The tower construction can deliver 12 phases in which one circuit contains of three phases. The 500kV circuits is 10 meters above the 150 kV circuits, in order to make safety clearance distance. The body structure for upper stage circuit has up straight uniform length, while the body tower structure of lower stage is close to pyramidal shape. The pyramidal structure is useful to strengthen the base foundation of the tower, while the slime and uniform contour is suitable to reduce burden of the tower at upper stage.

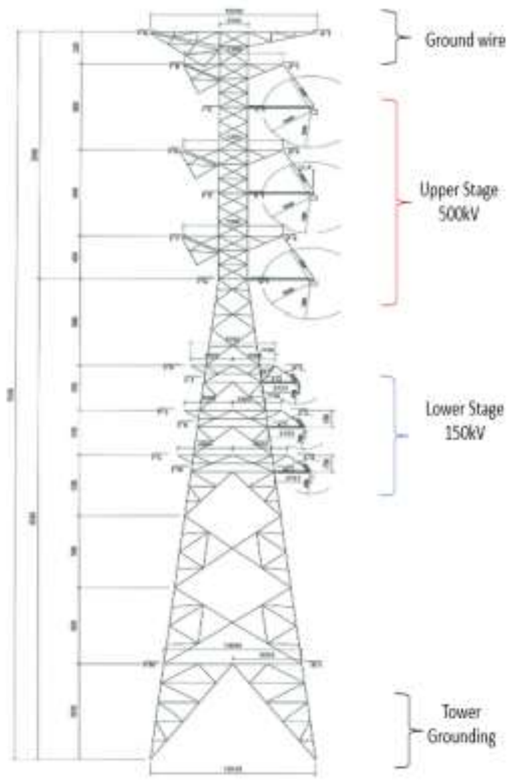

Fig.1 Construction of Tower Transmission for Quadruple Circuits Dual Voltage

The surge impedance equation model for arm related to ground wire and phase in quadruple circuit tower model follows the Equation (1). The surge arm impedance model for extra high voltage line transmission has similar value as they are constructed in the same length along the tower at upper stage. Due to the pyramidal shape for the lower stage and then the value of surge impedance arm at 150 kV are different for each phase [4,8].

$$Z_{arm} = 30ln\left[\frac{2(H^2+r^2)}{r^2}\right] (1)$$

Where H is length of arm and r is the radius of arm

To determine the body surge impedance of tower, then every stage between the arm must be determined by taking account the geometrical shape of the body construction. For ground wire part and the upper stage for 500 kV, Equation (2) is applied [4,9,10].

$$Z_{body\_upper} = \left(ln\left[\frac{2\sqrt{2}H}{r}\right] - 1\right)60 \qquad (2)$$

For the lower stage at 150 kV, every stack of the body tower impedance follows Equation (3) [4,10].

$$Z_{body_{lower}} = \left(ln\left(cot\left(0.5tan^{-1}\left(\frac{r_{avr}}{H}\right)\right)\right) - 1\right)60 \ (3)$$

while the average radius of body tower (r_{avr}) is determined by Equation (4) and by considering the Fig. 1

$$r_{avr} = \frac{r_1h_2+r_2H+r_3h_1}{H} \qquad (4)$$

The current waveform for lightning strike follows the mathematical model in Equation (5) for Heidler model [10].

$$i_p = \frac{I_{peak}}{\eta}\left(\frac{\left(\frac{t}{\tau_1}\right)^n}{1+\left(\frac{t}{\tau_1}\right)^n}\right)exp\left(\frac{-t}{\tau_2}\right) \qquad (5)$$

and

$$\eta = exp\left(\frac{-\tau_1}{\tau_2}\right)\left(\frac{n\tau_2}{\tau_1}\right)^{\frac{1}{n+1}} \ (6)$$

With I_{peak} is lightning peak current, η represent the correction factor for the peak current, τ_1 and τ_2 are rising and decay time for current, the steepness of current has n value [9,10].

MATERIALS & METHODS

The value of insulator string composed from 11 pieces has capacitance values of 9.1pF for 150kV implementation, while it has 2.275 pF for 500kV insulation string. The ground resistance value is assumed to be in pure resistive model and it has 10 Ohm as commonly required in transmission line in Indonesia [4,11,12].

The peak current values of in lightning strike that most often occurs in Java Island in which most of 500kV and 150kV transmission line are laid down are 5 and 9 kilo Ampere (kA) [13]. The other dominant current peak for lightning strikes is 15 and 23 kA [13]. Those peak values are considered in this work to get voltage stress of quadruple circuit with two voltage operating voltage at one tower transmission.

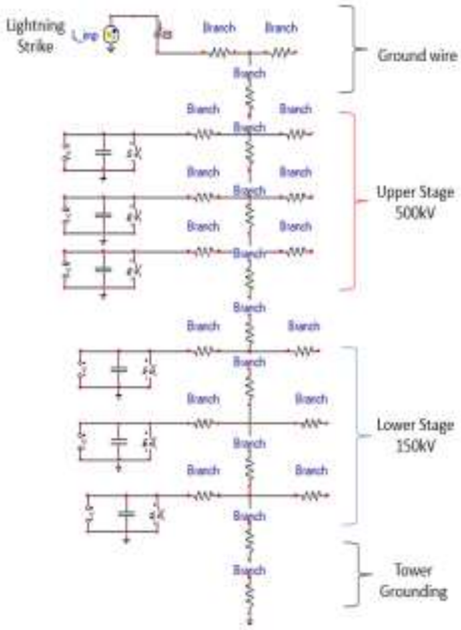

Fig.2 Quadruple Circuit Tower Mode Dual Voltage

Table 1. The Propossed Surge Impedance of Tower Model in Ohm

Stage	Cross Arm	Body Tower
Ground Wire	147.16	37.65
500kV	116.98	120.35
Up-Phase 150kV	-	111.48
Mid-Phase 150kV	-	119.52
Low-Phase 150kV	-	126.63
Upper Body Junction	-	65.37
Lower Body Junction	-	96.03
Up-Pyramid Body	-	41.77
Mid-Pyramid Body	-	35.33
Low-Pyramid Body	-	125.23

In this work, two kinds of three phase sources are connected to the tower model for the second experiment. The upper circuits have been injected by 408, 25 kV_{peak} line to ground with operation frequency 50Hz. The two pairs circuits at lower stage of the tower are supplied by electric source voltage 50Hz with 122,48 kV_{peak} line to ground. The ground wire on the top of the tower is directly struck by lightning. The observations on the potential rising are recorded for each phase on 500kV and 150 kV side.

RESULT AND DISCUSSION

For the first experiment, the ground wire in the tower model was struck by lightning with a peak current of 5kA as shown in Fig.3. Furthermore, in Fig. 4 and Fig.5 show the distributed stress voltage contained in the line with a working voltage of 500kV and 150 kV. The highest voltage stress felt by the tower section which distributes a working voltage of 500kV is 953 kV with a negative peak. The tower section that transmits a working voltage of 150 kV has a stress of 211 kV. From these results, the voltage stress that occurs for a lightning strike is 5kA, the voltage stress that occurs is indeed above the working voltage but it is still below the maximum withstand value of each insulator 500kV and 150kV. According to IEC 60076-3 2013 standard, a 150kV string insulators generally has a maximum withstand voltage 750kV and for a working voltage of 500kV generally it has a maximum withstand voltage 1550kV.

Fig. 6 and Fig.7 show a result of a lightning strike with a peak current of 9kA. The maximum voltage stress that occurs is 1389kV for a nominal line voltage of 500kV and 331.25 kV for a nominal line voltage of 150kV.

Experiments for the peak current lightning strike to the transmission tower model of 15 kA resulted in a maximum voltage stress which was occurred at 2112kV for the nominal line voltage of 500kV and 611.6 kV for the nominal line voltage of 150kV. These results are shown in Fig. 8 and Fig. 9.

The experimental results for a maximum lightning strike of 23 kA from the peak of the lightning current show the stress profile of the tower model as shown in Fig. 10 and Fig.11. The maximum voltage stress that occurs is 3453.7kV for the nominal line voltage of 500kV and 1006 kV for the nominal line voltage of 150kV.

Fig. 12 and Fig.13 show the distribution of stress stresses in the tower section for the 500kV and 150 kV line sections, respectively. The experimental results show that the chance of a strike that exceeds the ability of the string insulator at a working voltage of 500 kV occurs on phase-A or on the top channel when a lightning strike of 15kA or more occurs. The peak lightning current of 15kA can exceed the maximum withstand voltage of the insulator, which is above 1550kV. In the tower section of 150kV lines, the phenomenon of voltage stress also looks similar, because the chance of a strike that exceeds the electric strength of the string insulator at a working voltage of 150 kV also occurs on the A-phase or at the top of the line when a lightning strike of 15kA or more occurs. The magnitude of the voltage stress that occurs when the peak current is above 15kA allows the back flashover phenomenon to occur due to the jump of electrons in the form of a tower body to the phase line. If phenomenon makes a weakening of the local insulation strength, then there is a possibility of a phase-to-ground short circuit disturbance to follow after the occurrence of the above back-strike phenomenon.

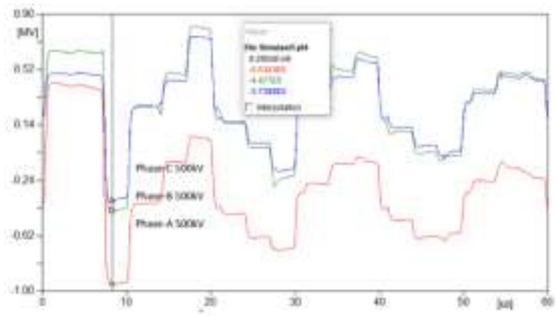

Fig.3. Voltage Stress at 500kV side during Lightning Strike 5 kA_{peak}

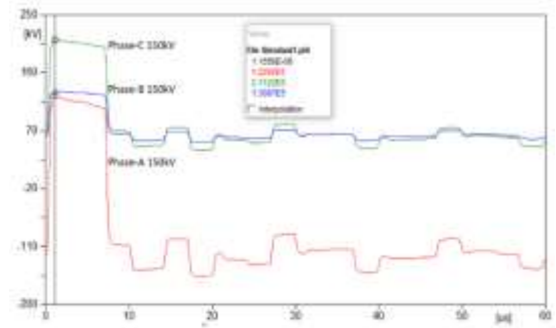

Fig.4. Voltage Stress at 150kV side during Lightning Strike 5 kApeak

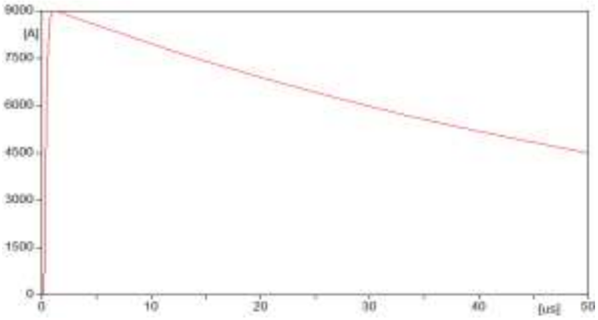

Fig.5. Lightning Current at 5 kApeak

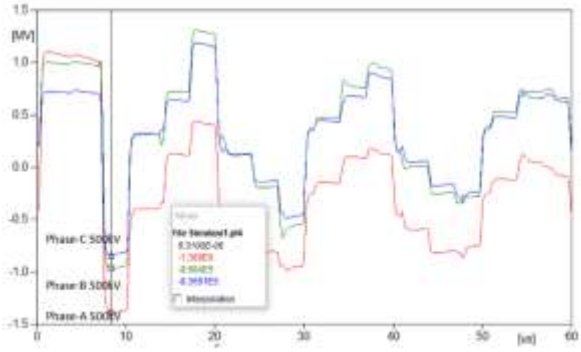

Fig.6. Voltage Stress at 500kV side during Lightning Strike 9 kApeak

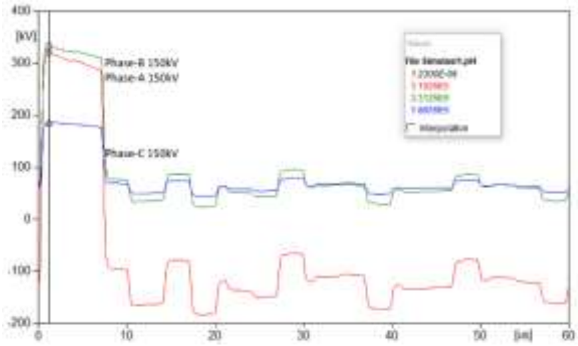

Fig.7. Voltage Stress at 150kV side during Lightning Strike 9 kApeak

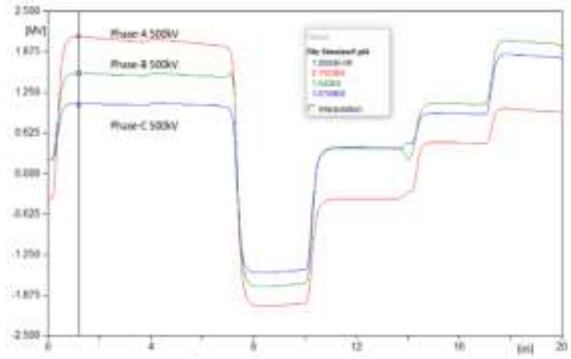

Fig.8. Voltage Stress at 500kV side during Lightning Strike 15 kApeak

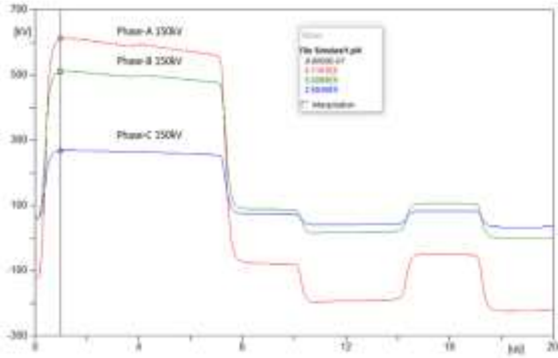

Fig.9. Voltage Stress at 150kV side during Lightning Strike 15 kApeak

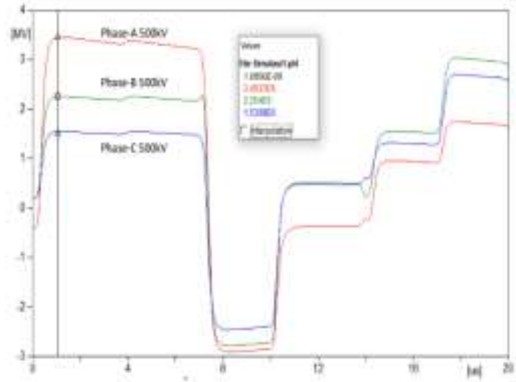

Fig.10. Voltage Stress at 500kV side during Lightning Strike 23 kApeak

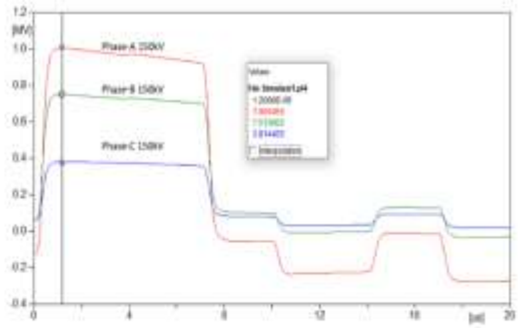

Fig.11. Voltage Stress at 150kV side during Lightning Strike 23 kApeak

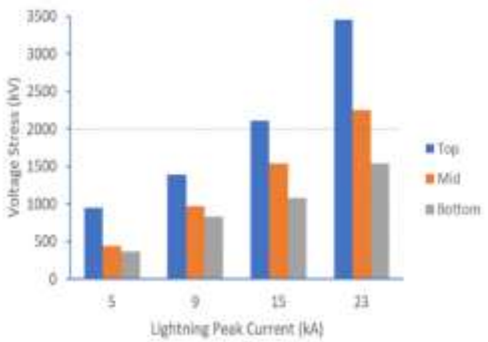

Fig. 12 Stress distribution on the 500kV sides at the top, middle and bottom of the tower for various variations of the peak lightning current

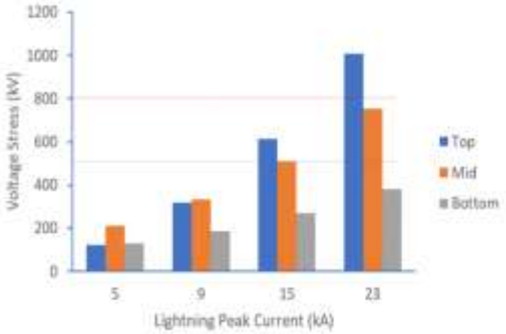

Fig. 13 Stress distribution on the 150kV sides at the top, middle and bottom of the tower for various variations of the peak lightning current

CONCLUSION

An investigation to find out the distribution stress voltage on transmission tower in a quadruple circuit has been carried out by involving the tower model based on its geometric shape. The experimental results with the help of software programs show that there is an increase in stress in the form of stress on the parts of the tower. In conditions of lightning strikes that have a peak current above 15 kA, it is noted that there is a condition of voltage stress that exceeds the insulation strength used for working voltages of 500kV and 150kV. However, the peak lightning current which often occurs in the range of 5kA and 9 kA when it strikes the tower has not resulted in a voltage stress that exceeds the maximum withstand voltage of the applied string insulators. The results obtained are expected to be a reference in the planning and operation of large electric power distribution involving multiple working voltages through transmission towers.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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