# Transient Overvoltage Simulation in 500 kV Transmission Line Plan of Sarawak, Malaysia using PSCAD

**Yanuar Z. Arief, Nur Izziani Roslan, Mohd Hafiez Izzwan Saad, Lakshmanan Gurusamy, Nor Asiah Muhamad**

***Abstract*: Transmission system is a crucial system in electrical power since the system transmit the electricity from power generation to consumer load. According to World Bank, the power losses from transmission lines are rapidly increasing from year to year at the rate of 3.85% in the year of 2013 to 5.792% in 2014. Losses in transmission system are most likely from power quality problems such as transients. Transients are the outcome of high unexpected increment in voltage or current surge magnitudes. The peak values of both voltages and current are usually more than twice of that normal voltage and current amplitudes. The surges due to transients can vitally cause power system failure and breakdown of electrical equipment especially at the substations. There were few known transient overcurrent and overvoltage problems, which are due to faults, lightning and line energizing, respectively. This research work mainly focuses on simulating transients for 500 kV transmission system which employ Sarawak as the case study location. Sarawak currently has main 275 kV transmission line covering the whole Sarawak from Miri to Kuching known as Sarawak backbone, but due to lots of industries and rapid development and urbanization boom in Sarawak, there is a planned of 500 kV transmission line as a backup if the 275 kV transmission line proves inadequate. In Sarawak, the 500 kV is planned to be energized at 275 kV. But, in fact this work is for that transmission line to be operated at 500 kV, hence, monitoring the highest transient may occur.***

***The results revealed that lightning and three-phase faults of 1.0 s fault time duration cause the highest change in amplitude of current on the line up to 9.06 pu and 9.27 pu, respectively.***

***The highest lightning amplitude is observed when lightning was simulated at the receiving end of the line which is near to the Tada substation.***

***Keywords* : 500 kV transmission system, substation, switching surge, lightning surge, PSCAD**.

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## I. INTRODUCTION

Transmission lines are integral part of generation, transmission, and distribution of any power generating plants to consumer loads of grid network. These transmission lines have been used since 19th century by using hydraulic transmission to deliver power to power up industries. In Malaysia, there are six main voltage range for distribution and transmission system, which are 415 V or 400 V, 11 kV, 33 kV, 132 kV, 275 kV and 500 kV, respectively. The 500 kV transmission line is the main transmission for some places in Peninsular Malaysia (West Malaysia) while as a plan of transmission grid for Sarawak (East Malaysia), covering from Similajau to Tondong with approximate length of 505 km in total [1]. The predominant reason for a higher voltage transmission line is to reduce power losses especially for long distance transmission of electricity.

In recent times, the power quality problems constitute the prior causes to power losses during power transmission. There are several types of power qualities such as transients, harmonic, noise, flicker, voltage swell and voltage sag. Power quality is defined as the concept of grounding and powering electronic equipment in a way that is acceptable to the operation of that equipment in accordance with the wiring system of the premise and other connected equipment [2-3]. Meanwhile, transient is defined as voltage or current having impulsive nonrecurring changes in the magnitude.

An impulse transient is described by the time to decay to half of its peak value and time to reach peak value, usually caused by lightning [4-6]. The transients are known to occur due to faults, lightning and line energizing.

An oscillatory transient can cause damage to power line insulators while an impulsive transient can cause equipment damage at the point of inception [7-8]. Transient is one of main power quality problem that can interrupt power transmission and at some point, can cause electrical breakdown.

Power system computer aided design (PSCAD) is a software to simulate and design the power system with comprehensive library ranging from simple elements to complex devices. With the development of simulation tools and new system models, simulation achieves such realistic interpretation of actual conditions in a network while in real-time, that the produced results are capable of providing a highly reliable prediction of the system behavior [9]. There has been research conducted to study the ultracapacitors (UCAP) to improve the power quality of the distribution system, the change in the UCAP voltage was not observable in this case due to the limitations of PSCAD software which only contain short duration of simulation [10].

## II. SIMULATION PROCEDURE

Fig. 1 depicts the simulation flowchart. Firstly, the simulation of this transient overvoltage analysis on 500 kV transmission line plan in Sarawak was employed using PSCAD software. The software has capability to analyze the given data and simulate in accordance to the observed situation. From the flowchart, the first step is to define the parameters of all power system in Sarawak. The parameters include the transmission line configuration and power output of the power stations. With the parameters confirmed, the circuit is designed in accordance to real data situation using Sarawak's power system criteria. The data collected from Sarawak Energy are then fed into the simulation circuit and run for a simulation fault analysis. Using the same parameters and input data of Sarawak system, the simulation circuit was observed and measured for lightning and switching surge cases. All results were compared and analyze either using PSCAD and Microsoft Excel.

This work was analyzed using Sarawak, Malaysia 500 kV transmission line plan. Sarawak currently has 36 power stations. The main transmission line for Sarawak is 275 kV known as Sarawak backbone which spread from Tudan to Sejingkat. The 500 kV transmission line plan which soon to be established and would cover from Similajau to Tondong. The need of 500kV transmission line arises due to the power capacity is expected to dramatically rise with heavy industries and commercialization outlined by the Sarawak government for the next few decades to come. Fig. 2 shows the current grid with proposed 500 kV transmission line system and the existing 275 kV transmission line [11]. The dash line shows the plan of 500 kV transmission line for Sarawak. There are three voltage levels for main transmission line in Sarawak from one substation to another substation which are 132 kV, 275 kV and 500 kV, respectively. The distance of transmission line from one point to another was obtained based on literature and Sarawak Energy report.

Fig. 3 shows a section of the grid system as a circuit model diagram of Sarawak power system which consists of different types of electrical power component such as voltage source, system bus, transmission line and transformer. This circuit was adopted from [11]. The circuit was improved with additional of Murum power station and Balingian power stations. Running capacity of Balingian Power Station is 600 MW, while running capacity for Murum Power Station is 944 MW.

The transient analysis on 500 kV transmission line under fault conditions, line energizing and lightning, respectively. The detail simulated circuit and the parameter are discussed in the following sections.

### A. Faults Simulation Model

For fault simulation studies, there were four types of faults being simulated which are single-line to ground fault, double-line to ground fault, line to line fault and three-phase fault, respectively. All types of faults were applied at 0.2 s of simulation time with 0.05 s fault time duration. Meanwhile, for single line to ground fault and three phase faults was applied twice at time of 0.2 s for 0.05 s and 1 s duration to compare the differences between longer fault period and shorter fault period. The fault was injected at the middle of transmission line where readings were taken at three different locations which were near fault location, near the substation (receiving end) and at the substation. The fault current and the current subsequent fault were measured by taking readings of peak current and voltage drop magnitude during and after fault occurrences. The simulation circuit for fault analysis is shown in Fig. 4.

### B. Line Energizing Model

Using the same circuit and parameters of Sarawak power system, line energizing was simulated by using circuit breaker to open and close transmission line that were connected to substations. The circuit breakers are located at each end of transmission line connected to substations, there are the circuit breakers to energize and de-energize transmission line. The scenarios for circuit breaker are depicted in Table 1. The simulation circuit for line energizing analysis is shown in Fig. 5.

**Table- I: Circuit breaker scenario for line energizing circuit**

| | Sending End (Tondong Substation) | Receiving End (Tada Substation) | Both end |
|---|---|---|---|
| BRK A (initial state condition) | open | close | Open |
| Time of first breaker operation | 0.2s | 1.0s | 0.2s |
| BRK B (initial state condition) | close | open | Open |
| Time of first breaker operation | 1.0s | 0.2s | 0.2s |

### C. Lightning Model

For lightning simulation analysis, the transmission line was injected with high current amplitude of 30 kA and 120 kA, respectively. The typical lightning current is 30 kA to 120 kA in which the 30 kA and 120 kA were classified as low and high lightning current accordingly. The time to apply lightning current was set at 0.15 s with 1.2/50 µs of surge waveform according to IEC standard.

The lightning was injected at the middle of 500 kV transmission line and at the receiving end. The measures were taken at two different locations, namely middle line and receiving end of the line. The simulation circuit for lightning analysis is shown in Fig. 6.

## III. RESULTS AND DISCUSSION

### A. Faults

The fault analysis was simulated with four different fault scenarios which were single line-to-ground fault, double-line to ground fault, line-to-line fault and three-phase fault, respectively. During single line-to-ground fault, only one phase of power transmitted was induced with a fault at the middle of the line affects the two other phases of the line. The voltage of faulty phase dropped as current magnitude increased. Fig. 7 (a) shows the result for single line to ground fault current of 3.78 pu of that nominal current at phase A of the waveforms.

Double-line to ground fault involved phase one and two that were connected to ground. This type of fault was unlikely to occur compared to single line to ground fault. It is to be noted with this type of fault, the magnitude of current increase during fault at the fault location and some disturbances before the current return to its normal condition. The maximum fault current also increased vary to the single line to ground fault. The highest fault current during fault occurrence was at 3.98 pu of the nominal current value as shown in Fig. 7(b).

Line to line fault involved two lines without reaching the ground differed from the double line to ground fault which involved two lines but were connected to ground. From simulated waveform as shown in Fig. 7(c), the line to line fault were likely to have noise more than double line to ground fault. The figure showed the peak current of line to line fault is at 5.17 pu of the nominal current value.

Three-phase fault is a crucial fault but unlikely to occur compared the other three types of faults above. The fault involved all three-phase line of the transmission line and connected to ground. The three-phase fault causes waveform to have severe disturbances compared to single line-to-ground, double-line to line and line to line faults. Fig. 7(d) shows the current during fault which lead to a 5.25 pu of the nominal current value.

Fig. 8 shows the highest peak current between all four types of fault on 500 kV Sarawak transmission line plan. The reading was taken at two different point of location which are receiving end and middle line which is the fault location. The highest current which is the most severe faults is three-phase fault measured at the receiving end with 5.25 pu followed by line to line fault measured at the receiving end, it was 5.17 pu. As discussed before, the receiving end showed higher magnitude of current due to the overlapping current of fault current and current from the other end of the substation. The less severe fault on 500 kV transmission line was the line to line fault measured at fault location in which reach only 3.76 pu current then followed by single line to ground fault measured at fault location with 3.78 pu. Although at the fault location for line to line fault is the lowest but the receiving end showed high current increase with 5.17 pu. There were quite a number for methods to protect the transmission line. It is a necessary to find fault on transmission line if the faults are still not returned to its normal value after times of resetting. Locations of faults for the repair purposes on overhead lines which dates to the eighties is still an interesting for researchers and utilities personnel [12].

As simulated above, single line-to-ground fault was highly probability for fault occurrences. The fault can cause current surges on the line which was high current increment. Then, the single line-to-ground fault was simulated using the same concept but with longer fault time duration of 1.0 s. The results were shown in Fig. 9.

As can be seen from the Figure 10, the highest peak current is 9.27 pu for a three-phase fault occurs at the middle line measured at the receiving end of 500 kV transmission line plan. Three-phase fault as stated before has severity higher than other types of faults but very unlikely to occur. The severity for fault duration of 0.05 s and 1.0 s was differed. The highest peak current increased as the measurement took place for a 1.0 s of fault duration. This is due to the fault that occurred could possibly increasing as high current travelled in longer distance with longer fault duration.

### B. Line Energizing

By utilizing the same parameters as depicted in Figure 4, line energizing was simulated by coupling circuit breaker to open and close the transmission line that were connected to substations. At time interval of 0.2 s, the circuit breaker was set to start the first operation which is to close breaker after having initially in the state of open condition. There were three main case studies regarding the line energizing, namely line energizing at receiving end, line energizing at the sending end and lastly line energizing at both end at the same time.

The first case study was to energize the line at the receiving end which is near Tada substation. The line was already energized at sending end which is near the Tondong substation and energized at the other end after 0.2 s. The resultant current at the receiving-end of the line as shown in Fig. 11(a).

Second case study was the energization of line at sending end of the line. The sending end refers to the transmission line near Tondong substation of Kuching division. The receiving-end voltage shows that the voltage before energizing at the sending-end to be higher than that after energizing. This is because the receiving end carry power from Bakun and Murum hydropower station which is large power station in Sarawak with high capacity. Bakun's running capacity is 2,400 MW per day made it to be the largest hydro power station in Sarawak. During the energization, voltage waveform seems to have disturbances before return to its nominal value. The voltage waveform reached nominal value after line energization is due to the power is being distribute evenly through Tondong substation.

For the third energizing case, the circuit is being energized at both receiving and sending end of the line at the same time. The highest peak current occurred during this case is at the receiving end of the line which is 3.89 pu.

The line was initially zero without any current transmit, after the energization at 0.15 s, the magnitude of current increase causes surges to the transmission line and reach at nominal value of 0.26 s.

Figure 12 shows the highest currents and voltages for all three cases. The highest peak current among the three cases is at the third cases of line energizing for both ends which are

Tondong and Tada substations while the highest voltage was at the second case of line energizing 500 kV transmission line plan.

### C. Lightning Surge

Malaysia has a high record of isokeraunic level nearly 200 thunderstorm days per year. The high number of lightning strike is responsible for 50% of the total number of system failures and has caused multiple trip-outs on the EHV transmission lines each year [12]. About 30 kA to 120 kA lightning current may occur during lightning strike. Meanwhile, the typical lightning current is typically in Malaysia is more than 20 kA [13-15]. These will cost fatal death and breakdown of electrical equipment.

For simulation lightning current at 30 kA and 120 kA, the circuit was injected with 30 kA and 120 kA current surges of 1.2/50 µs. There are two given situations at which currents are injected at the middle of the line and the receiving end of the line. The results are as shown in Figure 13. It shows that there is not much different in magnitude increment between 30 kA and 120 kA. Both have the highest increment of 9.05 pu for 30 kA and 9.06 pu for 120 kA at the receiving end measured at receiving end of the line. Meanwhile, the lowest current increment for both studies are lightning strike at mid location of the line measured at the receiving end. The results are shown in Figure 13(c). The chart shows the results taken from two locations of the line which are mid-line and the receiving end of the line. The highest peak current occurred when the lightning current injected at the receiving end of the line measured at the receiving end of the line for both currents 30 kA and 120 kA.

## IV. CONCLUSION

Sarawak has high potential for renewable energy such that hydropower plant that could be commissioned in various location in Sarawak. Hence, large power is able to be transmitted throughout Sarawak and even supply to the neighboring countries, like Indonesia and Brunei. However, the biggest challenge faced due to its vast land area of 124,450 km$^2$. To transmit power without high power losses, the high voltage transmission line is vital. The existing 275 kV transmission line is already 30 years old to supply to about millions of consumers. Therefore, the need of 500 kV transmission system is vital for Sarawak electrical power transmission. This work exhibits the investigation result on the 500 kV system plan with three types of cases involved which are faults study, line energizing and lightning, the results showed three phase faults, which is 1.0 s fault time duration has the highest severity on transmission line which the peak current measured was 9.27 pu followed by lightning with 120 kA current injection of 9.06 pu. This can cause severe damage onto the system if not being protected especially at the substation.

This transient analysis was expected to give useful input into behavior of 500 kV grid system under various loadings to the local power generating authority in evaluating the transmission line protection system because transient is one of the highly possibilities to occur on power system compared to other power quality problems. The transient also caused the fatal damage to the electrical equipment if the protection system is not properly designed.

## ACKNOWLEDGMENT

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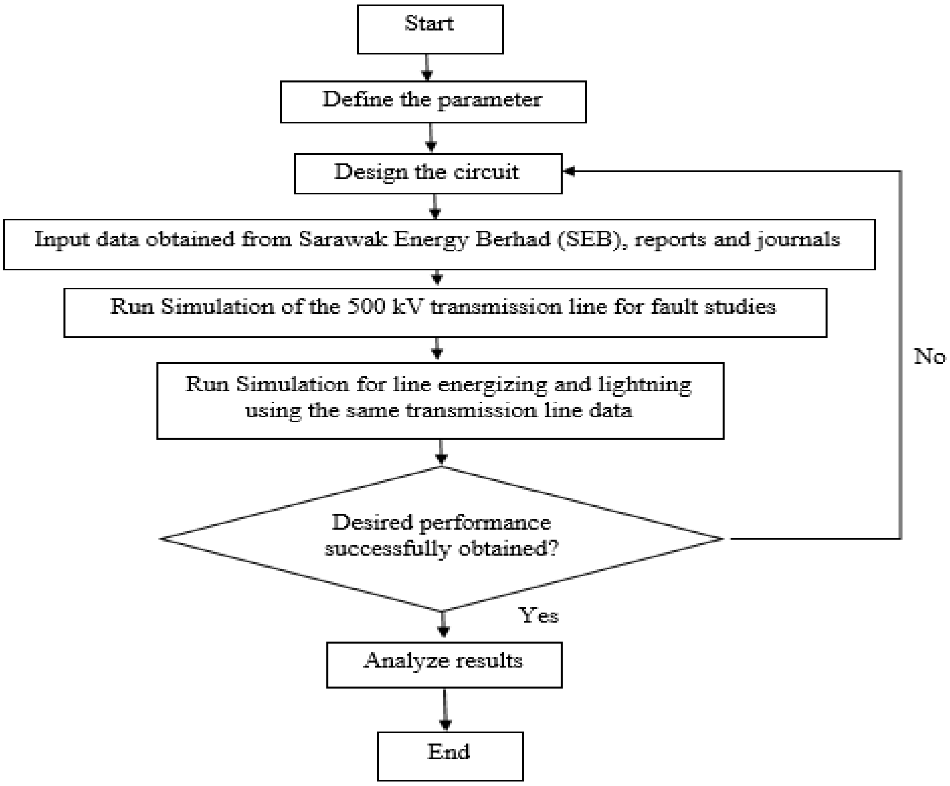


**Fig. 1. Transient overvoltage analysis flowchart**

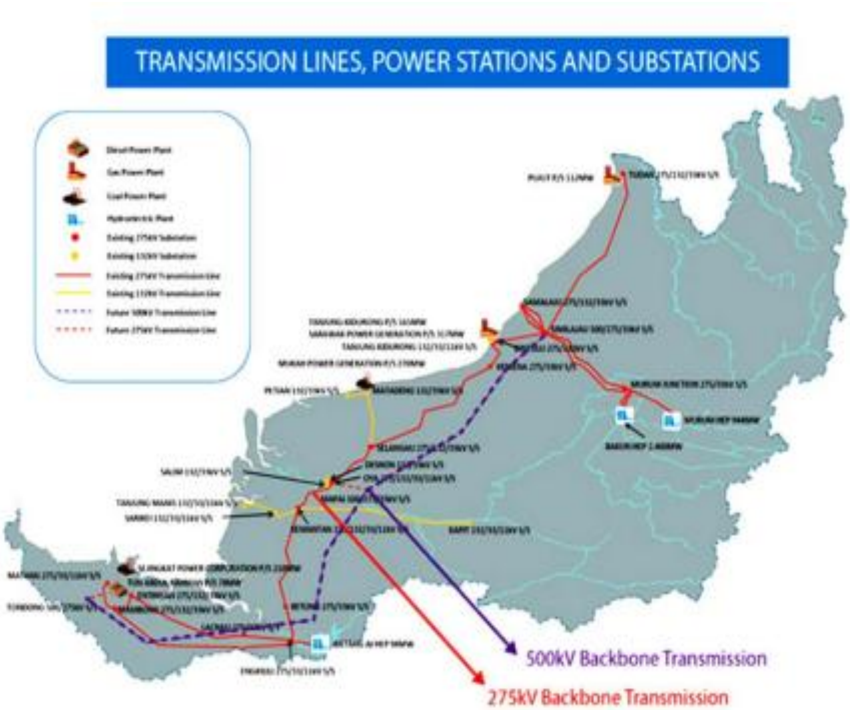


**Fig. 2. Current Sarawak grid diagram with the existing 275kV system and 500kV transmission line system plan [11]**

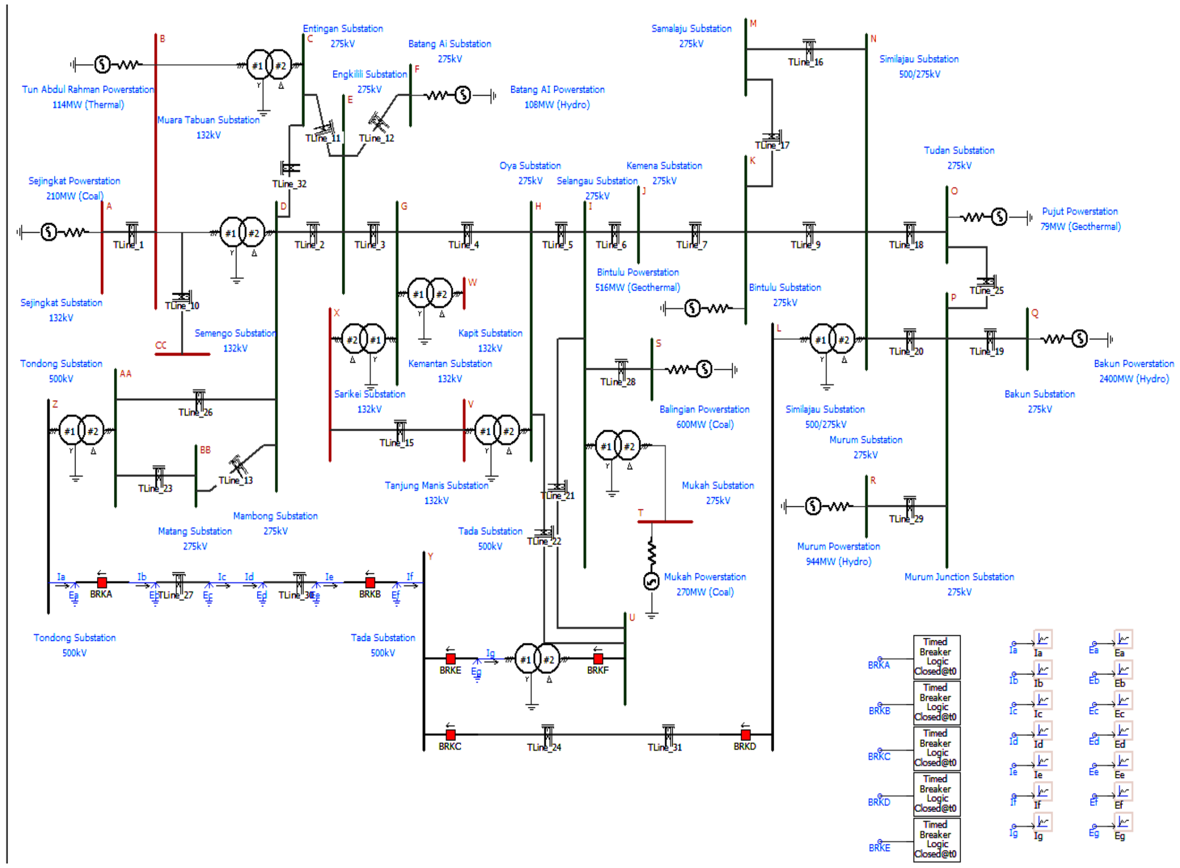


**Fig. 3. Modeling of Sarawak power system using PSCAD by improving with Balingian and Murum Power Stations.**

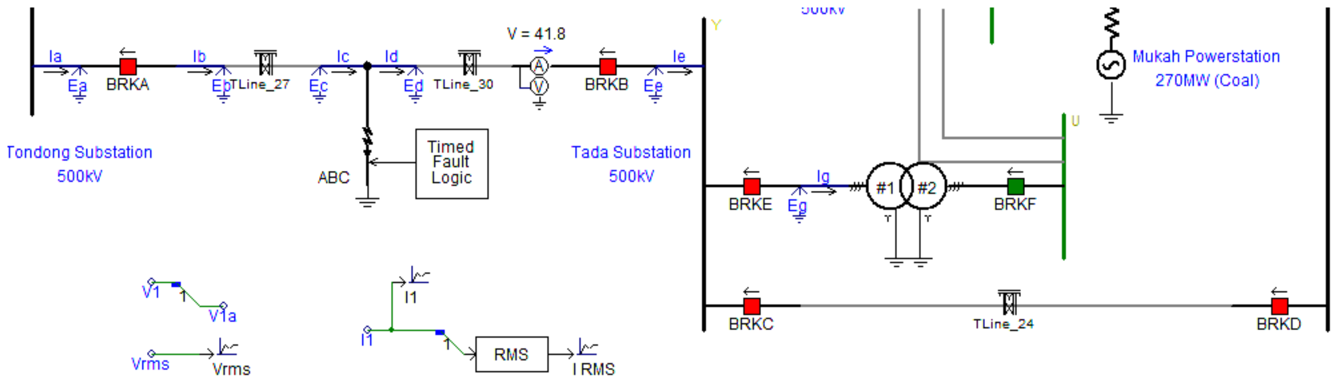


**Fig. 4. Fault simulation model in PSCAD.**

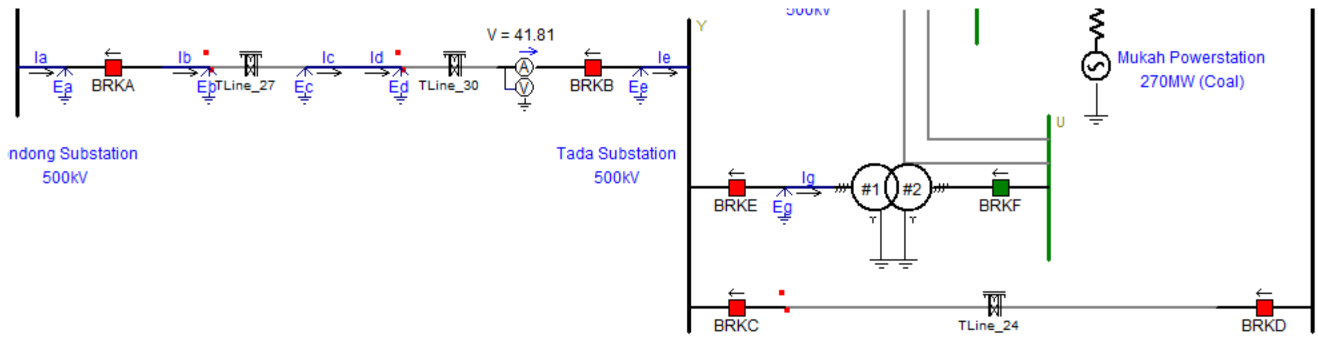


**Fig. 5. Line energizing simulation model in PSCAD.**

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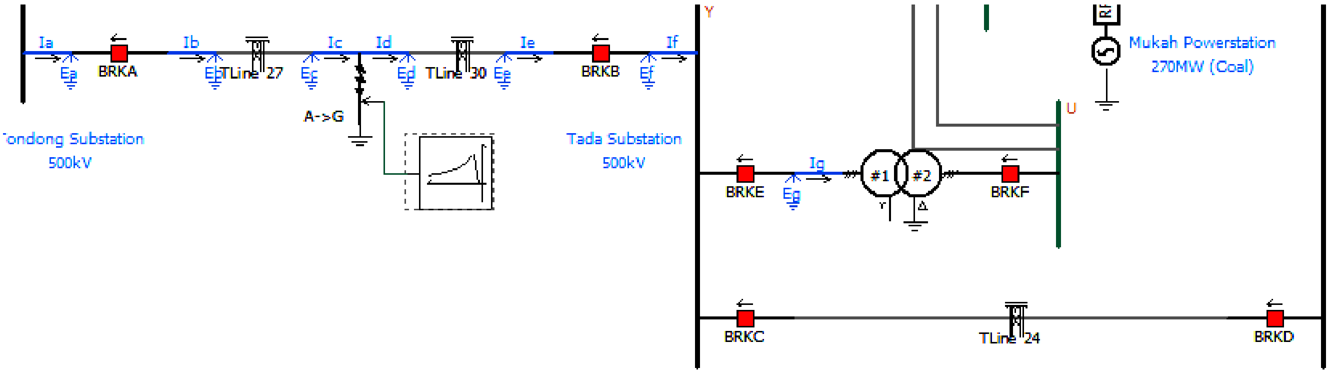
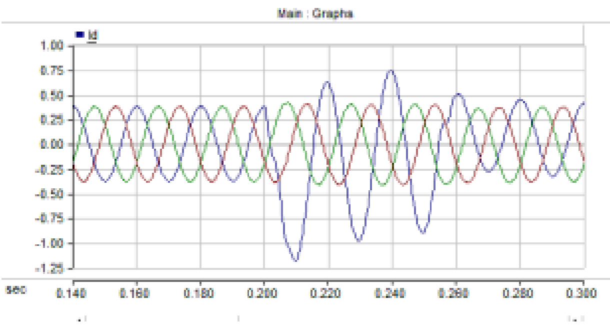
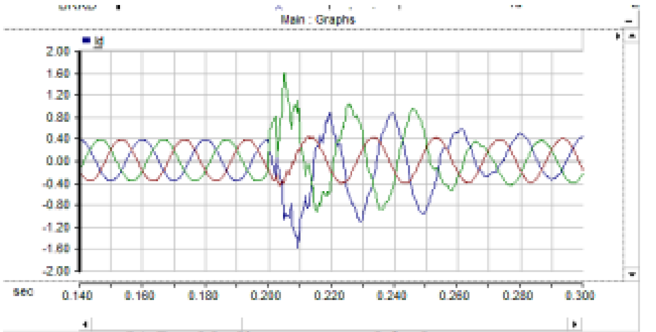


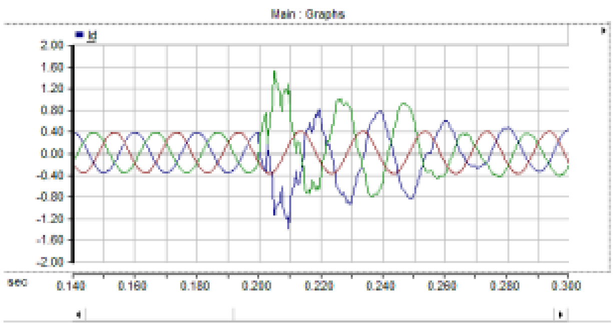

Fig. 6. Lightning simulation model in PSCAD.



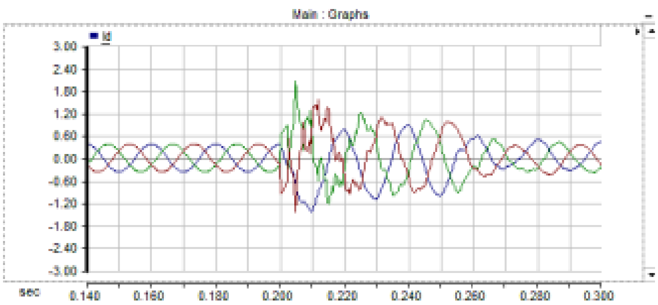

(a) Single line-to-ground fault current




(b) Double-line to ground fault current

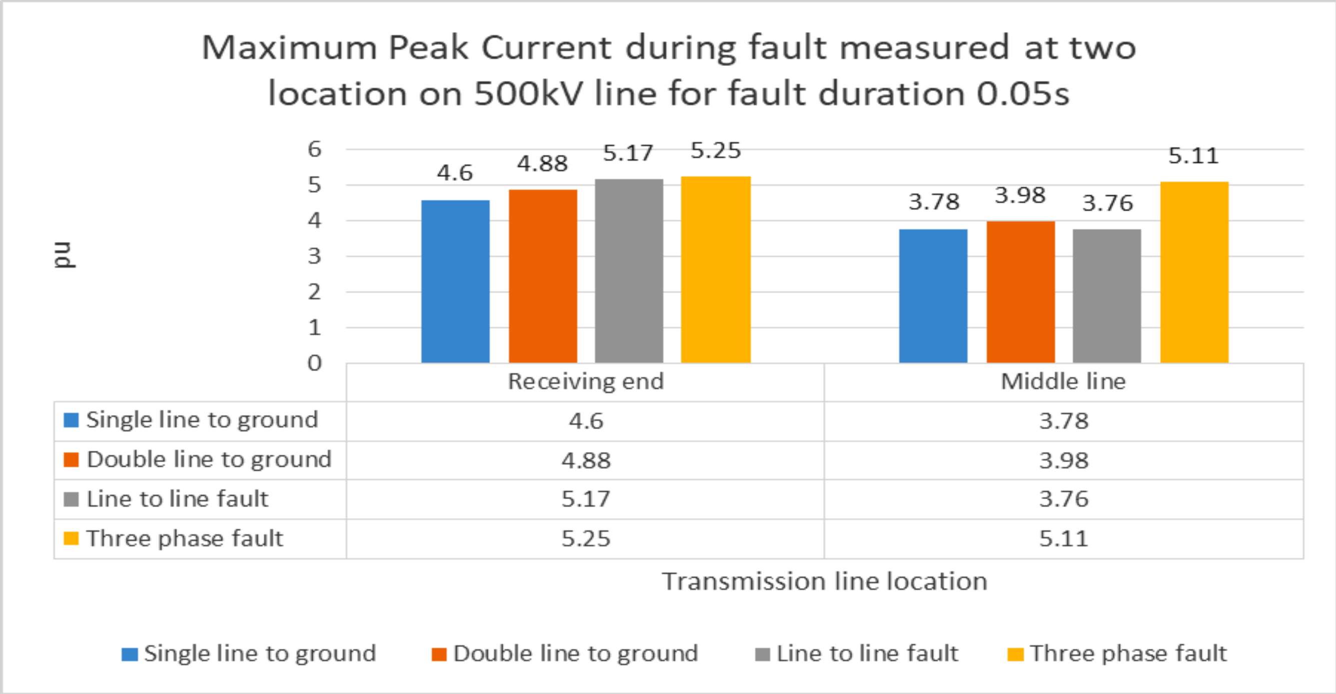



(c) Line to line fault current



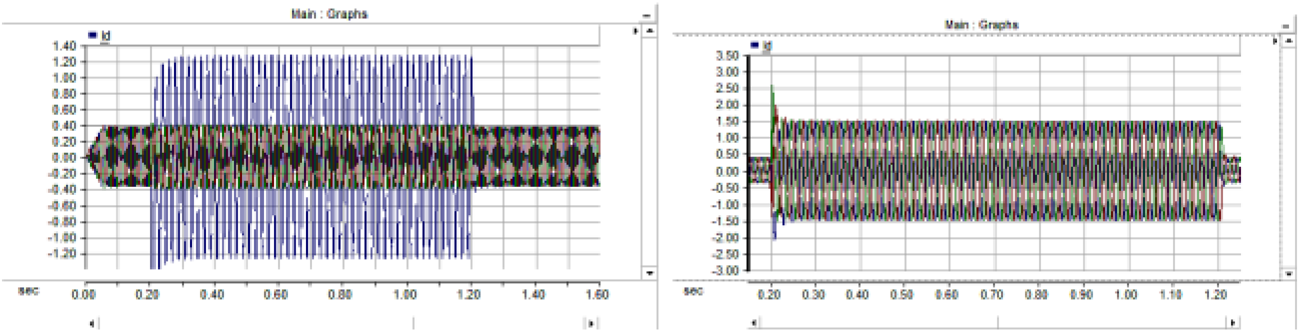

(d) Three-phase fault current

Fig. 7. Results of fault occurrence as simulation results in PSCAD.



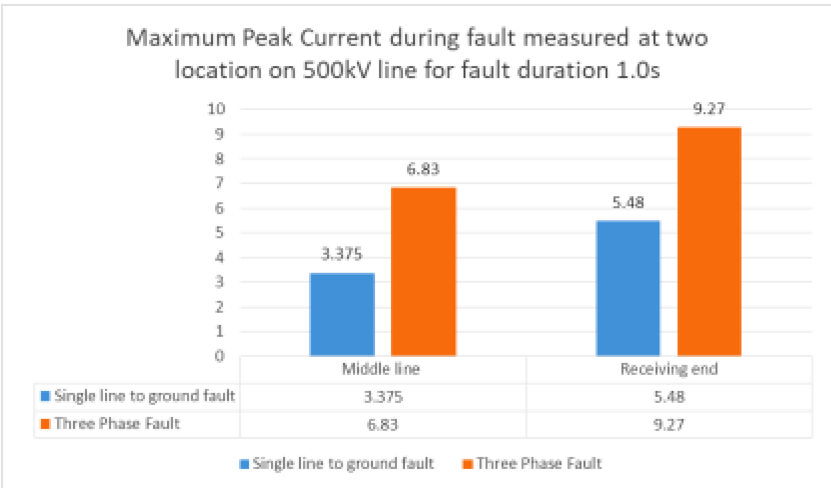

| | Receiving end | Middle line |
|---|---|---|
| Single line to ground | 4.6 | 3.78 |
| Double line to ground | 4.88 | 3.98 |
| Line to line fault | 5.17 | 3.76 |
| Three phase fault | 5.25 | 5.11 |

**Fig. 8. Maximum peak current during fault measured at two locations on 500kV for 0.05s fault time duration.**




**(a) Single line to ground fault current** **(b) Three-phase fault current**

**Fig. 9. 1.0 s fault time duration of fault occurrence as simulation results in PSCAD.**




| | Middle line | Receiving end |
|---|---|---|
| Single line to ground fault | 3.375 | 5.48 |
| Three Phase Fault | 6.83 | 9.27 |

**Fig. 10. Maximum peak current during fault measured at wo location on 500 kV line for fault duration of 1.0** s.

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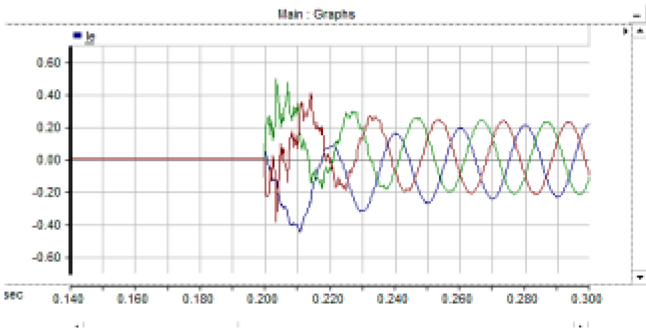
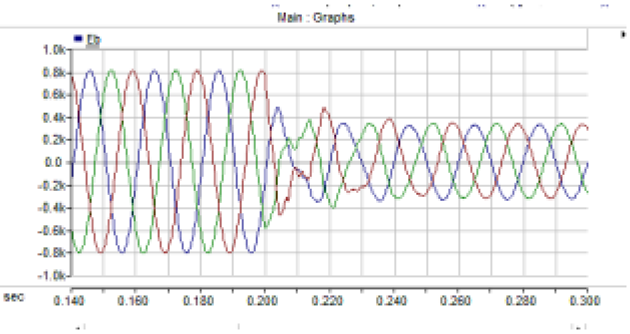
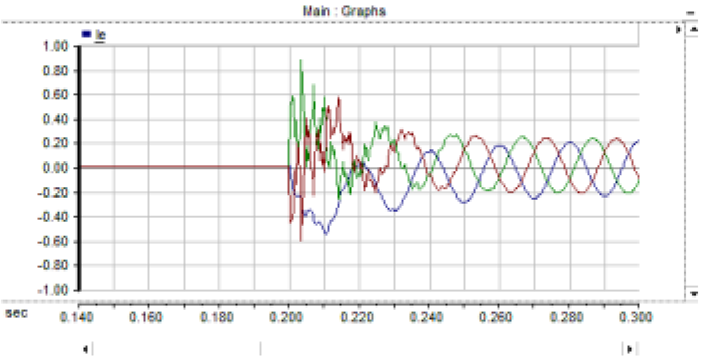



**(a) Line energizing at receiving end (Tada Substation)**




**(b) Line energizing at sending end (Todong Substation)**




**(c) Line energizing at both end (Tada and Tondong Substation)**

**Fig. 11. Current profile during line energizing at 500kV transmission line plan.**

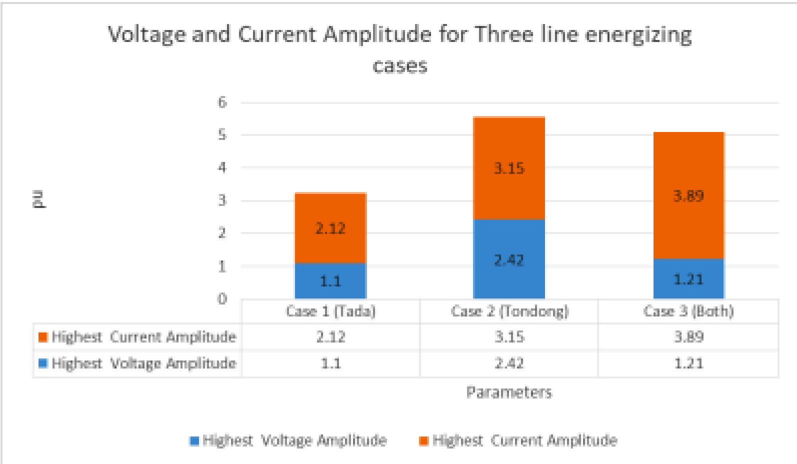
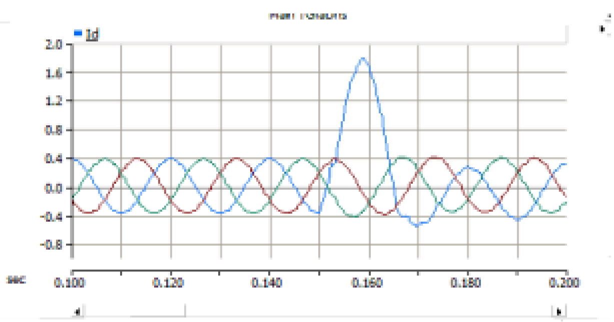
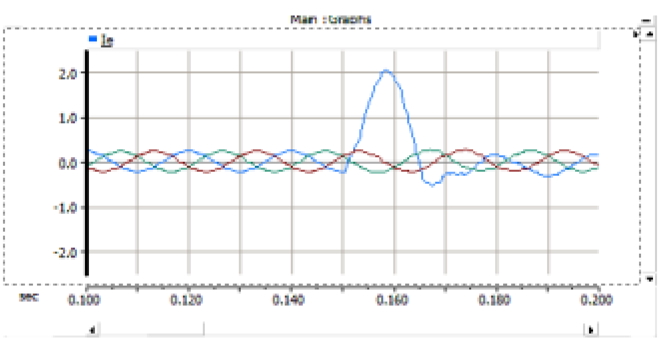



**Fig. 12.** **Voltage and current amplitude for three cases of line energizing obtained from simulation results in PSCAD.**




**(a) Current profile with injected with 30 kA of lightning current (b) Current profile with injected with 120 kA of lightning current**

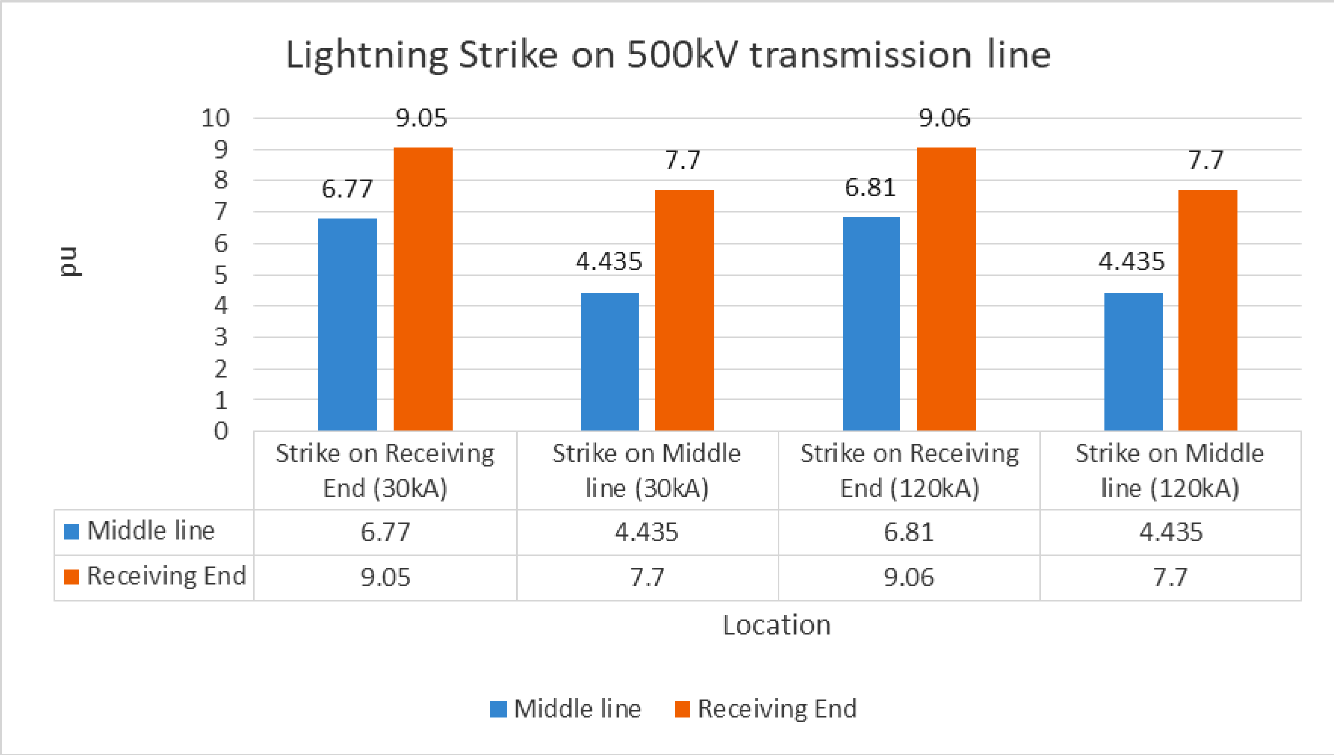



**Fig. 13. Voltage and current amplitude for three cases of line energizing obtained from simulation results in PSCAD.**