Analysis of Resonance in Sumatra 500 kV Extra High Voltage Transmission Line Energization Schemes

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Abstract. Various analyzes are needed on the transmission line before energizing the extra-high-voltage transmission line. One of the analyzes that need to be carried out in lightly loaded double-circuit transmission lines equipped with shunt reactors is resonance analysis. Resonance causes a high increase in voltage on the line that has not been energized due to the interaction of shunt reactors with the remaining energized phase(s)/circuit(s) through capacitive coupling. This study focuses on resonance analysis which is carried out using electromagnetic transient analysis. As a result, there are several potential resonances in Sumatra 500 kV transmission line energization schemes.

Keywords: *Resonance; shunt reactor; energization; EHV transmission line.*

1. Introduction

RUPTL PLN 2021-2030 was prepared to provide information and an overview of plans for developing Indonesia's future electric power system, including the Sumatra system development plan [1]. It is stated that the construction of a 500 kV backbone transmission will be carried out in the eastern corridor connecting large-scale power plants and large load centers in Sumatra. Transmission lines aim to transfer electric power from power plants with many cheap primary energy sources (South Sumatra, Jambi, and Riau) to load center areas with limited primary energy sources (Sumbagut). Based on the RUPTL PLN 2021-2030, it is planned to build the 500 kV New Aurduri - Peranap transmission line for 210 km and the 500 kV Peranap - Perawang transmission line for 180 km, which is estimated to be Commercial Operation Date (COD) in 2021. However, there are several obstacles in the project, so the estimated COD time of the transmission section would be COD in 2022.

Figure 1 New Aurduri - Peranap - Perawang 500 kV Transmission Line

For safety and reliability of operation, it is necessary to control voltage and reactive power that meet voltage limit standards (Grid Code) [2]. The shunt reactor is used to compensate for the existing capacitance along the transmission line to limit overvoltage on the transmission line [5]. Installing shunt reactors in lightly loaded double-circuit transmission lines causes parallel resonance on the de-energized transmission line [7]. Resonance causes a high increase in voltage on the line that has not been energized due to the interaction of shunt reactors with the remaining energized phase(s)/circuit(s) through capacitive coupling. Shunt capacitances of double-circuit lines occur between conductor to ground, interphase, intercircuit-unlike phases, and intercircuit-like phases [3]. Resonance can also happen on a fully shunt-compensated transmission line. Several studies have conducted resonance analysis on extra high voltage transmission lines [3][5][6][7][8]. The results show that the transmission line is very vulnerable to resonance. Therefore it is necessary to analyze the resonance potential of Sumatra 500 kV transmission line to bring the proper energization process.

2. Methodology

Load flow analysis is carried out to analyze power flow in the network. It is the basis for further investigation, such as electromagnetic transient analysis. The Load flow analysis for the New Aurduri - Peranap - Perawang transmission line energization schemes carried out under off-peak load conditions (LWBP). The off-peak load condition was chosen as the basis for the simulation because the transmission line load is lower in this condition, which means the transmission line is more capacitive. The result of load flow simulations should meet the criteria set out in the grid code. In this case, the system voltage must be maintained within limits according to the Sumatra Electric Power System Network Rules as stated in the Minister of Energy and Mineral Resources Regulation No. 20 of 2020. It is noted that the system voltage must be maintained within the voltage limits listed in Table 1 :

Table 1 Nominal Voltage Limits of Sumatra Transmission Line

No	Nominal Voltage	Limits
1	500 kV	+5%, -5%
2	275 kV	+5%, -5%
3	150 kV	+5%, -10%

The voltage difference for the voltage synchronization process of the transmission line should not be more than 0.03 p.u. In this research, the power system analysis was performed using DIgSILENT PowerFactory software to calculate load flow and electromagnetic transient analysis on transmission lines. Electromagnetic transient analysis is performed to calculate transient analysis in the form of resonance. The main objective of the study of electromagnetic transients is to review whether there is a potential for resonance in New Aurduri - Peranap - Perawang 500 kV line energization schemes.

The simulation of 500 kV New Aurduri - Peranap - Perawang transmission line energization schemes was carried out from the New Aurduri side with four main conditions:

- The energization of 500 kV New Aurduri - Peranap (2 circuits) and 500 kV Peranap - Perawang (2 circuits) transmission lines
- The energization of 500 kV New Aurduri - Peranap (2 circuits) and GITET 500 kV Peranap - Perawang (1 circuit) transmission lines
- The energization of 500 kV New Aurduri - Peranap (1 circuit) and 500 kV Peranap - Perawang (1 circuit) transmission lines
- The energization of 500 kV New Aurduri - Peranap (1 circuit) and 500 kV Peranap - Perawang (2 circuits) transmission lines

The simulation of 500 kV Perawang - Peranap - New Aurduri transmission line energization schemes was carried out from the Perawang side with three main conditions:

- The energization of 500 kV Perawang - Peranap (2 circuits) and 500 kV Peranap - New Aurduri (2 circuits) transmission lines

- The energization of 500 kV Perawang - Peranap (1 circuit) and 500 kV Peranap - New Aurduri (2 circuits) transmission lines

- The energization of 500 kV Perawang - Peranap (2 circuits) and 500 kV Peranap - New Aurduri (1 circuit) transmission lines

The simulation of 500 kV Perawang - Peranap transmission line energization schemes was carried out from the Perawang side with three main conditions:

- Energization of 500 kV Perawang – Peranap (Circuit/Line 1) transmission line

- Energization of 500 kV Perawang – Peranap (Circuit/Line 2) transmission line

- Energization of 500 kV Perawang – Peranap (Circuit/Line 1 or 2) transmission line

The line coupling modeling for 500 kV New Aurduri – Peranap – Perawang can be seen in Figure 2. There are two transposition points on the T180 and T352 transmission towers from the 500 kV New Aurduri - Peranap substation and two transposition points on the T168 and T264 transmission towers from the 500 kV Peranap – Perawang substation.

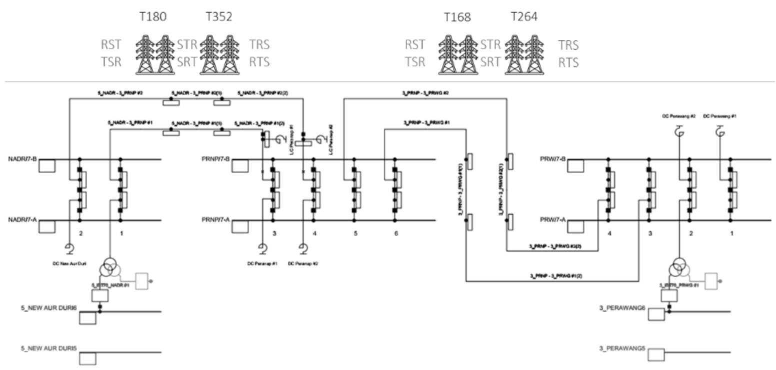

Figure 2 500 kV New Aurduri - Peranap - Perawang Transmission Line Coupling Model

The tower is a standard 500 kV (type AA) double-circuit transmission line shown in Figure 3.

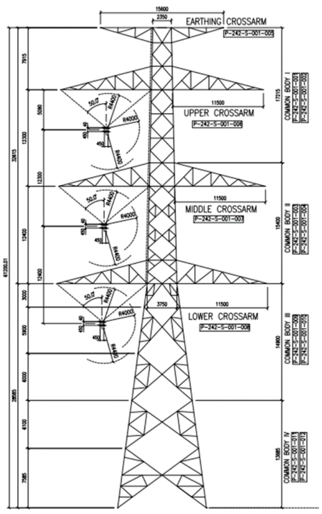

Figure 3 500 kV New Aurduri - Peranap - Perawang Transmission Tower

The shunt capacitances of the double-circuit transmission line can be seen in Figure 4.

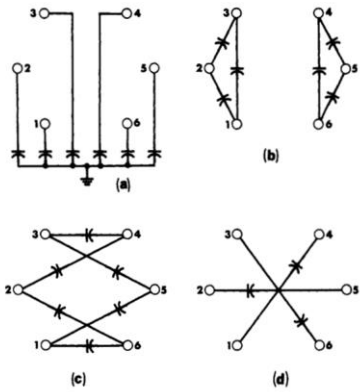

Figure 4 (a) conductor to ground, (b) interphase, (c) inter-circuit-unlike phases, and (d) inter-circuit-like phases

2.1 Transmission Line Charging

Line capacitance (network capacitance) and reactance (inductive reactance) are distributed along the transmission line. The charging MVar on extra high voltage transmission lines is calculated using the following relation.

$$r = 0.7788 \times r_a \quad (1)$$

$$C_N = \frac{2\pi k}{\ln\left(\frac{D_{eq}}{r}\right)} \quad (2)$$

$$X_C = \frac{1}{2\pi f \times C_N} \quad (3)$$

$$Q_c = \frac{U^2}{X_C} \quad (4)$$

Where r is the Geometric Mean Radius (cm), r_a is the conductor radius (cm), C_N is the capacitance to neutral (F/m), $k = 8.85 \times 10^{-12}\ F/m$, D_{eq} is the distance between the bundle centers (cm), X_C is the capacitance reactance ($\Omega.km$), f is the frequency (Hz), Q_c is the charging MVar (MVar/km), U is the line to neutral voltage (kV). Using an extra high voltage of 500 kV with 4 x ACSR Hawk bundle conductors will make the charging current (capacitive current) of the extra high voltage overhead lines significant, causing a relatively large line charging, around 1 MVar/km.

2.2 Resonance Analysis

Resonance causes a high increase in voltage on the line that has not been energized due to the interaction of shunt reactors with the remaining energized phase(s)/circuit(s) through capacitive coupling. Resonance can also occur on a fully shunt-compensated transmission line. Figure 5 explains how resonance occurs in a circuit that has not been energized.

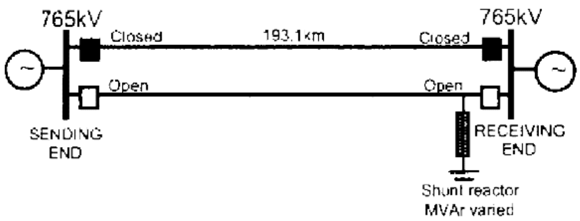

Figure 5 Resonance on the De-Energized Circuit

A reactor compensation of 70-80% (typical) should be used to avoid resonance. Several shunt reactors are on the 500 kV New Aurduri – Peranap – Perawang transmission line (diameter connected and line connected shunt reactors). The number and placement of shunt reactors in the actual conditions of the 500 kV New Aurduri – Peranap Perawang line are as follows:

- 500 kV New Aurduri substation: a shunt reactor (diameter connected, 100 MVar)
- 500 kV Peranap substation: two shunt reactors (diameter connected, each 100 MVar) and two shunt reactors (line connected, each 100 MVar) which are connected to 500 kV New Aurduri transmission lines
- 500 kV Perawang substation: two shunt reactors (diameter connected, each 100 MVar). The shunt reactors are under construction, but in this research, it is assumed that they also have been completed, so the resonance analysis in the energization schemes can be analyzed thoroughly

3. Result and Discussion

3.1 Resonance in 500 kV New Aurduri – Peranap – Perawang Transmission Line Energization Schemes

Figure 6 shows the resonance in the energization scheme for the 500 kV New Aurduri – Peranap – Perawang transmission line. Resonance occurs in line 2 of the 500 kV Perawang – Peranap transmission line when it is not energized yet.

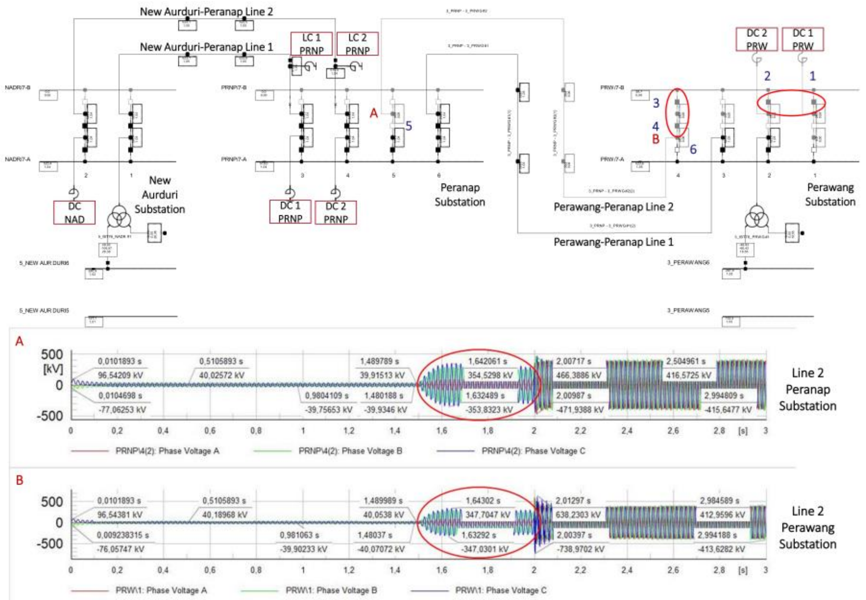

Figure 6 Resonance on the De-Energized Transmission Line (Diameter Connected Shunt Reactors)

Table 2 describes the closing steps of the circuit breaker. Closing the circuit breaker (PMT 7AB4 in Perawang substation) causes resonance and increases the voltage of line 2 up to 354.53 kVp.

Table 2 CB Closing Steps - Resonance on the De-Energized Transmission Line (Diameter Connected Shunt Reactors)

Step	CB	Transformer Tap	Time (s)	Description
1	7B1 PRW	-	0	Closing CB in Perawang Substation
2	7B2 PRW	-	0.5	
3	7B4 PRW	-	1	
4	7AB4 PRW	-	1.5	
5	7AB5 PRNP	-	2	Energizing Line 2 Perawang-Peranap
6	7A4 PRW	-	2.5	Synchronizing in Perawang Substation

Another scheme that causes resonance can be seen in Figure 7.

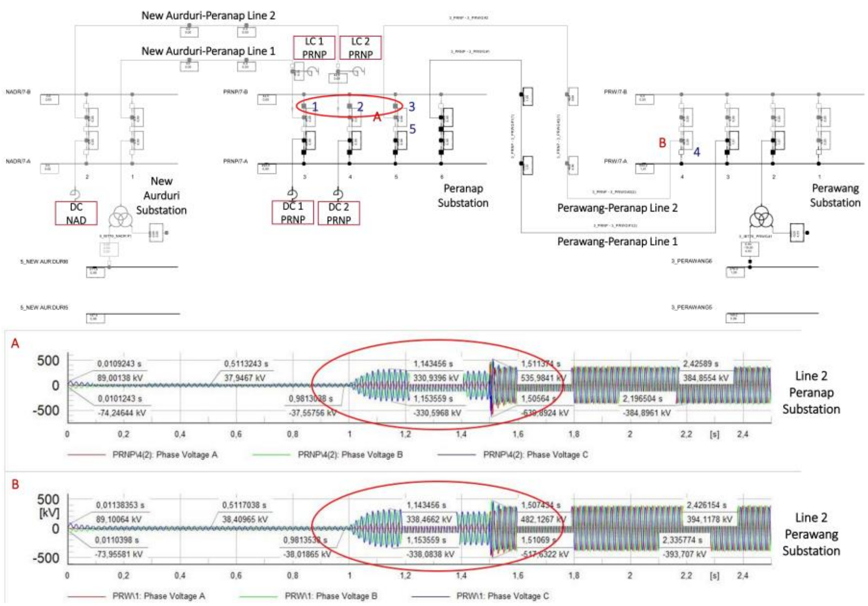

Figure 7 Resonance on the De-Energized Transmission Line (Line Connected Shunt Reactors)

Figure 7 shows the resonance in the energization scheme for the 500 kV Perawang – Peranap transmission line. Resonance occurs in line 2 of the 500 kV Perawang – Peranap transmission line when it is not energized yet. Table 3 describes the closing steps of the circuit breaker. Closing the circuit breaker (PMT

7B5 in Peranap substation) causes resonance and increases the voltage of line 2 up to 338.46 kVp.

Table 3 CB Closing Steps - Resonance on the De-Energized Transmission Line (Line Connected Shunt Reactors)

Step	CB	Transformer Tap	Time (s)	Description
1	7B3 PRNP	-	0	Closing CB of Line Connected Shunt Reactors in Peranap Substation
2	7B4 PRNP	-	0.5	
3	7B5 PRNP	-	1	
4	7A4 PRW	-	1.5	Energizing Line 2 Perawang-Peranap
5	7AB5 PRNP	-	2	Synchronizing in Peranap Substation

The schemes mentioned above cause resonance because the size of the shunt reactor's (diameter connected or line connected) compensation for line 2 has almost reached total compensation. The length of line 2 to be energized is ±180 km while the shunt reactor's capacity reaches 200 MVar. Therefore, it is necessary to change the steps of energization at this stage. From Figure 6 and 7, the energization scheme can be changed to a better one, so the resonance can be eliminated.

3.2 Changing the Energization Steps

Figure 8 shows the changing of the energization steps to avoid resonance in line 2 Perawang – Peranap (diameter connected shunt reactors).

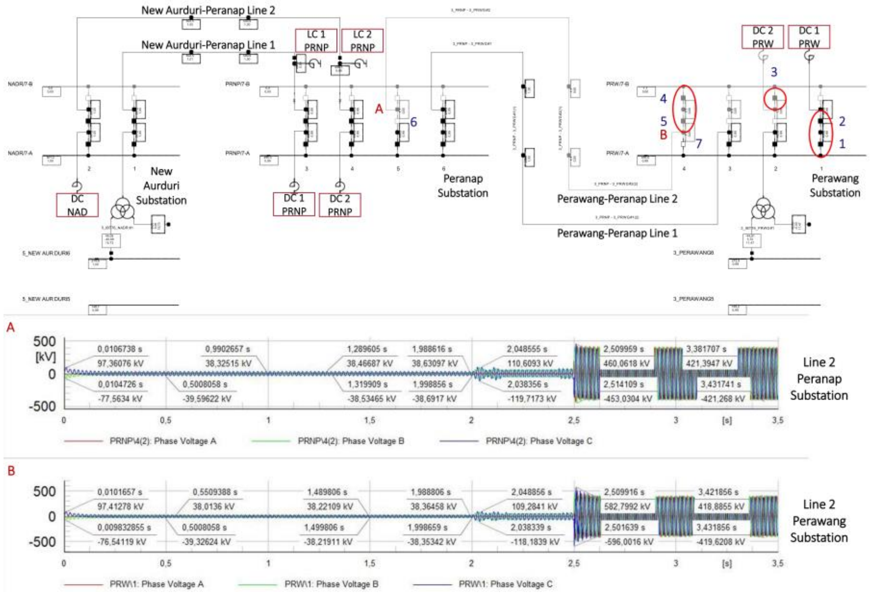

Figure 8 Changing of the Energization Scheme for Line 2 (Diameter Connected Shunt Reactors)

In Figure 8, it is found that the change in the energization steps is carried out by first energizing shunt reactor 1 in Perawang (diameter connected) before energizing line 2, which is connected to shunt reactor 2 in Perawang (diameter connected) so it does not cause resonance in line 2. Table 4 describes the changing of the energization scheme for Line 2 (diameter connected shunt reactors).

Table 4 CB Closing Steps - Changing of the Energization Scheme for Line 2 (Diameter Connected Shunt Reactors)

Step	CB	Transformer Tap	Time (s)	Description
1	7A1 PRW	-	0	Closing CB in Perawang Substation
2	7AB1 PRW	-	0.5	
3	7B2 PRW	-	1	
4	7B4 PRW	-	1.5	
5	7AB4 PRW	-	2	
6	7AB5 PRNP	-	2.5	Energizing Line 2 Perawang-Peranap
7	7A4 PRW	-	3	Synchronizing in Perawang Substation

The changing steps for the energization scheme 500 kV Perawang – Peranap (line connected shunt reactors) can be seen in Figure 9.

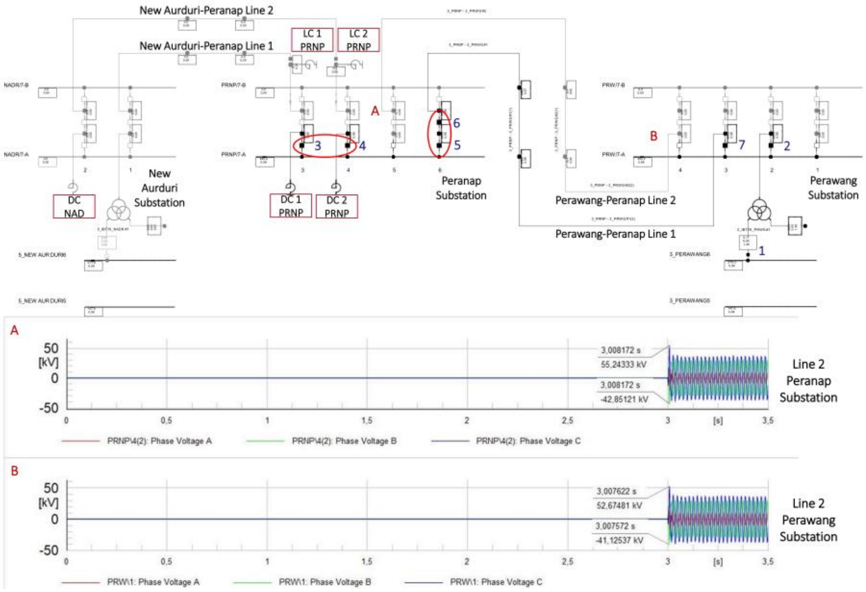

Figure 9 Changing of the Energization Scheme for Line 2 (Line Connected Shunt Reactors)

Some changes in the energizing steps of the Perawang – Peranap transmission line can only be carried out by energizing Line 1 or Line 2. Energization of 2 lines Perawang – Peranap transmission line is impossible because it causes resonance. Table 5 describes the changing of the energization scheme for Line 2 (line connected shunt reactors).

Table 5 CB Closing Steps - Changing of the Energization Schemes for Line 2 (Line Connected Shunt Reactors)

Step	CB	Transformer Tap	Time (s)	Description
1	275 kV PRW	-	0	Switching On the 500/275 kV Transformer
2	7A2 PRW	-	0.5	Energizing Busbar A in Perawang Substation
3	7A3 PRNP	-	1	Closing CB of Diameter Connected Shunt Reactors in Peranap Substation
4	7A4 PRNP	-	1.5	
5	7A6 PRNP	-	2	
6	7AB6 PRNP	-	2.5	
7	7A3 PRW	-	3	Energizing Line 1 Perawang-Peranap

4. Conclusion

From the results of resonance analysis in Sumatra 500 kV extra high voltage transmission line energization schemes, it is found that there is a potential for resonance to occur if the shunt reactor compensation for the line is almost at total compensation. Resonance causes the voltage of the de-energized transmission line to increase significantly (338.46 kVp & 354,53 kVp). Changing steps in the energization schemes could mitigate resonance.

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