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Study of 150 kV Overhead Transmission Line Configuration Planning from Kambang Pesisir Selatan to Bengkulu City

Fadhel Putra Winarta[1*], Muhammad Nasir Sonni[2], R. Reski Eka Putra[1], Muhammad Fahreza[1], Ricky Wahyudi[1]

[1]Department of Electrical Engineering, Padang State Polytechnic
Kampus Street, Limau Manis, Pauh, Padang, West Sumatra 25164, Indonesia
[2] Department of Electrical Engineering, Faculty of Engineering, Universitas Andalas
Kampus Street, Limau Manis, Pauh, Padang, West Sumatra 25163, Indonesia
E-mail: fadhelputra@pnp.ac.id

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ABSTRACT

Abstract **-** The need for electricity is increasing due to the rise of human living standards, therefore, the provision and supply of electrical energy must be increased. To meet the increasing electricity demand, the construction of new generating plants or expanding of the transmission network is required. The most rational alternative to overcome the growing load in the Bengkulu Province is to construct a 150 kV transmission network from Kambang (Pesisir Selatan, West Sumatra Province) to Bengkulu (Bengkulu Province). Therefore, the Bengkulu region gets electricity supply from two areas, i.e. the Central Sumatra Subsystem and the South Sumatra Jambi and Bengkulu Subsystem (S2JB). This 150 kV Transmission line span across of 396 kms that is matched with the government policy as an effort to enhance network reliability and adequacy of electricity supply in Sumatera region. This research aims to plan a transmission line from Kambang to Bengkulu City using load forecast based on the 2019-2028 RUPTL data of the Bengkulu area until year 2050. Calculation of 150 kV transmission line configuration is conducted by considering voltage regulation and load flow analysis by ETAP Software. The result of the Kambang – Bengkulu transmission line planning has capacity of 200 MW with receiving voltage of 150 kV, and frequency of 50 Hz, using 240 mm^2 ACSR conductors with double circuit configuration and 2 bundle of conductor per circuit. The transmission line resistance is $0{,}03006\ \Omega/km$, the inductance of $3{,}6923 \times 10^{-4} H/km$ and the capacitance of$44{,}488 \times 10^{-9} F/km$. The voltage regulation is 2,1% and the total line loss is 1.574 MW

Keywords: transmission line planning, transmission line constants, voltage regulation, losses.

1. INTRODUCTION

Power outages that often occur in the Bengkulu area result in consumers experiencing losses. One form of loss resulting from the blackout is the increase in the unit price of production for business actors. This causes business actors to incur additional costs because they have to buy generators and have to pay for fuel, which in the end will affect the amount of income. Frequent power outages are caused by a lack of electrical energy supply in the Bengkulu area. This is made worse by the fact that several areas in Bengkulu still rely on PLTD for electrical energy supply. However, as is known, the cost of generating PLTD is still very expensive. To overcome this problem, it is necessary to build a Kambang Bengkulu interconnection transmission line. Thus, it is hoped that the Bengkulu region will receive energy supplies from two directions, namely from the Central Sumatra Subsystem (Sumbagteng) and the South Sumatra Jambi Bengkulu Subsystem (S2JB).

In the 2019-2028 RUPTL it is stated that in order to increase the reliability of electrical energy distribution, expand and equalize electricity in several areas in the Sumatra region, it is necessary to realize the interconnection of the Sumatra system in 2028 [1]. The construction of a 150 kV transmission network from the west coast of West Sumatra, Kambang to the city of Bengkulu for 396 km is basically a government policy in an effort to meet electricity needs in Sumatra. Based on projected electricity needs outside Java, including South Sumatra, Jambi, Lampung, Bangka Belitung and Bengkulu, in particular, there is a tendency for energy sales to increase from 2019 to 2028.

The planned 150 kV transmission line is a type of overhead transmission line. This air transmission line has several advantages compared to underground transmission lines. The advantages of overhead power

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lines include: 1. Installation is easier and more flexible if expansion is desired. 2. Maintenance is easier (if there is a problem it is easy to detect and repair). 3. Prices for installation, maintenance and repairs are more friendly[2][3], [4]. So it can be said that overhead transmission lines are easier to serve load growth or system development than underground transmission lines, then the cost of constructing overhead transmission lines is also lower [5], [6] [7]

Construction of transmission lines requires careful planning so that electric power distribution is maximized. Planning in the construction of electrical energy transmission lines must consider things that include technical planning, both mechanical and electrical as well as economics[6][8]. With good electricity transmission line planning, it is hoped that once the transmission line is operational, the electricity system will become more reliable, efficient and effective.

Several studies that have been carried out related to transmission line planning such as in[6], [9] about 150 kV Bambe Incomer transmission planning and [10] explain about a design of 150 kV transmission lines with capacity of 35 MVA in Bulungan East Kalimantan. In the research, transmission lines are planned by taking into account several elements, namely transmission line configuration, determining conductor type, tower selection, distance between conductors, conductor height relative to the ground, determining the number of insulators and calculating the support value on the transmission line.

There are several limitation in transmission palnning in [6], [10], [11]. From an electrical analysis perspective, namely voltage regulation has not been taken into account. Does the design made meet the voltage standard requirements on the receiving side. Apart from that, the planning carried out in [6], [10], [11] is only based on the current load, so there is no guarantee that the lines will not experience overload, for example in the next 10 or 20 years. Therefore, in this research, transmission line planning is based on load values obtained from load forecasting with estimates until 2050. Calculations are also carried out by determining the constants of the transmission line, calculating the magnitude of the voltage regulation, and adding a power flow study to the planning of the transmission line from South Coast Kambang to Bengkulu to determine the magnitude of the losses that occur, and to obtain the initial conditions for planning the new system.

In this research, planning for the 150 kV Kambang - Bengkulu transmission line was carried out using load forecasting data in the 2019-2028 RUPTL for the Bengkulu area to predict the load in 2050. In this research the electrical characteristics and mechanical characteristics will be discussed in planning the 150 kV Kambang - Bengkulu transmission line.

2. METHOD

The flow diagram scheme of the research can be seen in Figure 1 below.

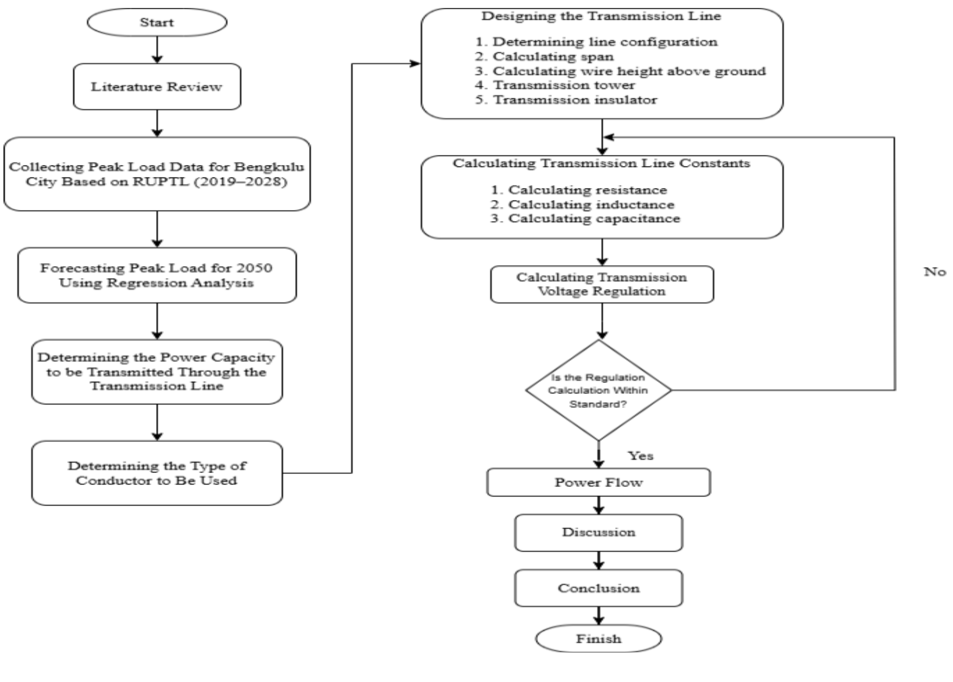

Figure 1. Flow Chart

The data required includes: Transmission line route map data from the Kambang coast of West Sumatra to the city of Bengkulu, Real data and peak load estimates for the city of Bengkulu taken based on RUPTL

(2019-2028), Conductor wire specification data for the ACSR conductor type, and KHA data for ACSR type conductor wire.

Load estimation is done by making predictions or forecasting loads that will occur in the future based on data on previous load conditions. Load estimation uses statistical methods, namely the Trend Analysis Method. Long-term electricity load forecasting in planning the expansion of the transmission line network is needed so that the power distributed is in accordance with the built transmission capacity.

Calculation and planning analysis of a 150 kV transmission line from Kambang, West Sumatra coast to Bengkulu city with estimates of peak loads in Bengkulu city until 2050. Analysis and calculations are carried out based on mechanical characteristics and electrical characteristics. A power flow study is conducted using ETAP software to analyze the distribution of electrical power from generation units through transmission lines to load centers.

3. RESULT

3.1 Load Forecasting

The load forecasting for 2050 is based on real data and estimated peak load data in the city of Bengkulu based on RUPTL (2019-2028). Real data is load data from the previous year, namely 2019. Meanwhile, estimated data is load data from 2020 to 2028 as seen in Table1.

Table 1. Data of Bengkulu City peak load

Year	Load (MW)	X (Year)	X.Y	X^2
2019	223	1	223	1
2020	234	2	468	4
2021	247	3	741	9
2022	265	4	1.060	16
2023	278	5	1.390	25
2024	292	6	1.752	36
2025	306	7	2.142	49
2026	321	8	2.568	64
2027	337	9	3.033	81
2028	353	10	3.530	100
Total	ΣY=2856		ΣXY=16.907	$\Sigma X^2=385$

To estimate peak load data in 2050, the regression analysis method is used. The results of data processing are presented as in Table 2

Table 2. Result Regression Analysis

Year	Peak Load (MW)
2040	525,40
2041	539,93
2042	554,47
2043	569,00
2044	583,53
2045	598,07
2046	612,60
2047	627,13
2048	641,67
2049	656,20
2050	670,73

Using the trend analysis method with the linear regression equation $Y = a + bx$ where Y represents the projected load value in the year 2050 and x is the time variable encoded from the years for which data is available. To solve the linear regression equation, it is first necessary to determine the value of x corresponding to the year 2050.

Based on the regression formula:

$\sum y = a.n + b.\sum x$ The following values are obtained $(a \times 10) + (b \times 55) = 2.856$

$\sum XY = a.\sum x + b.\sum x^2$ The following values are obtained $(a \times 55) + (b \times 385) = 16.907$

These two equations form a system of linear equations

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$(10a) + (55b) = 2.856$
$(55a) + (385b) = 16.907$
To solve this system using the elimination method

$(10a) + (55b) = 2.856 \quad | \times 5{,}5 \qquad = 55a + 303b = 15.708$
$(55a) + (385b) = 16.907 \quad | \times 1 \qquad = 55a + 385b = 16.907 \; -$

The difference between the equations for a and b is calculated as $\quad -83b = -1.199$

$$b = 14{,}53$$

By substituting the value $b = 14{,}53$ therefore
$(10a) + (55 \times 14{,}53) = 2.856$
$(10a) + (799{,}33) = 2.856$
$(10a) = 2.856 - 799{,}33$

$$a = \frac{2.056{,}67}{10} = 205{,}67$$

So, the final results area $a = 205{,}67$ *and* $b = 14{,}53$, Thus, the regression analysis is obtained $Y = 205{,}67 + 14{,}53\,x$. Next, by substituting x = 32 which corresponds to the year 2050, the projected load in 2050 is calculated to be 670,63 MW. The value of x for the year 2050 can be seen in table 2.

3.2 Generation forecast in Bengkulu

After getting an estimate of the peak load in 2050, the next step is to determine how much generation capacity is needed to serve the load in Bengkulu. To supply a load in 2050 of 671 MW, a generator larger than 671 MW is needed. The total generating capacity in Bengkulu currently is 430.64 MW as seen in table 3.

Table 3. Generation data in Bengkulu

Musi (Pekalongan) Hydropower Plant	3 ×71 MW
Tes Hydropower Plant	4 × 4,41 MW
Bengkulu Thermal Power Plant	2 × 200 MW
Total	430,64 MW

Based on table 2 above, there is a difference between the peak load in 2050 and the current total generation capacity. To determine the load that will be supplied in 2050, it is 671 MW-430,64 MW=240,36 MW, which is the value that will be supplied to the city of Bengkulu in 2050.

3.3 Transmission Voltage

Determining the transmission voltage is part of the overall system design. The choice of transmission voltage is closely related to the amount of power that will be transmitted and the existing systems that will be interconnected. Therefore, the selection of transmission voltage is carried out by taking into account the power distributed, the number of circuits, as well as the existing and planned voltages.

In the previous sub-chapter, we discussed and determined the amount of power and the method of fulfilling the load by importing power from the Sumbagteng system. The condition of the Central Sumatra electric power system or the Sumbagteng sub-system uses a system voltage of 150 kV. So, to reduce power losses and efficiency of construction implementation, the SUTT operating voltage from Kambang to Bengkulu uses a voltage of 150 kV. The choice of voltage is also based on the current condition of the electric power system in Bengkulu, which is supplied from the southern region of S2JB, where the system voltage is the same, namely 150 kV. And the choice of this voltage is also based on the consideration of the long distribution distance and with a voltage of 150 kV it is still possible to distribute power with a large capacity.

3.4 Determining the Size and Type of Transmission Conductor

Planning a transmission line also includes determining the size and type of transmission conductor. Determining the size and type of transmission conductor is determined by the current passing through the conductor. The greater the current flowing in the conductor, the greater the power sent will be. Current calculations are carried out based on the power that will be distributed. The planned power to be distributed is 200 MW, so the current calculation is as follows[12][13][14]:

$$I = \frac{S}{\sqrt{3}\,Vr} \tag{1}$$

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Where :
I : Current per phase (A)
S : Power delivered (MVA)
Vr : System Voltage (kV)

$$I= \frac{200 \times 10^6}{\sqrt{3} \times 150 \times 10^3} = 769{,}800 \text{ A}$$

To maintain power continuity, it is necessary to use double circuit lines. The advantage of this type of double circuit is that if one line is disconnected, the transmission can still deliver power using another line.
For double circuit line, it is:

$$I= \frac{769{,}800}{2} = 384{,}8 \text{ A}$$

From the calculation above, it is determined that the line uses an ACSR wire type conductor with an aluminum area of 240 mm^2 which has a current carrying capacity of 638 A

3.5 Calculation of Distance Between Conducting Wires

To calculate the horizontal distances between the wires in the middle of the Phylon, the following Safety Code Formula is used.

$$a = 0{,}3\ inch\ per\ Kv + 8\sqrt{b/12} \tag{2}$$

Where :
a : Distance between conductor
b : Sag in inches
From the equation above, so that the equation can be solved, it must first know the value of the sag.

3.6 Calculating the Sags of the ACSR Wires

In this calculation what is sought is to determine the support and tension of the wire by taking into account the influence of wind pressure and the influence of heat. The conductor used is ACSR and has a cross-sectional area of 240 mm in accordance with PLN standards. The data taken from the 150 kV transmission line is:

Cross sectional area	: 240 mm
Type of the conductors	: ACSR
Weight of the conductors	: 1.110 kg/m
Transmission line span length	: 300 m
Maximum working tensile stress	: 10.210 kg

To find the weight value of the conductor wire, use the formula[14]

$$b = \frac{a^2}{8C} \tag{3}$$

Where

$$C = \frac{\sigma}{\gamma} \tag{4}$$

b = sag, meter
a^2 = span, meter

From the data above it can be calculated
Specific wire weight (γ)

$$\gamma = \frac{G}{q} = \frac{1{,}11\ kg/m}{240/mm^2} = 4{,}625 \times 10^{-3}\ kg/m/mm^2 \tag{5}$$

Wire tensile specific stress (σ)

$$\sigma = \frac{H}{q} = \frac{10.210\ kg}{240/mm^2} = 42{,}54\ kg/mm^2 \tag{6}$$

Therefore, the sag is

$$C = \frac{\sigma}{\gamma}\frac{42{,}54\ kg/mm^2}{4{,}625\ \times\ 10^{-3}} = 9197{,}83\ m$$

$$b = \frac{300^2}{8 \times 9197{,}83} = 1{,}223\ m$$

Spacing between pylons (L_1)

$$L_1 = a + \frac{(a^2)}{(24\ C)^2} = 300 + \frac{300^3}{(24\ \times (\frac{42{,}54}{4{,}625} \times 10^{-3})^2} = 300{,}001\ m \quad (7)$$

Length of wires between pylons in maximum temperature (Lt)

$$Lt = Lo[1 + \alpha(tm - t)] = 300[1 + 23 \times 10^{-6}(90 - 20)] = 300{,}483\ m \quad (8)$$

Working tensile stress at maximum temperature (Ht)

$$Ht = \sqrt{\frac{a^3 \times G^2}{24(Lt - a)}} = \sqrt{\frac{300^3 \times 1{,}110^2}{24(300{,}483 - 300)}} = 1694{,}048 \quad (9)$$

Sags in maximum temperature (bt)

$$bt = \frac{a^2 \times G}{8 \times Ht} = \frac{300^2 \times 1{,}110}{8 \times 1694{,}048} = 7{,}371\ m \quad (10)$$

By knowing the value of the sags, calculation of the horizontal distances between the wires in the middle between pylons is as follows

$$a = 0{,}3\ inch\ per\ Kv + 8\sqrt{b/12}\ =\ 61{,}02\ inch\ = 1{,}55\ meter \quad (11)$$

Hence, the free distance between the conductor and other conductors takes into account the safety factor of 115%, so $1{,}15 \times 1{,}55 = 1{,}78 \approx 2\ meter$

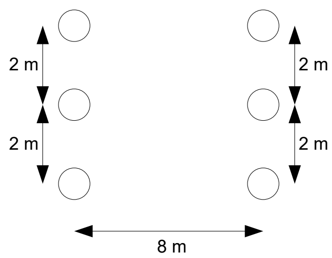

Figure 2. Transmission Line Conductor Configuration

3.7 Calculating Ground Clearance

To determine the free distance between the conductor wire to the ground (Phase to Ground Clearance) use the safety Code formula. The minimum wire height formula above the ground is as follows.

$$H = 20ft + (kV - 50) \times 0{,}5\ inch + 0{,}75(bt, maks - bt, kerja) \quad (12)$$

$$H = 6{,}096 + 100 \times 0{,}0127 + 0{,}75(7{,}371 - 1{,}223)$$

$$H = 12{,}25\ meter$$

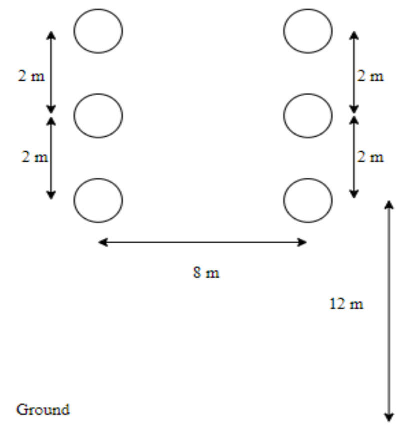

Figure 3. Conductor Configuration Calculation Results

3.8 Transmission Tower Planning

In this plan, the type of tower chosen is a steel tower with a square-shaped reinforced concrete pillar. The total distance of the line is 396 km with a working voltage of 150 kV and the distance between transmission line tower is 300 meters. To determine the number of transmission line towers, namely

$$\frac{396\ km\ \times 1000\ m/km}{300\ m} = 1320\ towers$$

In planning this transmission line, the tower type used is Type AA Transmission Suspension Tower as seen in Figure 4. below.

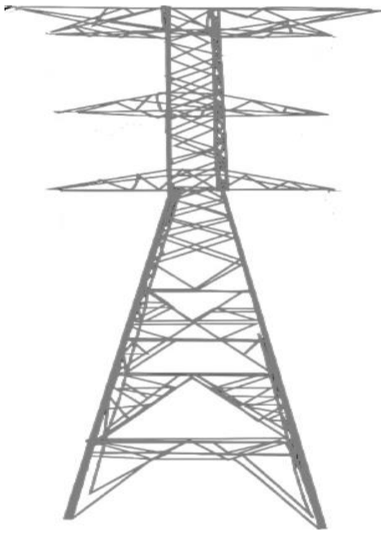

Figure 4. Tower Suspension Type AA

3.9 Insulation Planning

The type of insulator used is a porcelain hanging insulator, especially a clevis type insulator. This hanging insulator was chosen because the working voltage to be transmitted is a high voltage of 150 kV. The type of hanging insulator that is stretched for one insulator has a standard working voltage of 15 kV, so for a working voltage of 150 kV the average number of standard insulators is 11. Because the tower used is a double line tower type which has 6 conductor currents, the number of insulators that will be used is 11 x 6 = 66 insulators for one suspension type tower. As is known, the number of towers that will be used is 1320 towers, so the total number of insulators required is: 1320 x 66 = 87120 insulators

3.10 Transmission line Constants

The transmission line system has constants that can influence the characteristics of distributing electrical power. What is meant by constants are the electrical characteristics of the line, namely resistance, inductance, capacitance[4], [8], [15], [16].

Calculating of Resistance

There are two types of resistance in transmission lines, namely AC resistance and DC resistance. To determine the AC resistance value on the transmission line, use the following equation[13], [17]

$$R = 1{,}02 \times \ \rho \frac{l}{A} \tag{13}$$

For this type of aluminum conductor, it has a conductivity value of 61%, the resistance value for the double lines two bundle transmission line is as follows[13], [14].

$$R = 1{,}02 \times 2{,}83 \times 10^{-8} \times \frac{1 \times 10^{3}}{240 \times 10^{-6}}\ 0{,}03006\ \Omega/km$$

Calculating of Inductive Reactances of Double Circuit Transmission Lines of Two Bundles

The GMD (Geometric Mean Distance) of double circuit, two beams transmission lines is

$$GMD = \sqrt[3]{GMD_{RS} \times GMD_{ST} \times GMD_{TR}} \tag{14}$$

By entering the distance value between the phases of each conductor as in Figure 2

The procedure to determine the values of GMD between phases are $GMD_{RS,}\ GMD_{ST}, dGMD_{TR}$ is as follows

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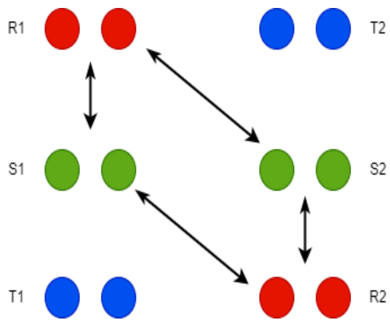

Figure 5. GMD of phase R and S of double circuit two bundle

$$GMD_{RS} = \sqrt[4]{d_{R1S1} \times d_{R1S2} \times d_{R2S1} \times d_{R2S2}} = \sqrt[4]{2 \times 8{,}24 \times 8{,}24 \times 2} = 4{,}0595\ m$$

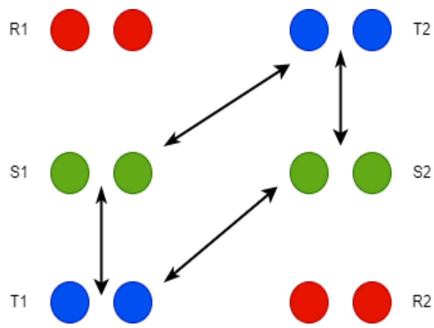

Figure 6. GMD of phase S and T of double circuit two bundle

$$GMD_{ST} = \sqrt[4]{d_{S1T1} \times d_{S1T2} \times d_{S2T1} \times d_{S2T2}} = \sqrt[4]{2 \times 8{,}24 \times 8{,}24 \times 2} = 4{,}0595\ m$$

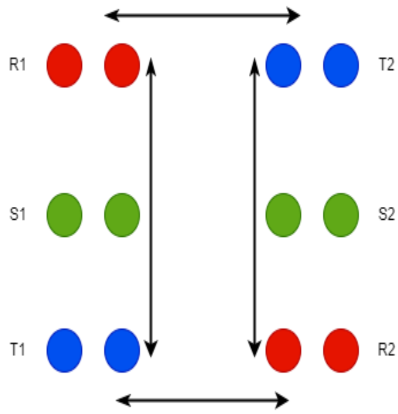

Figure 7. GMD of phase T and R of double circuit two bundle

$$GMD_{TR} = \sqrt[4]{d_{T1R1} \times d_{T1R2} \times d_{T2R1} \times d_{T2R2}} = \sqrt[4]{4 \times 8 \times 8 \times 4} = 5{,}6568\ m$$

By entering the values of d_{RS}, d_{ST},d_{TR} in the equation above, the GMD value is

$$GMD = \sqrt[3]{4{,}0595 \times 4{,}0595 \times 5{,}6568} = 4{,}5342\ m$$

GMR (Geometric Mean radius) Calculation

To determine the GMR value in a double circuit with two bundles conductors with a sub-conductor distance of 0.4 m, there is a difference with a double circuit without bundles. The difference is that for double circuit two bundles, the first value that must be determined is the GMR for the sub-conductor distance. After getting the GMR value for the sub-conductor distance, then determine the GMR value for the distance between conductors for the ACSR 26/7 conductor type, the GMR value is $r' = 0{,}8839 \times 10^{-2}$ [14]. The calculation is as follows[13], [17]

Figure 8. Distance between sub conductor

$$Ds_R = \sqrt{r' \times S} = \sqrt{0{,}8839 \times 10^{-2} \times 0{,}4} = 0{,}0594\ m$$
$$Ds_S = \sqrt{r' \times S} = \sqrt{0{,}8839 \times 10^{-2} \times 0{,}4} = 0{,}0594\ m$$
$$Ds_T = \sqrt{r' \times S} = \sqrt{0{,}8839 \times 10^{-2} \times 0{,}4} = 00{,}594\ m$$

$$Ds\ total = \sqrt[3]{0{,}0594 \times 0{,}0594 \times 0{,}0594 =}\ 0{,}0594$$

$$GMR_R = \sqrt{Ds\ \times R_1 - R_2} = \sqrt{0{,}0594 \times 8{,}94} = 0{,}7290\ m$$
$$GMR_S = \sqrt{Ds\ \times S_1 - S_2} = \sqrt{0{,}0594 \times 8} = 0{,}6897\ m$$
$$GMR_T = \sqrt{Ds\ \times T_1 - T_2} = \sqrt{0{,}594 \times 8{,}94} = 0{,}7290\ m$$

By entering the value of $GMR_{R,}\ GMR_S, GMR_T$ in the equation, the GMR is

$$GMR = \sqrt[3]{0{,}7290 \times 0{,}6897 \times 0{,}7290} = 0{,}7157\ m$$

Calculating Inductance and inductive reactance

To determine the value of inductance per phase in a double-circuit two bundle transmission line is as follows[13], [17]

$$L = 2.10^{-7}\ Ln\ \frac{4{,}5342}{0{,}7157} = 3{,}6923 \times 10^{-7} H/m$$

Next, find the inductive reactance value in the transmission line using the following formula

$$XL = 2\pi f l\ = 2 \times 3{,}14 \times 50 \times 3{,}6923 \times 10^{-7}\ 0{,}1160\ \Omega/km \quad (15)$$

Calculation of Capacitive Reactance in Double Circuit two Bundle Conductors

Calculating GMD (Geometric Mean Distance)

For the GMD value equal to equation 14, the GMD value is as follows

$$GMD = \sqrt[3]{4{,}0595 \times 4{,}0595 \times 5{,}6568} = 4{,}5342\ m$$

Calculating GMR (Geometric Mean radius)

The GMR is calculated as follows

Figure 9. Distance between sub conductor

The procedure to determine the value of r, the radius of the sub-conductor, is as follows

$$r = \frac{1}{2}\ 0{,}4\ = 0{,}2\ m$$

$$GMR = \sqrt[3]{GMR_R \times GMR_S \times GMR_T}$$

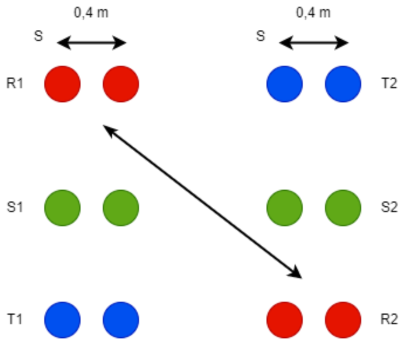

Figure 10. GMR for phase R of double circuit two bundle

$$GMR_R = \sqrt{r \times R1 - R2} = \sqrt{0{,}2 \times 8{,}94} = 1{,}3371\ m$$

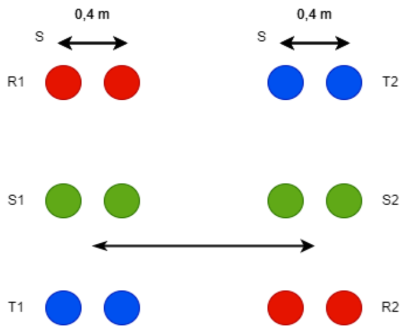

Figure 11. GMR for phase S of double circuit two bundle

$$GMR_S = \sqrt{r \times S1 - S2} = \sqrt{0{,}2 \times 8} = 1{,}2649\ m$$

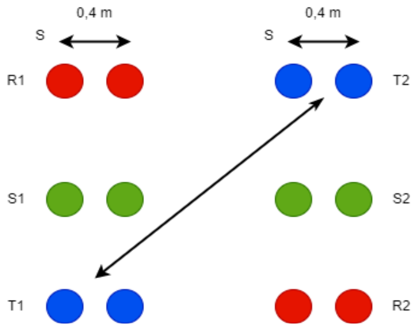

Figure 12. GMR for phase T of double circuit two bundle

$$GMR_T = \sqrt{r \times T1 - T2} = \sqrt{0{,}2 \times 8{,}94} = 1{,}3371\ m$$

By entering the value of $GMR_{R,}$ GMR_S, GMR_T in the equation, the GMR is
$GMR = \sqrt[3]{1{,}3371 \times 1{,}2649 \times 1{,}3371} = 1{,}3126\ m$

Calculating Capacitance and Capacitive Reactance

The capacitance of each phase is

$$C = \frac{2 \times 3{,}14 \times 8{,}855 \times 10^{-12}}{Ln\, \frac{4{,}5342}{1{,}3126}} = 44{,}482 \times 10^{-9}\ F/km$$

To find the capacitive reactance value in a transmission line, use the following formula

$$Xc = \frac{1}{2\pi f C} = \frac{1}{1{,}4100 \times 10^{-5}}\ \Omega/km \quad (16)$$

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3.11 Voltage Regulation

To determine the voltage regulation, the voltage on the sending side (Vs), the current on the sending side (Is), in planning the transmission line from Kambang to Bengkulu with a large load supplied is 200 MW with a working voltage of 150 kV and cos phi 0.9 is as follows[13].

It is known

$R = 0{,}03006\ \times 10^{-1}\Omega/km$

$L = 3{,}6923\ \times 10^{-4}H/km$

$Xl = 1{,}1600\ \times 10^{-1}\Omega/km$

$C = 44{,}488 \times 10^{-9}F/km$

$XC = \dfrac{1}{1{,}4100\ \times 10^{-5}}\Omega/km$

So that impedance and administration can be obtained along this transmission line. The impedance is as follows

$$Z = (R + JXl) \tag{17}$$
$$Z = (0{,}03006\ + j0{,}11600\ )$$
$$Z = 0{,}1198 \angle 75{,}46°$$

The admittance is

$$Y = (j\omega c) \tag{18}$$
$$Y = (j1{,}4100 \times 10^{-5})$$
$$Y = 1{,}4100 \times 10^{-5}\angle 90°$$

To find the voltage and current on the receiving side, use the following equation

$$\begin{bmatrix} Vs_{(l-n)} \\ Is \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} Vr_{(l-n)} \\ Ir \end{bmatrix} \tag{19}$$

From this equation, you must first know the constant values of A,B.C.D. For long transmission lines, the values of A,B,C,D are

$A = \cosh\ \gamma L$

$B = Zk \sinh\ \gamma l$

$C = Yk \sinh\ \gamma l$

$D = \cosh\ \gamma L$

Where:

$Zk = \ Caharacteristics\ Impedance$

$Yk = \ Admittance\ Characteristics$

$\gamma = \ Propogation\ Constant$

The characteristics impedance is

$$Zk = \sqrt{\frac{Z}{Y}} \tag{20}$$
$$Zk = \sqrt{\frac{0{,}1198 \angle 75{,}46°}{1{,}4100 \times 10^{-5}\angle 90°}}$$
$$Zk = 96{,}187 \angle -\ 7{,}26°$$

The admittance characteristics is

$$Yk = \frac{1}{Zk} \tag{21}$$
$$Yk = \frac{1}{96{,}187 \angle -\ 7{,}26°}$$

The propogation constant:

$$\gamma = \sqrt{Y \times Z} \tag{22}$$
$$\gamma = \sqrt{1{,}4100 \times 10^{-5}\angle 90° \times 0{,}1198 \angle 75{,}46°}$$
$$\gamma = 0{,}00130\ \ \angle 82{,}73°$$
$$\gamma = 0{,}000164 + j0{,}00128$$
$$\gamma = (\alpha + j\beta)l$$
$$\gamma = (0{,}000164 + j0{,}00128)395{,}7$$
$$\gamma = 0{,}0651 + j0{,}5102$$

The constants A,B,C,D on the transmission line are as follows

$\boldsymbol{A = \cosh\ \gamma L}$

$$\cosh \gamma L = \frac{1}{2}(e^{\alpha} \times e^{j\beta} + e^{-\alpha} \times e^{-j\beta}) \tag{23}$$

$$\cosh \gamma L = \frac{1}{2}(e^{0,0651} \times e^{j0,5102} + e^{-0,0651} \times e^{-j0,5102})$$

$$\cosh \gamma L = \frac{1}{2}(1,0672\ \angle 29,23° + 0,9370\ \angle -29,23°)$$

$$\cosh \gamma L = \frac{1}{2}(0,9312 + j0,5211 + 0,8176 - j0,4576)$$

$$\cosh \gamma L = \frac{1}{2}(1,7488 + j0,0635)$$

$$\cosh \gamma L = (0,8750\angle 2,08°)$$

The value of $e^{j\beta}$ in radiant:

$$e^{j\beta} = \frac{180}{\pi} \times \beta \tag{24}$$

$\boldsymbol{B = Zk\,\sinh\ \gamma l}$

$$\sinh \gamma L = \frac{1}{2}(e^{\alpha} \times e^{j\beta} - e^{-\alpha} \times e^{-j\beta})$$

$$\cosh \gamma L = \frac{1}{2}(e^{0,0651} \times e^{j0,5102} - e^{-0,0651} \times e^{-j0,5102})$$

$$\cosh \gamma L = \frac{1}{2}(1,0672\ \angle 29,23° -\ 0,9370\ \angle -29,23°)$$

$$\cosh \gamma L = \frac{1}{2}(0,9312 + j0,5211 - 0,8176 + j0,4576)$$

$$\sinh \gamma L = \frac{1}{2}(\ 0,1136 + j0,9788)$$

$$\sinh \gamma L = (\ 0,4926\angle 83,37°)$$

$$B = Zk\ \sinh\ \gamma l = (96,187\ \angle -\ 7,26°) \times (0,4926\angle 83,37°)$$

$$B = Zk\ \sinh\ \gamma l =\ 45,4199\ \angle 76,11°$$

$\boldsymbol{C = Yk\,\sinh\ \gamma l}$

$$C = \frac{1}{96,187\ \angle -\ 7,26°} \times (0,4926\angle 83,37°)$$

$$C =\ 0,0053\ \angle 90,64°$$

$\boldsymbol{D = A = \cosh \gamma L} = (0,8750\angle 2,08°)$

Phase to ground voltage of the receiving ends:

$$Vr_{(l-n)} = \frac{150.000}{\sqrt{3}}$$

$$Vr_{(l-n)} = 86.602,54\ V$$

Using the receiving end voltage as a reference,

$$Vr_{(l-n)} = 86.602,54\angle 0°$$

The receiving end current is

$$Ir = \frac{200 \times 10^{6}}{\sqrt{3}\ \times 150 \times 10^{3}}$$

$$Ir = \frac{769,800}{2}$$

$$Ir =\ 384,900\ \angle -25,8°$$

Then to determine the voltage at the sending end is

$$\begin{bmatrix} Vs_{(l-n)} \\ Is \end{bmatrix} = \begin{bmatrix} \boldsymbol{0,8750\angle 2,08°} & \boldsymbol{45,4199\ \angle 76,11°} \\ \boldsymbol{0,0053\ \ \angle 90,64°} & \boldsymbol{0,8750\angle 2,08°} \end{bmatrix} \begin{bmatrix} 86.602,54\angle 0° \\ 384,900\angle -25,8° \end{bmatrix}$$

$$Vs_{(l-n)} = (0,8750\angle 2,08° \times 86.602,54\angle 0°) + (45,4199\ \angle 76,11° \times 384,900\angle -25,8°)$$

$$Vs_{(l-n)} =\ \ 88.403,1067\ \ \angle 10,55°\ V$$

The current at the sending end:

$$Is = (0,0053\ \ \angle 90,64° \times 86.602,54\angle 0°) + (0,8750\angle 2,08° \times 384,900\angle -25,8°)$$

$$Is =\ \ 445,9185\ \ \ \angle 47,18°$$

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The voltage regulation is

$$Vr = \frac{[Vs] - [Vr_{L-L}]}{[Vr_{l-l}]} \times 100\%$$

$$Vr = \frac{[88.403,1067\ \ ] - [86602,54]}{[86602,54]} \times 100\%$$

$$Vr = 2,1\ \%$$

The value above is the voltage regulation value with two bundles conductors, which results in a voltage regulation value of 2.1%. This value still meets the permitted regulatory limit category according to PLN, so the transmission line planning from Kambang to Bengkulu will use a double circuit configuration with two bundle per phase.

3.12 Power Flow of the Transmission line

The Bengkulu electric power system uses a development system from the Sumatra interconnection system. Where the Sumatra interconnection system consists of two large systems, namely the Sumbagteng system and the South Sumatra system. Then in the Sumbagteng system there is an interconnection system for North Sumatra and West Sumatra which is currently operating via 150 KV High Voltage Air Lines (SUTT). Furthermore, in planning the 150 KV transmission line from Kambang to Bengkulu City which is adjusted to the existing load growth, Load Flow simulation will be used.

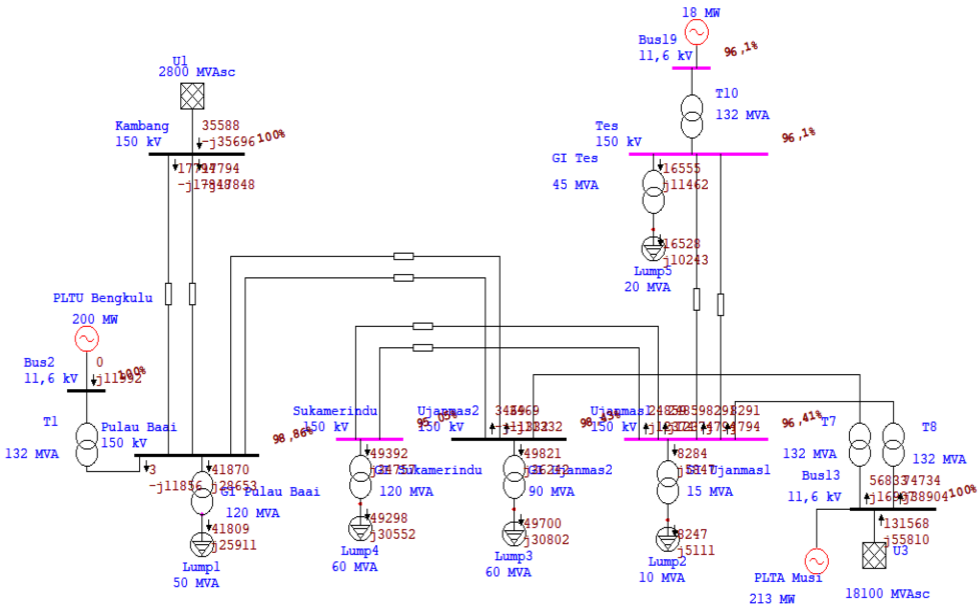

Figure 13. Load Flow Simulation

Table 4. Load Flow Results

No	Bus	Voltage Rate	Voltage Calculate	% Volt	MW
1	Kambang	150	150	100	35,588
2	Pulau Baai	150	148,297	98,86	41,873
3	Sukamerindu	150	142,576	95,05	49,392
4	Tes	150	144,152	96,1	16,555
5	Ujanmas1	150	144,62	96,41	74,585
6	Ujanmas2	150	147,638	98,43	56,759

Based on Table 4, in the S2JB subsystem there are buses experiencing load undervoltage, namely Test Bus, Sukamerindu Bus and Ujanmas 1 Bus with each voltage value obtained being 142.576 kV for Sukamerindu Bus, 144.152 kV for Test Bus, 144.62 kV for Ujanmas Bus1. If you observe the data results obtained from Table 3, especially the voltage values for each are in accordance with the PLN standard operating values.

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Table 5. Overall Load Flow Results

Buses	14
Branches	17
Generators	3
Power Grids	2
Loads	5
Load-MW	167,156
Load-Mvar	32,107
Generation-MW	167,156
Generation-Mvar	32,107
Loss-MW	1,574
Loss-Mvar	-70,512

Table 5 shows the power losses occurring in the electrical power system. In this system, the active power loss is 1.574 MW and the reactive power loss is -70.512 Mvar.

4. CONCLUSION

Based on the results of the analysis and simulation results that have been carried out on planning the 150 kV Kambang-Bengkulu transmission line, the following conclusions can be drawn:

a. Planning the Kambang-Bengkulu transmission line to have a sending power of 200 MW with a line to line receiving voltage (V_{RL-L}) 150 kV, pf 0,9 and frequency 50 Hz
b. The transmission line has a cross-sectional area of 240 mm^2 with a double-circuit, two-bundle configuration and a transmission line constant value with a resistance of $0{,}03006 \times 10^{-1} \Omega/km$, inductance $3{,}6923 \times 10^{-4} H/km$ and capacitance $44{,}488 \times 10^{-9} F/km$
c. The impedance value of the Kambang Bengkulu transmission line is $0{,}03006 + j0{,}11600\ \Omega$ with a voltage regulation of 2.1% and total line losses of 1,574 MW
d. The Load Flow results obtained are that there are 3 Buses (Sukamerindu, Tes, Ujan Mas1) in Marginal status with an active power loss value of 1.574 MW.

Based on the test results, it can be concluded that the load flow is generally in a marginal status, but still remains within the acceptable operating limits. This study may be further extended to include contingency analysis in transmission line planning to enhance system reliability. Furthermore, future research can also focus on the analysis and evaluation of transmission line protection systems to support the stability and operational security of the power system

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