Increasing the Efficiency of Bolangi Substation Extension by Using ACCC Conductor on 150 KV Sungguminasa-Bolangi Overhead Power Line

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Abstract: Electricity is one of the most important needs for society. Therefore, problems related to electricity will greatly affect a country. An example of this problem is the electricity crisis. Electrical energy crisis may occur due to lack of energy efficiency or high operating costs. One of the solutions to overcome these two problems is to optimize several components that play a part in the distribution of electrical energy such as the conductors used in the SUTT line. There are various types of conductors, including but not limited to ACSR and ACCC. Switching to a higher performing conductor can contribute to solving this problem. There are several studies that support replacing conductors with better ones can affect energy efficiency by increasing the power factor, reducing power losses, and increasing transmission efficiency so that they can contribute to solving the electrical energy crisis. The conductor that's going to be used is ACCC, which is a conductor capable of operating in high temperatures and has a low sag and is an upgrade and refinement of the ACSR conductor. By doing this conductor reconfiguration process, the power factor of the substation increased by 6.59%, transmission efficiency by 2.1% and reduced power loss by 52.82%.

1 INTRODUCTION

Electrical energy is an energy that is used by almost all people. Therefore, it is one type of energy that is extremely valuable, especially in the economic side (Arismunandar & Kuwahara, 2004). Electricity crisis in Indonesia is mostly related to economic problems, such as the high operating costs at substations or the lack of high energy efficiency on substations' lines which in turn may cause the aforementioned electrical energy crisis. Energy efficiency in this case is defined into more specific variables including but not limited to; difference in power factor, difference in power loss, and difference in transmission efficiency.

One of the possible solutions to solve this electrical energy crisis problem is to optimize the components that play a role in the distribution of electrical energy such as the conductor that's being used. The conductors used in High Voltage Overhead Lines (SUTT) play an important part in the performance and efficiency of the system.

This research is conducted at the High Voltage Overhead Lines of Sungguminasa – Bolangi where there is a power loss of 0.2022 MW and a SAIFI index of 0.57 which is high enough to cause a loss of economic value. These problems are directly related to the main component of the SUTT which is the conductor. They can be of various types, including but not limited to ACSR (Aluminum Conductor Steel-Reinforced Cable) and ACCC (Aluminum Conductor Composite Core).

ACSR is a type of conductor that has a high capacity, high strain resistance (around 131.9 kN), and is usually used on High Voltage Overhead Lines. The outer strand is made of high purity aluminium which results in good conductivity, light weight, and low cost. The inner strand is made of steel which has higher strength and inelastic deformation caused by mechanical loads such as wind. Steel also has low coefficient of thermal expansion under current load (Kenge et al., 2016). These things make ACSR sag much less than all-aluminium conductors (Lalonde et al., 2018).

ACCC is a type of high-temperature low-sag conductor which is capable of operating in high temperatures and has a low sag. It's an update or improvement to ACSR. It replaces the steel core in ACSR with carbon and glass fibre (Bryant, 2019). This gives ACCC several advantages over ACSR. Firstly, ACCC is capable of carrying twice as much current as ACSR in general (Wareing, 2018).

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Secondly, ACCC is lighter than ACSR, making it possible for the saved weight to be used for additional aluminium conductors. Thirdly, ACCC is softer than ACSR. The latter may use stronger pure aluminium which contributes to its tensile strength and improved sag under icy load conditions, but it has less electrical conductivity and has a limited operating temperature and more power loss than ACCC (Chen et al., 2012). Lastly, ACCC has a much smaller coefficient of thermal expansion (CTE) of 1.6 ppm/°C than ACSR. This allows ACCC to operate at a much higher temperature without excessive sag (Slegers, 2011).

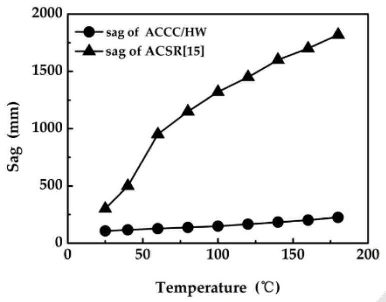

Figure 1: Comparison of sag between ACSR and ACCC conductor (Qiao et al., 2020).

Optimizing the conductor by reconfiguring it into a higher performing one can help solve the problem at Sungguminasa – Bolangi powerlines which is the lack of energy efficiency. Therefore, based on the advantages of ACCC over ACSR that have been described above, the former is more suitable for usage in High Voltage Overhead Lines as it will greatly help with the energy efficiency issue that is being faced. This study will calculate and compare the changes in efficiency after executing the reconfiguration process from ACSR conductor to ACCC on the High Voltage Overhead Lines of Sungguminasa – Bolangi wherein efficiency is again divided into several variables, including power factor difference, power loss difference, and transmission efficiency difference.

The purposes of this research will be divided into three clear, concise points:

1. To calculate and compare the difference in power factor before and after the conductor reconfiguration process
2. To calculate and compare the difference in power loss before and after the conductor reconfiguration process
3. To calculate and compare the difference in transmission efficiency before and after the conductor reconfiguration process

2 THEORITICAL REVIEW

There are studies that discuss the use of several types of conductors in substation lines. One of these studies compares two types of conductors with different specifications, one of them is the ACCC conductor which has better specifications on a 150 kV transmission system than the other conductor it's compared to. When compared, the ACCC conductor has smaller resistance per phase and has larger received power (MW) as well as larger current draw. The author states that there's an increase of 1.35% to the efficiency (Handayani et al., 2019).

Another study discusses the conductor reconfiguration process in the Mranggen Incomer High Voltage Overhead Lines. The author states that reconfiguration occurred because it utilized a single phi system. Therefore, using this system may cause a power outage if one of the lines is disturbed. Due to this concern, they reconfigured the process into a double phi system, followed by performing a series of calculations based on the results. It was discovered that the power loss in the Ungarang-Mranggen Line before the reconfiguration process was 5.86 kW and was reduced to 2.75 kW afterwards. Meanwhile, at the Mranggen Incomer Ungaran-Purwodadi line, the power loss was reduced from 13.39 kW to 8.9 kW after reconfiguration (Imam G, 2017).

3 RESEARCH METHODS

This study uses multivariate data analysis technique which is the method of processing a large number of variables, where the aim is to find the effect of these variables on an object simultaneously. The variables that are analysed include the difference in transmission efficiency, power factor, and power loss. After these variables have been calculated before and after the reconfiguration process, they will be compared and analysed whether there is a relation between variables or a relationship between several variables with one variable (Wustqa et al., 2018).

3.1 Reconfiguration Method

The reconfiguration method is divided into several steps, starting from de-energizing to installing the conductor itself. The figure below shows the initial condition of Bolangi 150 kV substation, without any reconfiguration process done.

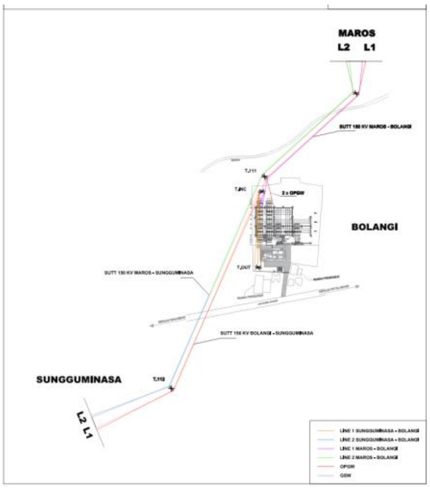

Figure 2: Substation's starting condition.

Stage 1 starts with de-energizing Maros-Bolangi #1 (Existing) line for 3 days to move conductor from Maros #1 (Existing) bay line to Maros bay line (New). Next is to re-energize Maros-Bolangi #1 via the new bay line one day after de-energizing it. Simultaneously, the relay distance at Maros #1 bay line will also be replaced with a new differential relay from new substation. After replacing the relay distance, point to point operation will be carried out to the RCC master station. After stage 1, the system will look like what is depicted in the figure below.

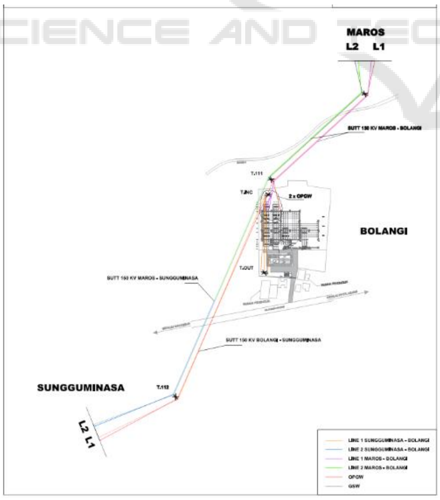

Figure 3: Stage 1 of the conductor reconfiguration process.

Stage 2A starts with de-energizing Maros #1 (New) bay line, Sungguminasa #1 (Existing) bay line, and 60 MVA bay transformer at 150 kV Bolangi substation for one day to carry out the conductor removal operation that's located above the two Bolangi substation busbars. After that, Maros-Bolangi #1 will be re-energized via the new bay line along with the 60 MVA bay transformer. Stage 2A is shown in the figure below.

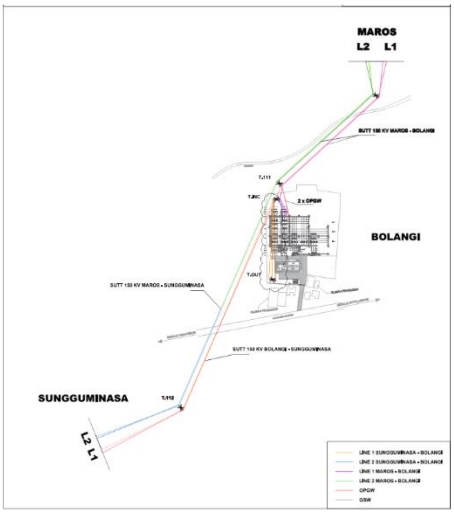

Figure 4: Stage 2A of the conductor reconfiguration process.

Stage 2B first start with de-energizing Bolangi-Sungguminasa #1 existing line again for 18 days (continuation of stage 2A) to allow for the conductor dismantling operation from T.Inc to T.112 and to do a conductor stringing operation from T.112 to the new gantry bay line of Sungguminasa #1 (New). After that, the Sungguminasa-Bolangi #1 line will be resuming operation via the new bay line. Also at this stage, OPWG configuration is also carried out for 4 days after stage 2A. This stage is depicted in the figure below.

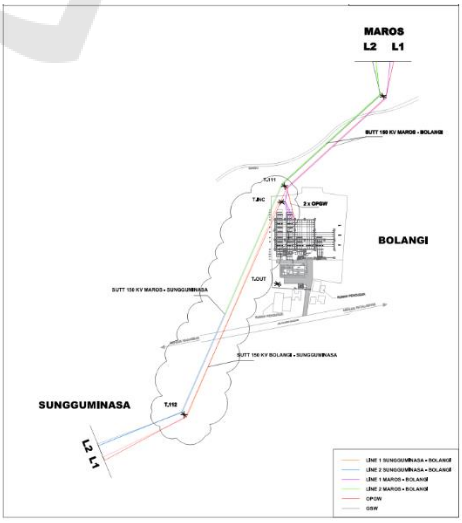

Figure 5: Stage 2B of the conductor reconfiguration process.

Next is stage 3 and 4. First, Sungguminasa-Maros #2 (Existing) line is to be de-energized for sixteen days to allow for the conductor dismantling operation from T.111 to T.112 and conductor stringing operation for the new conductor from T.111 to T.Out and T.112 to T.Inc. Simultaneously, the relay distance at Sungguminasa substation will also be replaced with a differential relay. After that, Sungguminasa-Bolangi #2 line will be operational. In stage 4, transmission line will change to Bolangi-New Power #2 line. Stage 3 and 4 are depicted together in the figure below.

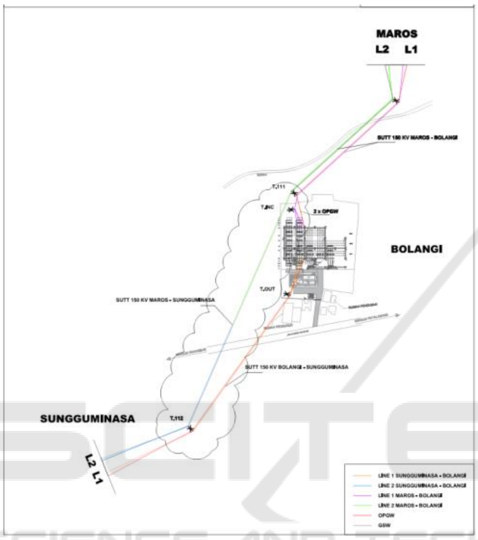

Figure 6: Stage 3 and 4 of the reconfiguration process.

Stage 5 is the conductor dismantling operation and GSW T.76 – T.77 in Maros-Sungguminasa / Bolangi #2 to T.01 Incomer New Power. OPGW reconfiguration will also be done. After that, New Power – Bolangi #2 line will be operational. Stage 6 is the last stage and it's the installation and operation of the new conductor in Maros-Sungguminasa. The T.76 T/L Maros-Sungguminasa and TIP 01 New Power incomer will be installed. After installation, the New Power Line – Maros #2 will be operational. This stage is shown in the figure below. Figure 8 also shows the before and after of the reconfiguration process with dotted lines indicating the before and solid lines indicating the after.

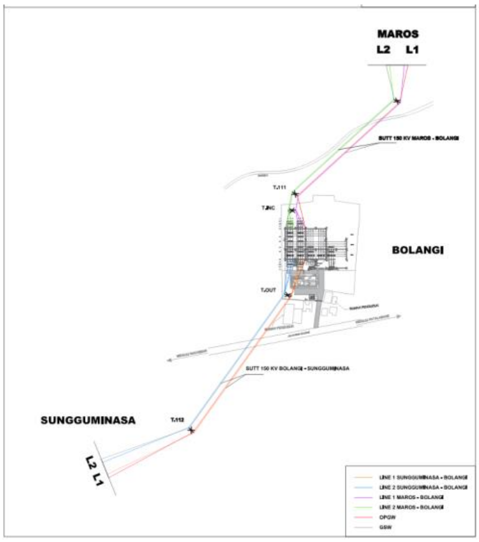

Figure 7: Stage 6 of the conductor reconfiguration process.

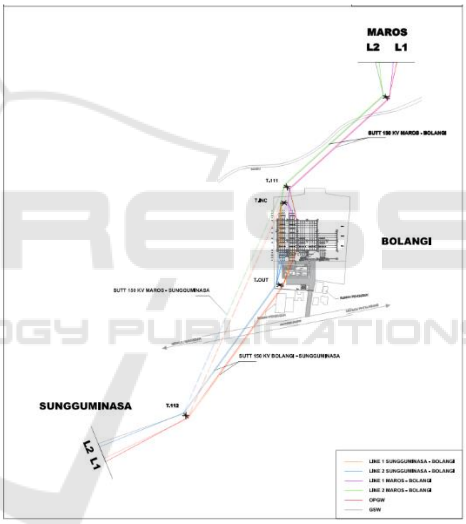

Figure 8: Comparison of system before and after the reconfiguration process.

4 RESULTS AND ANALYSIS

4.1 Results

Measurements of the observed variables for both ACSR and ACCC conductors were taken and put together into table 1 and table 2 respectively.

Table 1: Measurement results for ACSR conductor.

Measurement	Value
R (Resistance) (Ω/km)	0.1155
X_L (Reactance) (Ω/km)	0.3064
A (Surface area) (mm^2)	429.1
d (Conductor's length) (km)	4.1
b (Air pressure) (mmHg)	756.06
T (Average temperature) (°C)	28
I (Current) (Ampere)	372
Q (Reactive power) (MVAR)	39.1
P (Power) (MW)	85.8105
E (Phase voltage) (Volt)	144
r (Radius) (mm)	28.62
D (Distance between wires) (m)	2.5

Table 2: Measurement results for ACCC conductor.

Measurement	Value
R (Resistance) (Ω/km)	0.0514
X_L (Reactance) (Ω/km)	0.206
A (Surface area) (mm^2)	546.5
d (Conductor's length) (km)	4.1
b (Air pressure) (mmHg)	756.06
T (Average temperature) (°C)	28
I (Current) (Ampere)	387
Q (Reactive power) (MVAR)	25.2465
P (Power) (MW)	100.7348
E (Phase voltage) (Volt)	144
r (Radius) (mm)	14.315
D (Distance between wires) (m)	2.5

Firstly, resistance and reactance for both conductors must be multiplied by the respective conductors' length.

$$R_{ACSR} = 0.1155\ \Omega/km * 4.1km = 0.474\ \Omega \quad (1)$$

$$X_{L\ ACSR} = 0.3064\ \Omega/km * 4.1km = 1.26\ \Omega \quad (2)$$

After finding both resistance and reactance values, we can find the impedance using Pythagoras theorem and finding the phase by finding the arctan of reactance over resistance.

$$\theta = \arctan\left(\frac{X_{L\ ACSR}}{R_{ACSR}}\right) = \angle 69.4 \quad (3)$$

$$r = \sqrt{R_{ACSR}^2 + X_{L\ ACSR}^2} = 1.34\ \Omega \quad (4)$$

Put the two values together, we get the total impedance (Z):

$$Z = r\angle\theta = 1.34\ \angle 69.4 \quad (5)$$

First is to calculate the first variable which is the power factor. From the two tables of ACSR and ACCC measurements, we take the P (power) and the Q (reactive power) of each conductor and find the S (apparent power) and from there we can find the power factor.

$$S = \sqrt{P^2 + Q^2} = 94.29\ MVA \quad (6)$$

Plugging the apparent power into the power factor formula, we get:

$$\text{Cos}\ \phi_{ACSR} = \frac{P}{S} = 0.91 \quad (7)$$

$$\text{Cos}\ \phi_{ACCC} = \frac{P}{S} = 0.97 \quad (8)$$

Second is to calculate the power loss which is divided into two parts: transmission power loss and corona power loss. Calculating transmission power loss for 3 phase system is to multiply the current squared with resistance and three.

$$P_{loss} = 3 * I^2 * R = 0.1966\ MW \quad (9)$$

Before we can find the corona losses, we need to find the relative air density (δ) and the voltage gradient (E_g). We can find the relative air density using the following formula:

$$\delta = \frac{0{,}386b}{273+T} = 0.9695 \quad (10)$$

To find the voltage gradient for a 3-phase transmission line, we can use the formula from (W. S. Peterson, 1933).

$$E_g = \frac{0{,}4343E}{r * \log_{10}\left(\frac{D}{r}\right)} = 74.293\ kV/cm \quad (11)$$

Finally, after calculating both relative air density and voltage gradient, we can find the corona loss for both conductors with the following formula which is Peek's formula and is based on an equation from (F. W. Peek, 1929) to find the power loss due to the corona effect (ionization surrounding the conductor). Corona losses included losses caused by frequency, conductor's size, air pressure, temperature, and atmospheric conditions.

$$P_c = \frac{A}{\delta}(f+25)r^2\left(E_g - m\delta E'_{go}\right) * 10^{-2} \quad (12)$$

Where E'_{go} is the voltage gradient of the surface of the wire and m is the irregularity factor. Plugging in all of the values into the equation and we will get:

$$P_c = 0.0013618\ MW/km \tag{13}$$

To find the corona loss for the conductor, we need to multiply it with the conductor's length.

$$P_c = 0.00558338\ MW \tag{14}$$

After calculating both power losses, we can find the total power loss by adding the two together.

$$P_{total\ ACSR\ loss} = 0{,}20218338\ MW \tag{15}$$

$$P_{total\ ACCC\ loss} = 0{,}09755746\ MW \tag{16}$$

Transmission efficiency can be found by dividing the power with the total transmitted power, the latter of which includes the power and the total power losses, and then multiplying it by 100. The total transmitted power (P_{total}) is as follows:

$$P_{total\ ACSR} = P + P_{total\ ACSR\ loss} = 87\ MW \tag{17}$$

$$P_{total\ ACCC} = P + P_{total\ ACCC\ loss} = 100.83\ MW \tag{18}$$

Plugging these into the respective conductor's transmission efficiency formula, we will get both conductors' transmission efficiency.

$$\eta_{ACSR} = \frac{P_{ACSR}}{P_{total\ ACSR}} * 100 = 97.845\% \tag{19}$$

$$\eta_{ACCC} = \frac{P_{ACCC}}{P_{total\ ACCC}} * 100 = 99.9\% \tag{20}$$

4.2 Analysis

In this section, the results from the calculations that have been done in the previous section will be talked about and compared between the two conductors. First, the summary of all the important calculations have been put neatly into the table below.

Table 3: Summary of calculations.

	ACSR	ACCC
Power Factor	0.91	0.97
$P\ (MW)$	85.8105	100.7348
$P_{loss}\ (MW)$	0.1966	0.0947
$P_c (MW)$	0.00558	0.00287
$P_{total\ loss}$	0.20218	0.0976
P_{total}	87	100.8323
η (%)	87.845	99.9

Starting first with the power factor, the calculations for the power factor of ACSR resulted in 0.91. Power factor has a range of 0 to 1 with 0 being very inefficient and 1 being very efficient and therefore less power being wasted (Dani & Hasanuddin, 2018). 0.91 or 91% for power factor is already a good indication of efficiency, but it can still be improved since the upper limit is 1 or 100%. After the reconfiguration process into ACCC conductor, the power factor increased to 0.97 or 97% which is a 6.59% improvement.

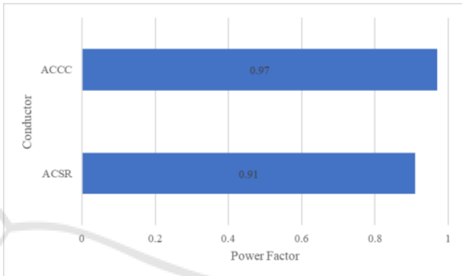

Figure 9: Comparison of power factor.

That number may sound insignificant, but if seen in the long term, such as in a few months or years, 6.59% will save electricity costs significantly. 6.59% in substation value can also be used to power several houses.

Moving on to the next variable which is power loss. The total power losses are shown as $P_{total\ ACSR\ loss}$ and $P_{total\ ACCC\ loss}$ for both ACSR and ACCC conductor respectively. Before the reconfiguration process, the total power loss is 0.2022 MW which is significantly more than after the reconfiguration process which is only 0.0976 MW. This equates to around 51.75% decrease of power loss which is very significant and in the long run will save even more power and benefit everyone economically. The figure below shows the comparison between both power losses.

Figure 10: Comparison of total power loss.

By dividing the corona losses by the total power losses, we can see that corona losses only contribute about 2.76 – 2.94% of the total power losses.

The last variable that’s compared is the transmission efficiency which is defined as the ratio between the power and the total power, the latter of which includes the total power losses and the power combined. Before the reconfiguration process, ACSR conductor has a transmission efficiency of 97.845%. After reconfiguring into ACCC, we have a transmission efficiency of 99.9%. Comparing these two values, there’s an increase of around 2.1% in transmission efficiency. Similar to power factor, the effect of this will be more significant as time goes on.

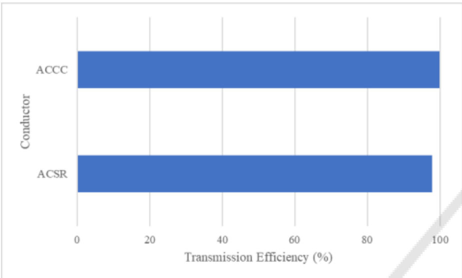

Figure 11: Comparison of transmission efficiency.

5 CONCLUSIONS

Based on this research which carries out the process of reconfiguring the conductor on High Voltage Overhead Lines from ACSR to ACCC conductor, there are several conclusions that can be drawn.

1. The reconfiguration process from ACSR to ACCC resulted in the increase of power factor by 6.59% from 0.91 to 0.97.
2. The reconfiguration process from ACSR to ACCC resulted in the decrease of power loss by 51.75% from 0.2022 MW to 0.09756 MW.
3. The reconfiguration process from ACSR to ACCC resulted in the increase of transmission efficiency by 2.1% from 97.845% to 99.9%.
4. Other factors such as air density, temperature, and atmospheric conditions only contribute around 2.76 – 2.94% to the total power loss of the system.

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