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STUDY OF CURRENT INSTABILITY TESTING IN ANDONGAN IN 150 KVA HIGH VOLTAGE AIR LINE

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A RTICLE INFO A BSTRACT

Air transmission lines generally use ACSR type conductors. As the demand for electrical energy increases, the effort to increase the capacity of the transmission line is carried out by optimizing the current-carrying capacity of the existing transmission line, but the problem that arises in this optimization is the increase in the voltage and slope of the conductor. This study aims to determine the effect of line current instability on conductor temperature, conductor slope, slope angle and conductor voltage, which is then useful for the construction of transmission line construction structures in accordance with the mechanical properties of the conductors used. This study uses the calculation of the heat balance equation. to calculate the conductor temperature. The Basic Span Length method is used to determine the equivalent span length.

KEYWORDS 150 KV Transmission, Air Line, Andongan, ACSR

INTRODUCTION

The rapidly increasing demand for electricity has led to the need for additional transmission line capacity in line with the expansion of the capacity of generating centers (Ananda, Hosea, & Chandra, 2006) . The emphasis of the problem in this study is that increasing the current-carrying ability can cause an increase in conductor voltage and slope, therefore it is necessary to investigate mechanical problems as a result of changes in line current. (Widodo, 2018) . In order to know how the characteristics will be useful in the design of transmission line construction (Arismunandar & Kuwahara, 1973) . Problems with mechanical performance include how the influence of line current on temperature, conductor voltage, and conductor slope (Arismunandar & Kuwahara, 1973) .

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Air transmission lines generally use ACSR *(Aluminum Conductor Steel Reinforced) type conductors* which have an allowable working temperature limit of 90°C. (Dario et al., 2016) (Hidayat, Saiful Jamaan, & Daby Embang, n.d.). Considering the increasing demand for electricity, efforts to increase the capacity of the existing transmission line are carried out by optimizing the current-carrying capacity of the transmission line. When a conductor wire is stretched between two points, the wire will follow a curved line from the two points which because of its own weight will bend downwards. (Lovrenčić et al., 2015) . When the weight that causes the conductor voltage is too large, it will cause the conductor wire to break or it can also cause the support tower to be damaged and fall. The conductor voltage that arises is also influenced by the loads on the conductor wire such as wind, snow, rain water and so on (Margunadi, 1986) (Amairi et al., 2010).
Changes in slope (due to conductor voltage, wire length and temperature) that are too large, can also pose a danger to all objects that are under it. (McCombe, 1949)

Air line is a transmission line that transmits electric power through wires that are hung on towers or transmission poles by means of insulators. The design of the transmission line will depend on several things such as the amount of power that must be transmitted, the distance and type of field that must be traversed, the available costs, other considerations, such as urban problems and the possibility of increasing the load in the future.

In Indonesia, the government has standardized the high voltage series, namely: Nominal Voltage (kV): 20 – 70 – 150 – 275 – 400 – 500, The main components of the transmission line are transmission poles or towers, conducting wires or conductors as energy conductors, and insulator. Transmission tower or pole is a transmission line supporting structure, which can be steel towers, steel poles, reinforced concrete poles and wooden poles. Steel, concrete or wood piles are generally used in lines with relatively low working voltage (below 70 kV) while steel towers are used for high or extra high voltage transmission lines. Broadly speaking, according to the shape or construction, transmission towers can be divided into 3 types, namely: Steel construction towers, Manesman towers, Wooden towers.

According to their function, transmission towers are divided into the following types:

1. **Tension tower**
   The transmission tower with this function, in addition to being a weight-bearer, also resists the tensile force of the High Voltage Air Line (SUTT) wires.
2. **Support pole (suspension tower)**
   This type of tower serves to support or support and must be strong against the gravity of the electrical equipment on the pole.

3. **Angle tower**
   This tower is a tension pole that functions to receive tensile forces due to changes in the direction of the High Voltage Air Line (SUTT).
4. **Pole end (dead-end tower)**
   This type of tower is a tension pole designed in such a way that it is strong enough to withstand the tensile force of the wires from one direction only. This final pole is placed at the end of the High Voltage Air Line (SUTT) which will enter the switch yard of the Substation.

5. **Transposition Pole**
A tower with this type of function is a tension pole that functions as a place to move the phase arrangement of the High Voltage Air Line (SUTT) wire.
The main parts of the transmission pile are composed of a pile frame, travers , foundations and sledges. The pole frame is part of the pole to support electrical equipment which is generally made of steel, wood or concrete which is designed in such a way that it is strong against the forces acting due to the pull of the conductor, wind and the gravity of the electrical material on the pole frame.

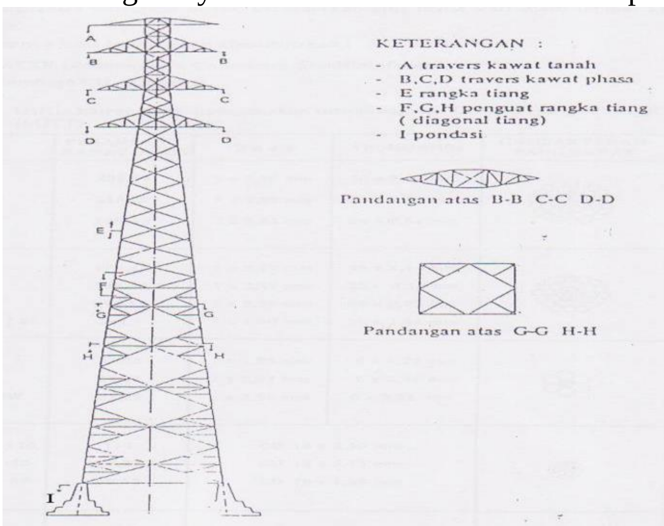

Figure 1. Transmission tower construction

If a wire is stretched between two tie points A and B (figure 2), the wire will not follow a straight line AB , but because of its own weight will bend down and form a julai (sag). The size of this bend depends on the weight and length of the wire. The tighter the wire pull, the less July will occur.

The weight of the wire will cause a tensile stress (kg/mm2) in the cross section of the wire. If the tensile stress of this wire is large, it can cause the wire to break, or it can damage the wire binding poles . Tensile stress depends on the weight of the wire and other loads acting on the wire (wind, ice, and wire temperature).

According to Stokes' law, because of this tensile stress, the wire will increase in length, depending on the modulus of elasticity of the wire, and the length of the wire itself. Medium due to temperature changes that occur around the wire will cause expansion and shrinkage depending on the magnitude of the temperature change, the coefficient of expansion of the wire and the length of the wire. The length of the wire depends on the length of the goal (the distance between the two tie points) and the size of the wedge. On the other hand, the slope depends on the length of the wire, the tension of the wire, and the temperature of the wire, and these three quantities affect each other.

Since the working voltage (kV) of the wire is generally high, a wire that is too large can pose a hazard to other objects in the wire itself. According to the applicable normalization, the height of the wire above the ground ranges from 7 to 8 meters.

Table 2
Minimum height of conductor from ground

Voltage	Minimum Height (feet)
Below 66 kV	20
66 kV – 110 kV	21
110 kV – 165 kV	22
Above 165 kV	23

So it has two limits on the values for stretching a wire, namely:

1. The tensile stress shall not exceed the allowable tensile stress under any circumstances. The maximum tensile stress will occur at the lowest temperature and there is a wind load.
2. The distance from the wire to the ground must not be less than the smallest permissible distance. The largest slope will occur at maximum temperature and at maximum load.

RESEARCH METHOD

A. ACSR conductor specific data used:

Conductor Type : HAWK
Actual cross-sectional area : 291.6 mm2
Nominal conductor diameter : 21.8 mm
Number of wires/ diameter (in mm) :26/3.5 Al
7/2.75Stl
Wire weight per unit length :997.87 kg/km
Resistance (20°C) : 0.2669 ohm/km
Nominal voltage of conductor : 1800 kg
Elastic Modulus : 7700 kg/mm2
Coefficient of Length Expansion : 18.9 x 10-6 /°C

B. As research material is SUTT 150
kV area of Northern Sumatra in
transmission line
using ACSR HAWK conductors along 184 km.

Tools used:
one unit Intel Core 2 Duo T5750 @ 2.00 GHz 2GB RAM and assisted by Matlab 6.1 software.

path :
The stages of the implementation of this research are as follows:

1. Simulating and calculating the use of the ACSR HWK 240mm2 conductor on the 150 kV high voltage overhead line (SUTT) on the Sigli–Banda Aceh line, by taking a sample tower that has the same structure as the simulation. The parameters calculated are temperature, conductor tensile stress, maximum conductor tensile stress, maximum conductor slope and tilt angle
2. Do the same for ACSR conductors on tower poles that are not the same height.
3. Analysis of the calculation results and comparing the two conductors (analysis of cable data with the actual installed in PLN).
4. Make conclusions from research results.

RESULTS AND DISCUSSION

A. The conductor is supported by the same high pole

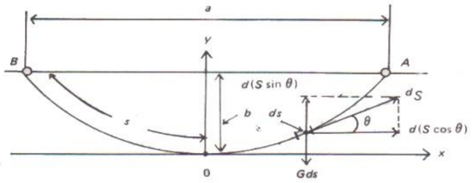

Figure 3. A piece of wire is supported at points A and B of the same height
(source : TS Hutahuruk, Electrical Power Transmission, page: 150)

To calculate the conductor voltage and the slope in the conductor wire can be obtained from the Chain Line Equation (Catenary Equation).

$$\boldsymbol{\sigma_{t2}}^3 + \boldsymbol{A}\,\boldsymbol{\sigma_{t2}}^2 = \boldsymbol{B} \quad (7)$$

$$\boldsymbol{A} = \frac{l^2\,\delta_m{}^2}{24\,\sigma_{t1}{}^2}\boldsymbol{E} + \boldsymbol{\alpha}\,\boldsymbol{E}(\boldsymbol{t_2} - \boldsymbol{t_1}) - \boldsymbol{\sigma_{t1}} \quad (8)$$

$$\boldsymbol{B} = \frac{a^2\,\delta_m{}^2}{24}\boldsymbol{E} \quad (9)$$

$$\boldsymbol{\sigma_{t1}} = \frac{T_r}{k.q} \quad (10)$$

With,

$\boldsymbol{l}$ = length of conductor wire or *span* (meters)
$\boldsymbol{\delta_m}$ = Specific total weight of wire (kg.m $^{-1}$ .mm $^{-2}$)
$\boldsymbol{E}$ = Modulus of elasticity of wire (kg/ mm ^{2})
$\boldsymbol{\alpha}$ = Coefficient of wire length expansion
$\Delta \boldsymbol{t} = \boldsymbol{t_2} - \boldsymbol{t_1}$ = Change in temperature (°C)
T_r = nominal tensile stress (kg)
$\boldsymbol{\delta_{t1}}$ = Initial specific tensile stress (kg.mm $^{-2}$)
$\boldsymbol{k}$ = factor of safety (2 – 5)
$\boldsymbol{q}$ = cross-sectional area of the conductor (mm ^{2})

For example, for the minimum temperature$(\boldsymbol{t_1})$ maximum stress has been determined $(\boldsymbol{\sigma_{t1}})$. The maximum stress occurs at the minimum temperature $\boldsymbol{t_1}$. If **a**, $\boldsymbol{\delta_m}$, $\boldsymbol{E}$, $\boldsymbol{\alpha}$, $\boldsymbol{t_2}$,$\boldsymbol{t_1}$ and $\boldsymbol{\sigma_{t1}}$is known, then A and B can be searched, and then $\boldsymbol{\sigma_{t2}}$can be calculated.

From figure 3, for example:

$\boldsymbol{q}$ = cross-sectional area of the wire (mm ^{2})
$\boldsymbol{\sigma}= \boldsymbol{H/q}$ = Specific tension of wire (kg/m/mm ^{2})
$\boldsymbol{\gamma}$== Specific weight of wire (kg/m/ mm $\boldsymbol{G/q}$ ^{2})
$\boldsymbol{H}$ = Horizontal tension of wire (kg/m)
$\boldsymbol{G}$ = Weight of wire per unit length (kg/m)
$\boldsymbol{L=2s}$ = length of wire (meters)
$\boldsymbol{b}$ = Maximum slope or *sag* (meters)
$\boldsymbol{a}$ = Length of goal or *span* (meters)

Thus, the horizontal tensile stress at temperature $\boldsymbol{t2}$can be calculated as follows:

$$\boldsymbol{T_{\alpha 2} = \sigma_{t2}\, q} \quad (11)$$

The conductor voltage at temperature t $_2$ is:

$$\boldsymbol{T_{t2} = T_{\alpha 2} + \frac{l^2.w^2}{8\,T_{o^2}}} \quad (12)$$

The length of the conducting wire at temperature t $_2$ is:

$$\boldsymbol{L_{t2} = l + \frac{l^3\,w^2}{24\,T_{o2}{}^2}} \quad (13)$$

The slope at temperature t $_2$ is:

$$\boldsymbol{D_{t2} = \frac{l^2.w}{8\,T_{ot^2}}} \qquad \boldsymbol{D_{t2} = \frac{l^2.w}{8\,T_{ot^2}}} \quad (14)$$

The slope angle is:

$$\boldsymbol{Sin\,\theta = \frac{w\,.L_{t2}}{2.T_r}} \quad (15)$$

with :

L = Width of goal (span) (m)
D = Andongan (sag) (m)
w = Weight of conductor per unit length (kg.m $^{-1}$)
T = Tensile tension of conductor (kg)
T_o = Horizontal tensile stress (kg)

B. The conductor is supported by a pole that is not the same height

If the supporting poles are not the same height, then what is calculated is the sloping slope (obligue), which is stated by the formula:

$$\boldsymbol{b = \frac{l^2.w}{8\,T_{\alpha 2}}} \quad (16)$$

i.e. distance b between the line AB and the tangent to the bend of the wire parallel to the line AB.

The relationship between inclined slope and slope at the supporting points is expressed by:

$$\boldsymbol{b_A = b\left(1 - \frac{h}{4.b}\right)^2} \quad (17)$$

$$\boldsymbol{b_B = b\left(1 + \frac{h}{4.b}\right)^2} \quad (18)$$

The voltage across the conductors at the supporting points A and B is given by:

$$\boldsymbol{S_A = T_{\alpha 2} + (G.b)} \quad (19)$$

$$\boldsymbol{S_B = T_{\alpha 2} + (G(b_A + h))} \quad (20)$$

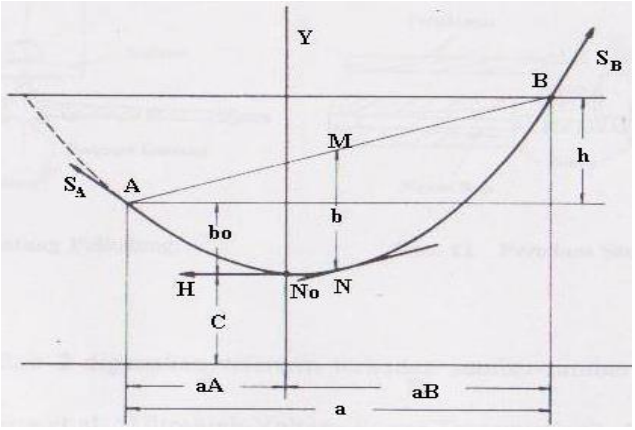

Figure 4. A piece of wire is firmly supported at points A and B which are not the same height
(source: TS Hutahuruk, Electrical Power Transmission, page: 152)

C. Analysis of Wind Pressure Against Conductors

Wind pressure affects the specific weight of the wire. The weight of the wire itself works vertically while the wind pressure is considered to be working horizontally. The vector sum of these two forces is the total specific weight of the wire. Generally the wind pressure is expressed as,

$$\boldsymbol{P = f.p.F} \quad (21)$$

With,
$\boldsymbol{P}$= wind pressure (kg)
f = form factor
$\boldsymbol{p = v^2/16}$= Specific wind pressure (kg/mm ^{2})
$\boldsymbol{v}$= wind speed (meters/second)
$\boldsymbol{F}$= Surface area of the perpendicular wire
wind direction (m ^{2})

Because the wind pressure is uneven, the coefficient of inequality ($\boldsymbol{d}$= 0.75 in Indonesia) is used, so equation (21) becomes:

$$\boldsymbol{P = f.d.p.F} \quad (22)$$

The value $\boldsymbol{p}$depends on the height of the wire above the ground, as follows:

Table 3. Specific wind pressure values

Wire Height Above Ground (M)	$\boldsymbol{p}$ (Kg/M ^{2})	$\boldsymbol{v}$ (M/Second)
0 – 25	60	31
25 – 60	70	33.5
60 – 100	90	38
100 – 150	115	43
150 – 200	130	43.5

Source: TS Hutauruk, Electrical Power Transmission, p;155

The value of the form factor $\boldsymbol{f}$ depends on the diameter of the wire, and the prices are:

Table 4. Form factor values

Wire Diameter (mm)	Form factor $\boldsymbol{f}$
up to 12	1.2
12 – 16	1.1
above 16	1.0

Source: TS Hutauruk, Electrical Power Transmission, p;156

Value $\boldsymbol{F}$taken = wire length x wire diameter.

$$\delta_m = \sqrt{\delta^2 + \delta_w{}^2} \qquad (23)$$

With,

δ_w == Specific wind pressure (kg.m $\frac{P}{q}$-1 .mm -2)

δ = W /q= Specific self weight of wire (kg.m $^{-1}$ .mm $^{-2}$)

δ_m= Specific total weight of wire (kg.m $^{-1}$ .mm $^{-2}$)

D. Calculation of Basic Span Length

The basic span or often called the goal, is usually determined based on the type of transmission pole construction and consideration of the bearing strength and conductor distance. However, a mathematical calculation can be used to determine the length of this goal. The application of this method is sometimes necessary given the existence of short and varied sections for the goals in a section.

$$\text{basic span}, L = \sqrt{\frac{a^3 + b^3 + c^3 + d^3}{a+b+c+d}} (22)$$

With,

L = Equivalent goal length (meters)

a, b, c and d = length of span in a row (mtr)

Then the magnitude of the slope for the equivalent span can be calculated:

$$b = \frac{L^2 . G}{8\,H} (23)$$

The research was carried out by calculating the temperature, conductor tensile stress, maximum conductor tensile stress, maximum conductor slope and tilt angle due to changes in current flowing in the conductor wire using Matlab.6.1 software for ACSR type HAWK 240mm2 conductors (Thrash, 1999) (Hidayat et al., n.d.). Calculation of the ACSR type HAWK 240mm2 conductor with a diameter that is close to the same as the actual ACSR conductor installed at PLN is carried out with the aim of being a reference/comparison in the analysis (Migiantoro, 2002) . The method used in this research is to use the equation of conductor temperature analysis, to get the relationship between current-carrying ability and conductor temperature. Meanwhile, to calculate the mechanical performance of the conductor includes the maximum conductor, maximum conductor slope and tilt angle using the Catenary Equation method and the Basic Span Length method (Prasetyono, 2007) (Kwon, 2011).

E. Conductor Temperature Analysis

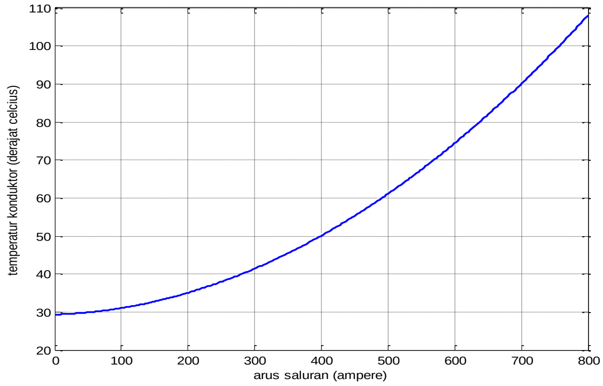

Figure 6

Graph of the relationship between the increase in line current and the temperature of the conductor

The heat generated in the conductor is affected by temperature and heat by electrical losses as a result of the current flowing in the conductor. The calculation in this study is to use the Hawk type ACSR conductor with specific data in accordance with those used in the field. It can be seen from the graph that the increase in line current will be followed by an increase in temperature. If it is considered that the maximum allowable temperature in this conductor is 90°C, then the maximum allowable current to flow is 698.4 amperes.

F. Analysis of the Effect of Channel Current on the Same Height Transmission Tower Slope

An increase in line current will result in a change in the slope of the conductor. When the line current increases, it causes an increase in skew which is then followed by an increase in the slope angle of the conductor. This can be seen in Figure 7 and Figure 8 below which show a graph of the calculation results of the slope and angle of the conductor slope. Taking into account the maximum allowable temperature limit for the ACSR conductor of 90°C, the maximum slope achieved is 13.1510 meters.

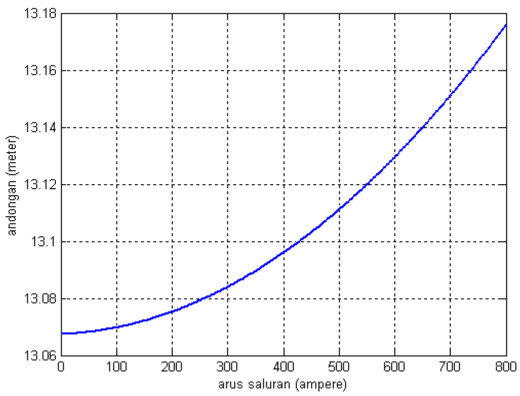

Figure 7
Graph of the relationship between the increase in line current and the slope of the conductor

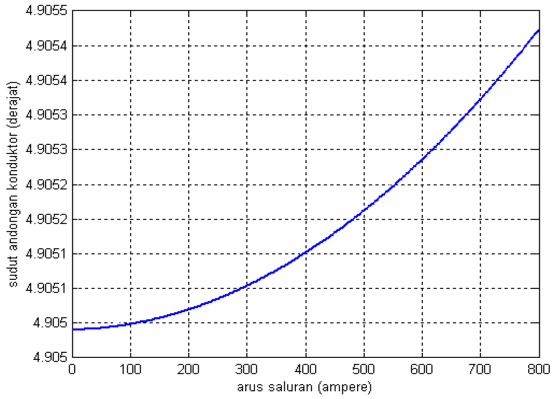

Figure 8
Graph of the Relationship of the Increase in Line Current to the Slope Angle of the Conductor

Changes in line current also result in a decrease in the conductor voltage (Syahputra & Tharo, 2021) . This is because an increase in current causes an increase in the temperature of the conductor, this temperature increase causes an expansion of the conductor which then increases the slope of the conductor. This increase in slope of the conductor causes the conductor voltage between the transmission towers to decrease.

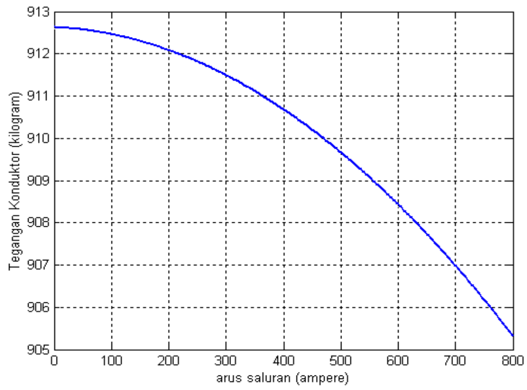

Figure 9
Graph of the relationship between the increase in line current and conductor voltage

Taking into account the maximum allowable temperature limit for the ACSR conductor, the magnitude of the conductor voltage drop that occurs when the maximum line current is 698.4 amperes is 906.9936 kilograms.

G. Analysis of the Effect of Channel Current on Unequal Height Transmission Tower Slopes

The goal distance or span also affects the slope value. The farther the goal distance, the higher the wedge produced and the greater the stress (DARIO et al., 2016) . The angle formed on the paddle is even greater if the goal distance between the two towers is further away (SLAMET, nd) .

Given that the length of the goal (span) of each tower is not the same , then the span is equivalent (basic span). In the case of calculating this equivalent span, data on the length of the inter-tower gates will be taken, namely data on transmission towers numbered 260 to 273, with the following data:

Table 5. Data span tower 260 to tower 273

Transmission Tower	Goal Length (m)
260 – 261	385.57
261 – 262	363.98
262 – 263	304.45
263 – 264	294.58
264 – 265	330.00
265 – 266	340.00
266 – 267	340.00
267 – 268	339.99
268 – 269	339.99
269 – 270	326.42
270 – 271	347.91
271 – 272	301.65
272 – 273	306.99

With the data from the existing goal length, it will get the basic span L length of 335.2613 meters using equation (22) above. Then the size of the andongan is (using equation 23) obtained a value of 15.6955 m.

CONCLUSION

Based on this research, it can be concluded that; The increase in line current results in an increase in conductor temperature which is then followed by an increase in the slope value and tilt angle and a decrease in conductor voltage; Taking into account the maximum permissible temperature limit for the HAWK 240 mm2 type ACSR conductor of 90°C, the following conclusions are obtained:

- The maximum conductor line current is 698.4 amperes.
- The maximum conductor voltage is 906.9936 kg.
- maximum conductor slope is 13,1510 meters.
- The maximum tilt angle is 4.9053°.

Changes in the current of the ACSR HAWK type 240 mm2 conductor from 0 amperes to 750 amperes resulted in an increase in conductor temperature of 232.97%; The size of the ACSR HAWK 240 mm2 conductor that is achieved at a temperature of 90°C is 13.1510 meters. This result is different from the calculation carried out by PLN, which is 11.16 meters. The difference in the results of this calculation is caused by differences in the technical data of the conductors used because PLN uses the ACSR HAWK 291.6 mm2 conductor.
With the increase in the ACSR HAWK 240 mm2 conductor slope from 13.0678 meters to 13.1626 meters, it can be seen that the stretching of the conductors has become longer even though it is only 0.801%; An increase in line current also results in a decrease in the conductor voltage. Based on the maximum temperature of 90°C, the conductor voltage that occurs is 906.9936 kilograms. The results obtained are also different from the results of calculations carried out by PLN,

which is 1365 kilograms. This difference in results is caused by several things, including:

- The calculation carried out by PLN is in a still water state or in a state without the influence of wind.
- The calculations carried out in this paper are on the ACSR HAWK 240 mm2 conductor, while the calculations carried out by PLN are on the 291.6 mm2 ACSR Hawk conductor.

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