Reliability Analysis of Aluminum Cable Steel Reinforced (Acsr) Conductors on the 275 Kv Nagan Raya - Sigli Transmission Line

Robi Alfandi, Siti Anisah, Zuraidah Tharo

Abstract

Conductors are one of the important components of transmission lines that play a role in distributing electricity from power plants to substations and then to consumers. Conductors stretched between two transmission towers do not follow a straight line, but due to their own weight, they curve downward, which is called sag. The 275 kV Nagan Raya - Sigli Transmission Line passes through several cities and forests, so it is necessary to calculate the sag as well as the reliability and current carrying capacity (KHA) that can be accepted by the conductor and the maximum ambient temperature of 400C, so that the reliability value of the conductor used can be obtained. The method used in this study is a quantitative method. Line current and ambient temperature cause an increase in conductor temperature, resulting in conductor expansion and increased length, thereby increasing sag. However, the tensile stress on the conductor is inversely proportional to sag; every 10°C increase in temperature increases sag by 0.41% and reduces conductor tensile stress by 0.41%. The results of this study obtained a maximum sag of 8.80709 m, indicating that the reliability of the conductor in transmission and sag can still be considered satisfactory because the clearance between the conductor and objects below the conductor, as well as the conductor's resistance to temperature due to current flow, are still in good condition and in accordance with SNI 04-6918-2002.

Keyword: ACSR Conductor Wire, 275 Kv Transmission Line Nagan Raya - Sigl

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Introduction

The construction of a 275 kV transmission network on the island of Sumatra is related to the government's policy to meet electricity demand in Sumatra. Based on projections of electricity demand on the island of Sumatra, there is a trend of increasing energy sales from year to year, ranging from 3% to 8%. Many of the supporting materials and electrical transmission equipment used by PT PLN Persero on the island of Sumatra have become a concern for the government in its use of the 275 KV network [3].

The increase in electricity capacity to date remains very limited, and various regions experiencing electricity crises are expected to continue to do so. However, in the future, a small number of regions experiencing electricity crises are expected to see relative improvements, even though they will not yet be able to recover to become reliable systems capable of providing electricity fully, including meeting adequate growth in demand. The 2007 to 2016 RUPTL states that improving the reliability of electricity distribution, expanding the network, and equalizing electricity distribution in several areas in Sumatra need to be realized [10]. On the other hand, in terms of service, the target electrification ratio is around 70% and the ratio of villages with electricity is around 90% with 76 million customers by 2020. Therefore, a reliable network is needed.

In general, conventional conductors have a permissible temperature limit not exceeding 75°C under daily load conditions and may increase to 90°C under emergency load conditions. Whereas mechanical conductors must be resistant to temperature changes caused by the current passing through them and must be resistant to all forces or pressures/tensions caused by mechanical and electrical loads, while in 275 KV transmission lines the normal temperature is 40-68°C and can increase to a maximum of 90°C, which is one of the advantages of the 275 KV network [10]. Air transmission lines must have a high current carrying capacity. To meet this current carrying capacity, the conductors used must be made of materials with high temperature characteristics (thermal resistance). In general, the conductors commonly used in overhead transmission lines are ACSR (Aluminum Conductor Steel Reinforced) aluminum conductors, which are stranded wires with a steel core surrounded by layers of aluminum strands. This type of conductor has limited heat resistance despite its high electrical conductivity, because it uses EC grade aluminum [13]. This is one of the reasons why ACSR conductors are used.

The power transmission line used by PLN Nagan Raya - Sigli uses 275 KV. This line is the main line or the largest line in transmitting electricity from the Nagan Raya Power Plant, Aceh. Therefore, a reliable current conductor is needed to maintain safety and avoid disturbances or natural events due to voltage. The impact on the 275 KV power transmission line in the event of a disruption would be fatal, such as an explosion in the transformer due to a surge, or it would also affect the surrounding community that is supplied with more than one surge of electricity [11].

Based on the background of the problem, it is necessary to analyze the reliability of steel-reinforced aluminum cable conductors on the Nagan Raya – SIGLI transmission line, which uses 275 KV transmission, because the working systems of each electrical current conductor are fundamentally different. Therefore, the reliability of steel-reinforced aluminum cable conductors on the Nagan Raya – Sigli electrical energy transmission line is also different. This study aims to analyze the reliability of steel-reinforced aluminum cable conductors in the Nagan Raya – SIGLI transmission line with a 275 KV transmission line[11]

Literature Review

2.1 Transmission System 275 kV

Indonesia uses transmission voltage standards of 66 kV, 150 kV, 275 kV, and 500 kV. The voltage generated by power plants is usually medium voltage. The electrical energy generated is then transferred through the transmission system, complete with substations. Due to the long distances involved, high voltage or extra-high voltage is required through distribution lines, which usually consist of primary distribution lines with medium voltage and secondary distribution lines with low voltage. medium voltage and secondary distribution lines with low voltage. The installation consists of electrical power usage installations leading to residential installations, which typically use low voltage, while large users such as industries use medium voltage or high voltage [9].

An electrical power system consists of several interconnected subsystems, commonly referred to as an interconnected system. It is clear that the flow of electrical energy begins at the power plant, travels through transmission and distribution lines, and ends at the user's installation, which is the utilization element [9].

Electricity from medium-voltage power plants is generally between 6 and 20 kV. In large power systems, this electricity is transferred through transmission lines, and the voltage must be increased from medium voltage to high voltage using substations. For very long distances, extra-high voltage is required, which is achieved using substations with step-up transformers. High voltage in Indonesia is 70 kV, 150 kV, and 275 kV. Meanwhile, extra-high voltage is 500 kV [9].

On a 275 kV transmission line, high transmission operating voltage can cause corona effects, which increase capacitance so that leakage capacitance to ground can no longer be ignored. In general, 275 kV transmission lines with a length of 70 km are classified as short-distance transmission. This transmission network transmits power at a voltage of 275 kV. Electrical power always flows towards the load, so in this case, the flow of power is also the flow of load. These loads are represented as fixed line impedance (Z), voltage (V), and current (I)[11].

2.2 The Effect of Andongan on Voltage System Stability

The study of electrical power systems generally includes the planning of generators, transformers, power lines, protection equipment, load estimates including peak and off-peak loads, additional electrical loads, and so on. As time passes and developments occur that impact people's lifestyles and needs, population growth, economic levels, services, and demand for goods and services, both directly and indirectly, will require an increase in electricity demand, so the study of electrical power systems must be constantly updated [13].

One aspect of electrical power system analysis is the analysis of system voltage, which is one of the determinants of electrical power system quality. Overvoltage, undervoltage, or unstable voltage will disrupt service to the load, prevent the load from operating optimally, and may even cause damage to the electrical load, ultimately harming electricity customers/consumers. Therefore, electricity providers, in this case PT. PLN, which serves large-scale electricity needs, especially in Indonesia, must always pay attention to the voltage quality of the power system. The conductor wire stretched between two transmission towers will not follow a straight line, but due to its own weight, it will bend downward, which is called sag. The magnitude of this curvature depends on the weight and length of the conductor wire itself. The effects that occur due to unstable sag include [3].

2.3 ACSR (Aluminium Conductor Steel Reinforced)

The ACSR conductor has an aluminum alloy fiber core surrounded by aluminum fibers containing zirconium (Zr). Aluminum containing zirconium has high conductivity and thermal resistance, while the aluminum alloy matrix in the center produces high tensile strength but is lighter and has better conductivity. This core fiber consists of thousands of aluminum oxide fibers (Nextel 3M's 650 ceramic) with a very small diameter.

ACSR conductors have great potential to replace existing conventional conductors. ACSR conductors can be installed quickly and easily to replace conventional conductors with available ROW (Rights of way) with little or no changes to towers and other supporting equipment. ACSR conductors can operate continuously at temperatures of 210°C and 240°C under emergency conditions, thereby increasing transmission capacity by two to three times compared to conventional conductors [7].

The ACSR system basically works the same as the distribution of electrical power, which is part of the electrical equipment system between the bulk power source (BPS) and customer service switches. In addition, a distribution system usually consists of several other supporting equipment and components such as distribution substations, sub-transmission systems, feeders and distribution transformers, as well as customer services (Logahan, 2012). In the distribution system, great attention is paid to integrated and adequate service quality. Factors that can determine the quality of service include the ability of the distribution system to continuously distribute electrical energy to customers, with a minimum level of interference [2]

2.4 ACSR Characteristics

The materials used to make this conductor consist of hard aluminum and high tensile strength steel wire coated with zinc, which is used as a protective/supporting layer. The properties of the aluminum material are no different from those used in All Aluminum Conductors (AAC). Aluminum conductor steel reinforced (ACSR) wire uses steel wire with the following characteristics:

a. Minimum tensile strength of 126.9 kg/mm²
b. The minimum weight of the zinc coating must comply with applicable regulations
c. No connections allowed
d. The zinc coating must be completely adherent and even, both
e. The wires are selected carefully and neatly
f. The steel wire used as a support is placed in the center position in accordance with the ACSR construction

Research Methodology

The type of research used by the researcher is descriptive qualitative research, in which the researcher will describe the reliability of ACSR conductor wire on the 275 KV Nagan Raya - Sigli transmission line. Qualitative methods are research procedures that produce descriptive data in the form of written or spoken words from people and observable behavior. The researcher is not required to form specific theories in advance regarding the aspects being studied, but can focus their attention on natural events as they are, according to the specified data. Meanwhile, the scientific approach used in this research is the communication science approach.

3.1 Research Location and Time

This research was conducted at PT PLN (Persero) in Suak Puntong Village, on a 275 KV transmission line that uses ACSR, regarding the reliability of the transmission wires used. The research period that the researcher will use in preparing this thesis is estimated to be from January 2023 until completion.

3.2 Data Sources and Types

The main sources of data in qualitative research are words and actions, while the rest are supplementary data such as documents and so on. Based on this explanation, data sources can be divided into two parts, namely:

a. Primary data, the primary data source in this study is all data obtained directly from informants as the first source in the form of interviews with informants at the PLN Persero ULTG Meulaboh Office, and both leaders, mechanics, and important informants that the researcher will need to obtain data on the reliability of ACSR conductor wires, and field observations on 275 KV transmission lines
b. Secondary data is supporting data or additional data in this study obtained from written sources such as documents, books, and statistical data related to this study

3.3 Data Collection Techniques

To obtain the data needed for this study, the researcher used data collection instruments as used in every field study. The data collection techniques in this study were related to qualitative data collection techniques, consisting of interviews, document studies, and observations. The interviews were unstructured, with interview guidelines that only contained the main points to be asked of informants in the field. Researchers were able to develop these questions in order to gather more in-depth data on the reliability of ACSR conductor wires on 275 KV transmission lines in Suak Puntong Village. Interviews are a data collection technique that involves asking questions to several PLN employees at PLN ULTG Meulaboh and to the managers responsible for providing information related to the research. Library Research, which involves analyzing relevant literature containing data necessary for this research related to theory and issues. Observation, which involves direct field observation of the reliability of ACSR conductor wires on the 275 KV Nagan Raya – Sigli transmission line.

3.4 Research Steps

The steps taken in this study can be seen in the form of a flowchart. The following is the research flowchart created in this study:

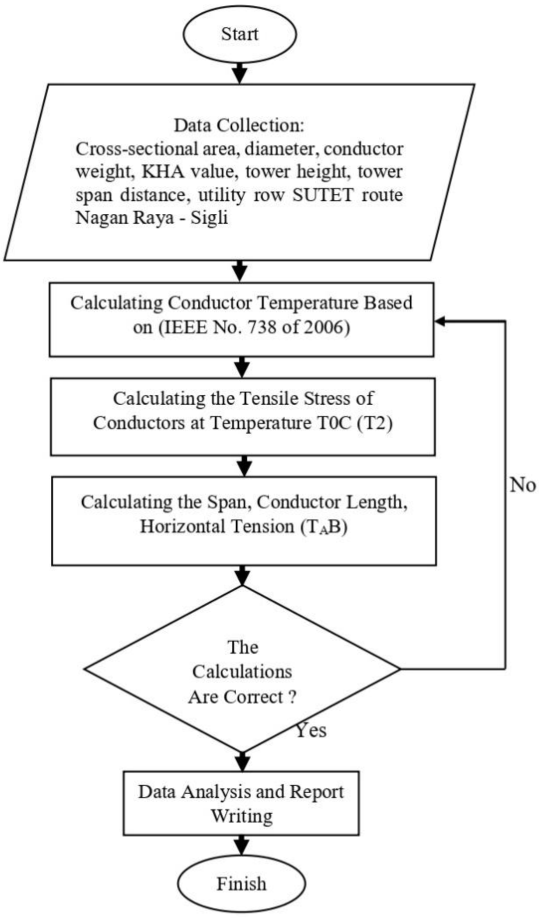

Figure 1. Research Flowchart

Results and Conclussion

Circuit Length	= 2 x 6,9 kms
Types of Conductors	= ACSR
Conductor Diameter (d)	= 28,62 mm
Conductor Cross-Section Area(q)	= 484,5 mm^2
Material	= Combination of Aluminum and Steel

4.1 Calculation of Conductor Temperature Due to Changes in Channel Current

The heat balance equation in air transmission ducts states that the amount of heat generated in the conductor is equal to the amount of heat dissipated, which can be calculated using the following equation:

$$\mathbf{W_c + W_s = W_k + W_r}$$

After obtaining the above equation, it can be arranged using the following formula:

$$C_3 \Delta t^4 + 4C_3 t_a \Delta t^3 + 6C_3 t_a{}^2 \Delta t^2 + (4C_3 t_a{}^3 + C_2)\Delta t - I^2 R - C_1 = 0$$

Where:

C_1 $= a\,E\,d_c$

C_2 $= \sqrt{p v_m}\, d_c$

C_3 =1,78 x 10^{-8}e

Δt = t_c - t_a

This equation can be used to determine the working temperature of the conductor as a result of channel changes

Table 1. Technical Data of Conductors for Temperature Calculation

Specifications	**Types of Conductors**
	ACSR
Cross-sectional Area (A)	484,5 mm^2
Diameter (d_c)	28,62 m
Ambient Temperature (t_a)	20^0C, 30^0C,40^0C
Air Pressure (p)	1 atm
Wind Speed (V_m)	10 m/s
High Current Carrying Capacity (I)	2 x 911A
Solar Absorption Coefficient (α)	0,6
Surface emissivity (e)	0,5
Temperature barrier (20^0C)	7,1 x 10^{-5} Ω/m
Temperature barrier (30^0C)	7,4 x 10^{-5} Ω/m
Temperature barrier (40^0C)	7,7 x 10^{-5} Ω/m
Solar Radiation Intensity (E)	1000W/m^2

After obtaining the data in the table above, calculations are performed to obtain the conductor temperature at the change in channel current.

1. C_1 = α E d_c
   = 0,6 x 1000 W/m^2 x 0,02862 m
   =17,172 W/m

   C_2 = $\sqrt{p v_m d_c}$
   = $\sqrt{1 x 10 x 0{,}02862}$
   = 0,53498 W/m

   C_3 = 17,8 x 10^{-8}
   = 17,8 x 10^{-8} x 0,5
   = 0,000000089

   $4C_3 t_\alpha$ = 4 x 0,000000089 x (20^0C)
   = 0,00000712

   $6C_3.t_a^2$ = 6 x 0,000000089 x $(20)^2$
   = 0,0002136

   $4C_3 t_a^3 + 18C_2$ = [4 x (0,000000089) x $(20)^3$] + [18 x 0,53498]
   = 9,63249

   $I^2 R_m + C_1$ = [$(900)^2$ x 7,1 x 10^{-5} Ω/m] + 17,172 W/m
   = 74,682 W/m

   So the polynomial form is as follows:

   0,000000089 Δt^4 + 0,00000712 Δt^3 + 0,0002136 Δt^2 + 9,63249 Δt-74,682= 0

2. C_1 = α E d_c
   = 0,6 x 1000 W/m^2 x 0,02862 m

$= 17{,}172$ W/m

$C_2 = \sqrt{pv_m d_c}$

$= \sqrt{1 x 10 x 0{,}02862}$

$= 0{,}53498$

$C_3 = 17{,}8 \text{ x } 10^{-8}.\ e$

$= 17{,}8 \text{ x } 10^{-8} \text{ x } 0{,}5$

$= 0{,}000000089$

$4C_3 t_\alpha = 4 \text{ x } 0{,}000000089 \text{ x } (30^0C)$

$= 0{,}00001068$

$6C_3.t_a^2 = 6 \text{ x } 0{,}000000089 \text{ x } (30)^2$

$= 0{,}0004806$

$4C_3t_a^3 + 18C_2 = [4 \text{ x } (0{,}000000089) \text{ x } (30)^3] + [18 \text{ x } 0{,}53498]$

$= 9{,}63925$

$I^2R_m + C_1 = [(900)^2 \text{ x } 7{,}4 \text{ x } 10^{-5}\ \Omega/m] + 17{,}172$ W/m

$= 77{,}112$ W/m

so the polynomial form is as follows:

$0{,}000000089\ \Delta t^4 + 0{,}00001068\ \Delta t^3 + 0{,}0004806\ \Delta t^2 + 9{,}63925\ \Delta t - 77{,}112 = 0$

3. $C_1 = \alpha\ E\ d_c$

$= 0{,}6 \text{ x } 1000\ W/m^2 \text{ x } 0{,}02862$ m

$= 17{,}172$ W/m

$C_2 = \sqrt{pv_m d_c}$

$= \sqrt{1 x 10 x 0{,}02862}$

$= 0{,}53498$ W/m

$C_3 = 17{,}8 \text{ x } 10^{-8}.e$

$= 17{,}8 \text{ x } 10^{-8} \text{ x } 0{,}5$

$= 0{,}000000089$

$4C_3 t_\alpha = 4 \text{ x } 0{,}000000089 \text{ x } (40^0C)$

$= 0{,}00001424$

$6C_3.t_a^2 = 6 \text{ x } 0{,}000000089 \text{ x } (40^0C)^2$

$= 0{,}0008544$

$4C_3t_a^3 + 18C_2 = [4 \text{ x } (0{,}000000089) \text{ x } (40^0C)^3] + [18 \text{ x } 0{,}53498]$

$= 9{,}63925$

$I^2R_m + C_1 = [(900)^2 \text{ x } 7{,}7 \text{ x } 10^{-5}\ \Omega/m] + 17{,}172$ W/m

$= 79{,}542$ W/m

So the polynomial form is as follows:

$0{,}000000089\ \Delta t^4 + 0{,}00001068\ \Delta t^3 + 0{,}0004806\ \Delta t^2 + 9{,}63925\ \Delta t - 77{,}112 = 0$

From the fourth-order polynomial equation obtained from the calculation, the increase in conductor temperature can be determined. From this increase in temperature, the conductor temperature can be calculated, and a graph showing the relationship between changes in channel current and conductor temperature can be obtained

Table 2. Calculation Results for Conductor Temperature at an Ambient Temperature of 20°C

Channel Flow (A)	Temperature Increase (Δt) ⁰C	Increase in Δt Against ΔI	Ambient Temperature (t_a) ⁰C	Conductor Temperature (t_c)⁰C
0	1,78264	-	20	21,78264
100	1,85634	0,07370	20	21,85634
200	2,07744	0,22110	20	22,07744
300	2,44595	0,36851	20	22,44595
400	2,96184	0,51589	20	22,96184
500	3,62511	0,66327	20	23,62511
600	4,43573	0,81062	20	24,43573
700	5,39368	0,95795	20	25,39368
800	6,49892	1,10524	20	26,49892
900	7,75142	1,25250	20	27,75142

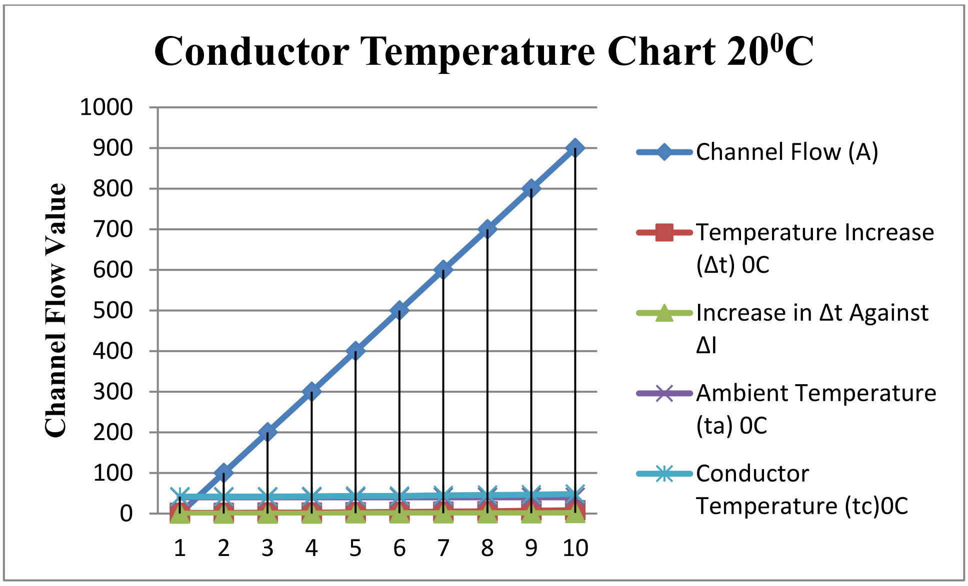

Figure 2. Graph of Calculated Conductor Temperature at Temperature 200C

Table 3. Calculation Results for Conductor Temperature at an Ambient Temperature of 300C

Channel Flow (A)	Temperature Increase (Δt) ⁰C	Increase in Δt Against ΔI	Ambient Temperature (t_a) ⁰C	Conductor Temperature (t_c)⁰C
0	1,78130	-	30	31,78130
100	1,85805	0,07675	30	31,85805
200	2,47206	0,38375	30	32,08831
300	2,47206	0,38375	30	32,47206
400	3,00929	0,53723	30	33,00929
500	3,69996	0,69067	30	33,69996
600	4,54402	0,84406	30	34,54144
700	5,54144	0,99742	30	35,54144
800	6,69212	1,15068	30	36,69212
900	7,99600	1,30388	30	37,99600

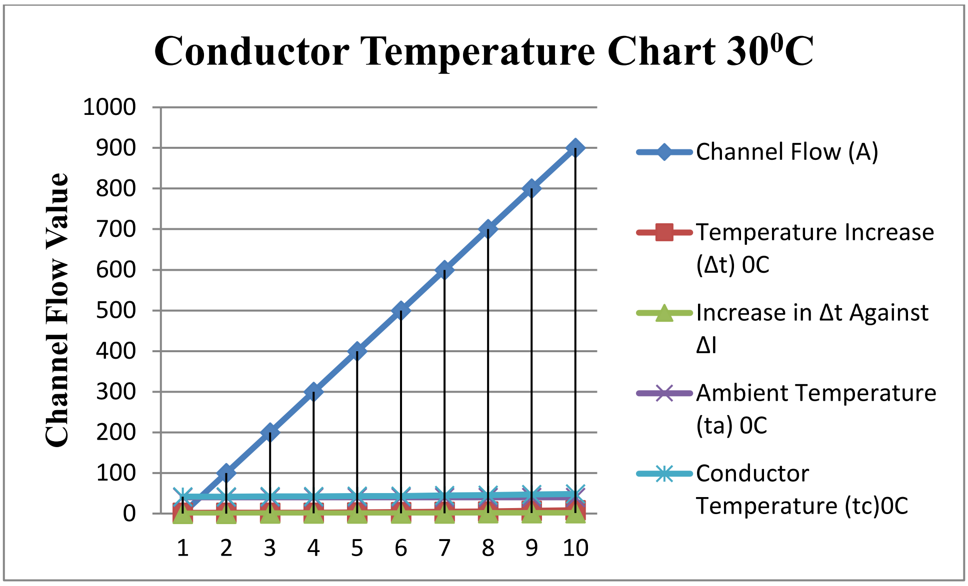

Figure 3. Graph of Calculated Conductor Temperature at Temperature 300C

Table 4. Calculation Results for Conductor Temperature at an Ambient Temperature of 400C

Channel Flow (A)	Temperature Increase (Δt) ⁰C	Increase in Δt Against ΔI	Ambient Temperature (t_a) ⁰C	Conductor Temperature (t_c)⁰C
0	1,77874	-	40	41,77874
100	1,85849	0,07975	40	41,85849
200	2,09772	0,23923	40	42,09772
300	2,49641	0,39869	40	42,49641
400	3,05453	0,55812	40	43,05453
500	3,77201	0,71748	40	43,05453
600	4,64878	0,87677	40	44,64878
700	5,68475	1,03597	40	45,68475
800	6,87980	1,19505	40	46,87980
900	8,23376	1,35396	40	48,23376

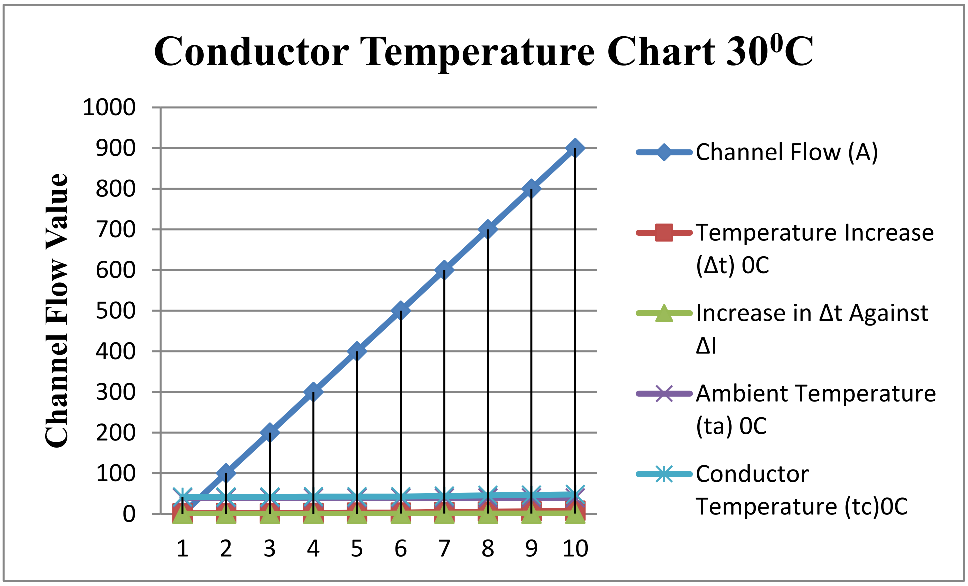

Figure 4. Graph of Calculated Conductor Temperature at Temperature 400C

Conclusion

Based on the results of the research that has been conducted, the following conclusions can be drawn:

a. The temperature of a conductor is affected by the current flowing through it. An increase in the current flowing through the conductor will cause heat loss in the conductor due to conductor losses
b. The resistance will increase as the current in the conductor reaches KHA, because the temperature of the conductor can cause it to expand, thereby increasing the resistance.
c. A 10°C increase in conductor temperature will add 0.03229 m or increase by 0.41%, and for every 10°C increase in conductor temperature, the conductor tensile stress will decrease by 10.4119 kg or decrease by 0.41%
d. The maximum sag occurs when the transmission line is loaded with a line current reaching its KHA at a maximum ambient temperature of 400C. The maximum sag obtained is 8.80709 m, which still meets the SNI 04-6918-2002 standard for the free distance from conductors, which is 5 meters from buildings and trees

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