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IMPROVEMENT OF THE SAG AMPACITY CARRYING LEVEL OF EXISTING 275 KV OVERHEAD LINE TOWER BY USING THE RE-CONDUCTORING APPROACH

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ABSTRACT

Urban cities grown in population day by day, proportionally to the electricity demand. The existence of the right of ways and the decreasing of land space to build new overhead transmission line towers, other criterion had to be observed. Other than upgrading towers, re-conductoring can be pursued if it does not violates the right of ways in any aspect. This project compares available conductors in the market to determine which will provide better performance in terms of current and sag for 275 kV lattice tower.

Keywords: overhead transmission line, conductor, modification.

INTRODUCTION

Electricity plays an important role in modern day routine. The needs to provide more electricity increases with the growth of men's population, specifically in urban cities yet very few of new overhead transmission line had been constructed (Mateescu *et al.* 2009). Current overhead transmission line may not be able to supply enough electricity to these urban cities in few years more. Thus, the purpose of this project is to increase the sag ampacity carrying level of existing 275kV overhead line tower by using the re-conductoring approach (Mateescu *et al.* 2009).

The power transfer capacity of an existing overhead transmission line can be upgraded by either increasing the size or number of conductors or increasing the voltage. By increasing the conductors and retaining the same voltage does not in any way change the electrical parameters. In general, existing structures are not loaded to their structural capacity in which they can accept larger conductors. While increasing the voltage involves in modification of both the electrical and structural aspects of an existing line (Kopsidas *et al.* 2010).

As the power consumption increases 5% each year, building new transmission tower would most likely violate the rights of way in which it will consume large space of area and disturb civilization. Though, another way of increasing the capacity of current that the overhead transmission line can deliver is by changing the existing conductor into one with higher current capacity without exceeding existing limitations such as sag constraints. Thus, re-conductoring method suits well (Hanson 1991).

The main objective of this project is to investigate the potential improvements in the sag ampacity carrying level of existing 275 kV overhead line tower by re-conductoring approach. In order to achieve this objective, work analysis will look at the potential of increasing the ampacity of the line by using suitable novel conductors that are currently available in the market. Matlab were used to obtain the maximum sag of the conductors by using the equations provided in this paper.

Overhead transmission line

There are three major parts that contributed into an overhead transmission line, which are the tower, conductor and insulator. The tower can be in variety of shapes which depends on the type of the line. Conductor acts as a medium in which the electric charge moves form one point to another which generally contains metallic attribute such as aluminium or copper. Insulators acts as a support to hold the conductors in place in order to provide sufficient distance between the tower and the conductor. Inheriting the insulation properties, it will resist the flow of electric current (BSI n.d.). By means of increasing the current capacity using re-conductoring method, only the conductor properties will be discussed throughout this project. Table-1 represents the previous work done by researches all over the world which provided information for this project.

Table-1. Previous work summary.

Project title	Method / Author	Outcome
Application of gap conductor and other special conductors for uprating	-Re-stringing (Kikuchi and Yonezawa, 2001)	-Use GTACSR and ZTACIR -Increases current and maintains sag
Evaluating opportunities for increasing power capacity of existing overhead line systems	-Re-conductoring (Kopsidas and Rowland 2011)	-Use 33 kV wooden pole structure-AAAC better than ACSR
Power transfer capacity improvements of existing overhead line systems	-Re-conductoring -Composite cross-arm (Kopsidas et al. 2010)	-ACSR LYNX and ACCR -Reduced sag and increased current
High temperature conductors: a solution in the uprating of overhead transmission lines	-Re-conductoring (Zamora *et al.* 2001)	-Use GTACSR, ZTACIR and ACSS -Reduced sag and increased current
ACSS/TW - An improved conductor for upgrading existing lines or new construction	-Re-conductoring (Thrash, F. R. 1999)	-Use ACSS/TW -Less sag -High temperature operation

Conductor

The conductor is the overhead cable or line used to transmit power between the two sides. Selecting the suitable conductor is crucial as it have to withstand the wind, ice and tension load that depends on the size and type of conductors used. The maximum sag under maximum ice or maximum temperature conditions are also related to the conductor in terms of certain physical, mechanical and dimension properties which in turn affects the structure heights. Environmental effects such as radio noise and audible noise should not be excluded from affecting the conductor (Ridley *et al*. 2007).

Conductors can be mainly classified into two major classes which are; homogenous or non-homogenous. Homogenous conductors consist of strands of wire with the same material while non-homogenous conductors consists of mixtures of different wire materials. Table-2 describes the classes of aluminium and aluminium alloys in summarization (Ridley *et al*. 2007).

Table-2. Aluminium and Aluminium alloy classes summarization.

Non-heat-treatable	Heat-treatable
Aluminium and aluminium alloys are hardened by plastic deformation.	Can be strengthened by plastic deformation, thermal treatments or the combination of the two.
1350 aluminium is in this category.	6201 aluminium alloy is used when higher strength is required.
H19 is the temper process.	T81 is the temper process
Can be softened with full-soft or O-temper.	

Conductor selection

Choosing the most appropriate conductor type and size is essential due to it being one of the major cost components of a line design. Among the considerations that can be made are the tension loads, ice and wind loads, the current loading of the line, voltage stability, environmental effects, electrical losses, ambient conditions and many others. The objective is to select a conductor that inherits the best conductivity-to-weight ratio or strength-to-weight ratio for the application. Other key factors in choosing the conductor types are the electrical and mechanical properties of the conductor type and size for a given line design problem (Kopsidas and Rowland, 2011), (Zamora *et al*. 2001). In the re-conductoring

ARPN Journal of Engineering and Applied Sciences

approach, the conductor to be replaced should not exceed the longitudinal tension and transverse ice and wind loads on the existing structures while maintaining electrical clearance and environmental limitations (Ridley *et al.* 2007).

Types of conductors

Table-3 shows the properties of the most commonly used conductor types in the utility industry except for the Aluminium Conductor Composite Reinforced (ACCR) which has limited service application to date (Ridley *et al.* 2007).

Table-3. Types of conductor and its properties.

Types of conductor	Properties
All-Aluminium Conductor (AAC)	-Composed of 1350-H19 aluminium wires. -Low cost, good corrosion resistance and moderate conductivity. -Ideal with short span with maximum current transfer.
All-Aluminium Alloy Conductor (AAAC)	-Composed of 6201-T81 aluminium alloy. -Comparable thermal ratings, improved strength-to-weight ratio, lower electrical losses and superior corrosion resistance compared to ACSR. -Preferred for distribution installations on the seacoast, farm and industrial areas.
Aluminium Conductor Steel Reinforced (ACSR)	-Composed of a solid or stranded galvanized steel core surrounded by one or more layers of 1350-H19 aluminium. -Provides equivalent or higher thermal ratings in comparison with AAC. -Steel core provides less elongation which means less sag at a given tension.
Aluminium Conductor Composite Core (ACCC)	-Consists of polymer-bound carbon-fibers encased in fiberglass tube. -Typically uses trapezoidal shaped, fully annealed 1350-O aluminium wires over a single strand or rod composite core.
Aluminium Conductor Composite Reinforced (ACCR)	-Constructed with Aluminium-Zirconium alloy wires over a reinforced core of stranded ceramic filaments -Composite core has lower thermal elongation and equal or greater strength than galvanized steel.

Clearances

Safe distances from buildings, people and objects underneath the conductor must be taken into consideration when designing overhead lines. Information regarding the shape of the terrain along the right-of-way, the conditions of wind, ice and temperature and also the height of the conductor are needed as to avoid any infringement to the minimum ground clearance. Figure-1 visualizes the safety clearance and other types of sag. The span length is the distance horizontal distance of the conductor, everyday sag is the sag of the conductor on daily operating basis, the maximum electrical loading sag is the maximum allowable conductor length on maximum operation and the minimum clearance to ground is the safety clearance that should not be violated (Kopsidas and Rowland 2011), (Centre 1989).

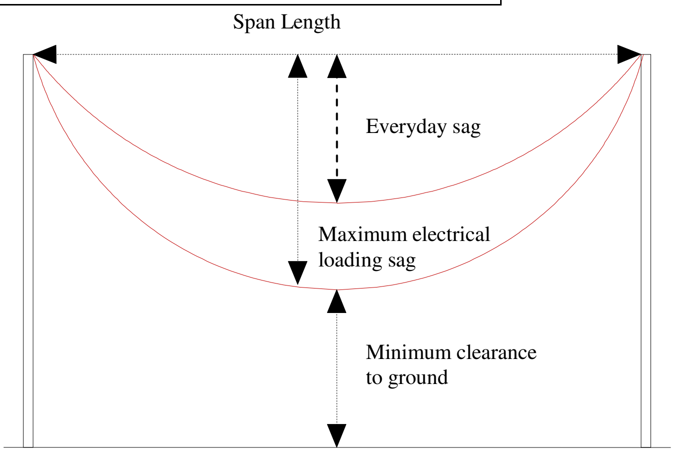

Figure-1. The visualization of safety clearance and other types of sag.

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The 275 kV Lattice tower system

This paper studied the typical 275kV lattice tower L3 type with standard suspension tower as shown in Figure-2. The maximum sag of the conductor in order to avoid clearance infringement can be calculated from the Figure which is 12.23 m. The span length used is 400 m with the maximum loading tension permitted by the strength of the structure is 72 kN and the maximum weight supported by each of the cross-arm is 30 kN (Kopsidas and Rowland 2011). The initial conductor used is ACSR Zebra since Malaysia uses this conductor on the 275 kV L3 tower and comparison was done with other types of conductor of similar characteristic.

Sag at maximum temperature

The temperature of the conductor will vary with the ambient temperature and line current which will cause variations in conductor sag. The current ratings of conductors that will later be determined is the maximum current obtained from the designated temperature specified. It is therefore necessary to obtain the maximum sag at maximum temperature without exceeding the MWT provided (International 1991), (Centre 1989). The value of maximum sag will be obtained from the Graphical User Interface (GUI) created in order to ease the process of this project. Table-4 represents the parameters of the selected conductor in comparison with the ACSR Zebra.

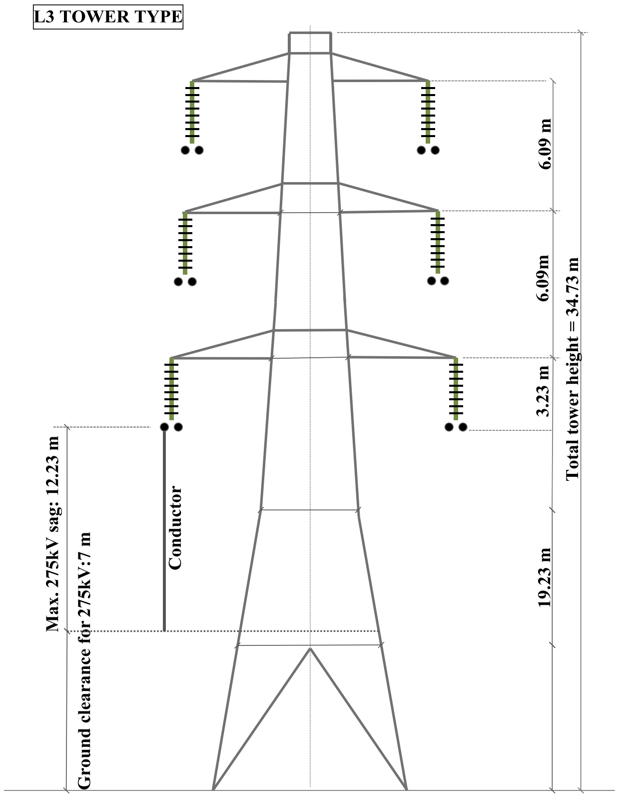

Figure-2. Outline diagram of 275 kV L3 type tower with normal suspension set structure (Kopsidas and Rowland 2011).

Table-4. Parameters used for the selected conductors.

	Conductor				
Parameter	**AAC Narcissus**	**AAAC Greeley**	**ACCC 415 mm^2**	**ACSR Zebra**	**3M Drake**
MWT, kN	34.5	47	50	52	50
Modulus of elasticity, kN/mm^2	57.57	58.6	73.4	73.2	80
Coefficient of expansion, /°C	23	23	19.23	19.91	16.5
Total cross-sectional area, mm^2	645.29	469.6	469.72	484.5	484
Diameter, mm	33.03	28.14	25.14	28.62	28.6
Bare conductor mass	1.79	1.293	1.252	1.621	1.384
Final tension 1st guess	17000	23000	25000	25000	25000

Table-5 shows the fixed values used in the calculation of the maximum sag. The initial and final temperature stated are according to the average temperature of Malaysia. Nil value of ice diameter is taken because there is no weather condition in Malaysia that will produce ice on the conductor. The gravity of the earth is constant at 9.806 m/s^2. The span length used for the tower is 400m while the wind pressure taken is at 380 N/m.

ARPN Journal of Engineering and Applied Sciences

Table-5. Fixed parameters condition.

Parameter	Value
Initial temperature, °C	22
Final temperature, °C	37
Ice diameter, mm	0
Gravity, m/s^2	9.806
Span length, m	400
Wind pressure, N/m	380

DC Resistance

The direct current resistance of a conductor is a function of its cross-sectional area, length and volume resistivity which can be expressed as equation (1) (Ridley *et al*. 2007):

$$R = \rho_v \left(\frac{L}{A}\right) \quad (1)$$

R = conductor resistance, Ω / unit length
ρ_v = volume resistivity of conductor material
L = conductor unit length
A = conductor cross-sectional area

Equation (1) is used to calculate the reference temperature of the selected resistivity values, typically 20ºC. Though in order to determine the dc resistance at other temperatures, the following equation (2) will be used (Ridley *et al*. 2007):

$$R_{T_2}{=}R_{T_{ref}}\left(1+\alpha_{ref}\left(T_2 - T_{ref}\right)\right) \quad (2)$$

α_{ref} = Temperature coefficient of resistance at reference temperature T_{ref}
T_{ref} = Reference temperature, $°C$
T_2 = Temperature at which new resistance is desired. $°C$
R_{Tref} = Dc resistance at reference temperature T_{ref}
R_{T2} = Dc resistance at temperature T_2

AC Resistance

Alternating current receives more resistance from the conductor compared to the direct current. The magnitude of this increment is expressed as the ac/dc ratio. The following equation (3) and (4) is used to calculate the AC resistance of a conductor (Ridley et al. 2007):

$$Abscissa\ value = \sqrt{\frac{f}{R_{dc}}} \quad (3)$$

R = frequency
ρ_v = dc resistance, Ω / mile

and,

$$R_{ac} = (R_{dc})\left(ratio_{ac\,/\,dc}\right) \quad (4)$$

$ratio_{ac/dc}$ = constant obtained from the abscissa value

Steady-State heat balance

The steady-state heat balance equation is given in equation (5) (Ridley *et al*. 2007):

$$q_c + q_r = q_s + I^2 R_{Tc} \quad (5)$$

Solving for *I*:

$$I = \sqrt{\frac{q_c + q_r - q_s}{R_{Tc}}} \quad (6)$$

q_c = convective heat loss rate, W/ft
q_r = radiated heat loss rate, W/ft
q_s = solar heat gain rate, W/ft
I = conductor current, amperes at 60 Hz
R_{Tc} = 60 Hz ac resistance of conductor at operating temperature $T_c, \Omega/ft$

Convected heat loss rate (q_c)

The convected heat loss rate (q_c) is the major heat loss from an overhead conductor. It is three to four times of the loss from radiated heat loss. Without any wind, there exist the natural convection heat loss which can be calculated by equation (7) and (8). T_{film} will be used to obtain the viscosity, density and thermal conductivity of air (Ridley *et al*. 2007):

$$q_c = 0.283\rho_f^{0.5} D^{0.75} (T_c - T_a)^{1.25} \quad (7)$$

q_c = convective heat loss rate, W/ft
ρ_f = density of air at temperature, $T_{film}, lbs\ /\ ft^3$
D = conductor diameter, inches
T_c = conductor temperature, $°C$
T_a = ambient temperature, $°C$

$$T_{film} = \frac{T_c + T_a}{2} \quad (8)$$

Radiated heat loss rate (q_r)

The radiated heat loss rate (q_r) is dependent upon the conductor diameter, emissitivity and conductor temperature rise above ambient and can be determined by using the following equation (9) *(Ridley et al.* 2007):

$$q_r = 0.138D\varepsilon\left[\left(\frac{T_c + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4\right] \quad (9)$$

q_r = radiated heat loss rate, W/ft
ε = emissivity
D = conductor diameter, inches
T_c = conductor temperature, $°C$
T_a = ambient temperature, $°C$

Solar heat gain rate (q_s)

Solar heating normally raises the conductor temperature by 5ºC to 10ºC above the air temperature and is usually included in thermal rating calculations. The solar heat gain rate equation is as provided in equation (10) and (11) (Ridley *et al.* 2007) :

$$q_s = \alpha Q_s \sin(\theta)\, A' \quad (10)$$

q_s = solar heat gain rate, $W\ /\ ft$
α = solar absorptivity
Q_s = total solar radiated heat flux, $W\ /\ ft^2$
θ = effective angle of incidence of the sun ray's degrees
A' = projected area of conductor, per unit length, $ft^2\ /\ ft$

$$\theta = \cos^{-1}[\cos(H_c)\cos(Z_c - Z_l)] \quad (11)$$

Hc = altitude of sun, degrees
Z_c = azimuth of sun, degrees
Z_l = azimuth of line, degrees

In order to calculate the current at operating temperature, certain parameters had been fixed according to Malaysia's scenario as shown in Table-6.

Table-6. Fixed parameters to calculate current.

Parameter	Value
Altitude of sun, Hc	70.1°
Azimuth of sun, Zc	180°
Solar absorptivity, α	0.5
Wind speed, Vw	0.447
Ambient Temperature ,Ta	35°

RESULTS

Maximum sag

Table-7 below represents the maximum sag obtained from ACSR Zebra 400 mm² at 80°C and other types of conductor with similar characteristic with it:

Table-7. Parabola sag value comparison at 70°C.

Types of conductor	**Parabola sag value** (m)
AAC Narcissus	15.030
AAAC Greeley	9.322
ACCC 415 mm²	8.359
ACSR Zebra	9.663
3M Drake	8.763

According to Table-7, only ACCC 415 mm^2 and 3M Drake have better sag value compared to ACSR Zebra. Having a lower sag value is better because of the maximum clearance to ground can be saved.

Table-8 represents the final sag value after each of the parameters was increased one at a time. The default value of ACSR Zebra sag was 7.9369 m. By comparing the sag values of the modified parameters with the default parameters, it can be observed that only the MWT and initial temperature values that contributed in reducing the value of the sag after increased modification.

By increasing the MWT, will increase the rated strength of the conductor. The higher the rated strength, the stronger the conductor will react to the stress applied with accordance to various factors.

While increasing the initial temperature yields to smaller range of temperature applied to the conductor as that result in smaller thermal expansion done to the conductor.

All of the other parameters contributes to the increasing value of the sag as they are related to the load that the conductor had to endure.

Table-8. The parabola sag value with modified parameters of ACSR Zebra.

Parameter	Default value	Modified value	Parabola sag value, m
Maximum Weight Tension, kN	52	65	6.59
Modulus of elasticity, kN/mm^2	73.2	90	8.09
Coefficient of expansion, /°Cx10^{-6}	19.91	25	8.13
Total cross-sectional area, mm^2	484.5	550	8.03
Initial temperature, °C	22	40	7.28
Final temperature, °C	40	90	10.27
Ice diameter, mm	0	25	13.31
Diameter, mm	28.62	40	8.64
Gravity, m/s^2	9.806	15	11.61
Bare conductor mass, N/m	1.621	1.8	8.77
Span length, m	400	500	12.51
1st guess, N/m	25000	30000	7.80
Wind pressure, N/m	380	450	8.28

Maximum current

Table-9 represents the maximum electrical current loading at different temperature for the conductors used by using the parameters stated before.

Table-9. Maximum electrical loading at different temperature.

Temperature	60°C	80°C	100°C	120°C	140°C	160°C
Conductor	Current (A)					
ACSR Zebra	554	814	997	1142	1263	1369
3M Drake	569	844	1032	1187	1316	1428
AAC Narcissus	688	1021	1259	1446	1605	1746
AAAC Greeley	674	997	1227	1411	1569	1707
ACCC 415 mm^2	535	780	952	1089	1204	1304

Figures 3 and 4 describes the current rating versus temperature between ACSR Zebra with ACCC 415 mm^2 and ACSR Zebra with 3M Drake respectively. It can be observed that ACCC 415 mm^2 delivers the lowest current compared to both ACSR Zebra and 3M Drake in which 3M Drake offered the opposite. This shows that having lower sag does not result in higher current delivered. Though, the 3M Drake conductor has lower sag value and higher current delivered compared to ACSR Zebra.

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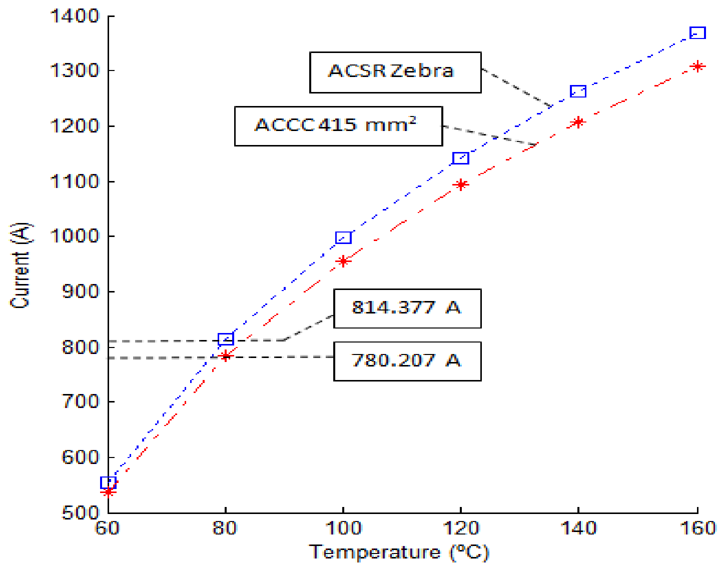

Figure-3. Current vs. temperature of ACSR Zebra and ACCC 415 mm^2.

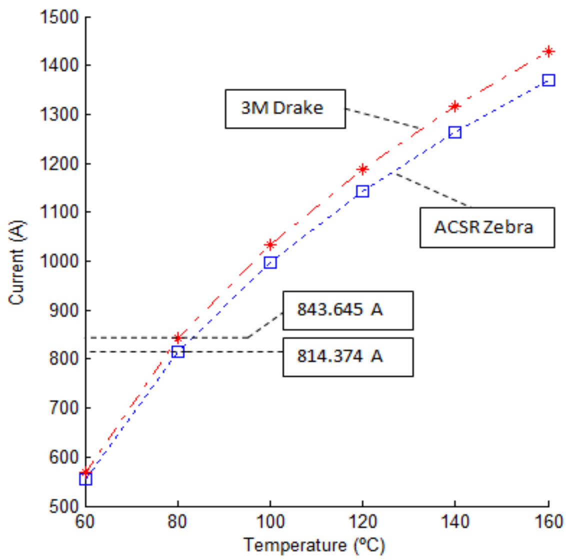

Figure-4. Current vs. temperature of ACSR Zebra and 3M Drake.

Table-10 represents the comparison between ACSR Zebra with 3M Drake conductors in terms of maximum power per phase at maximum operating temperature without infringing the safety clearance. 3M conductor can provide power uprating of up to 20% compared to the existing capability.

Table-10. Power per phase comparison.

Conductor	**Max. Op. temp.** (°C)	**Ampacity** (A)	**Power per phase** (MVA)
ACSR Zebra	138	1201	190
3M Drake	167	1445	229

CONCLUSIONS

ACSR conductor had been dominating the market of overhead line business for the past years. Though, with the existence of this new 3M conductors, engineers should be aware of the benefits of this conductor. In order to fulfill the demand of electricity in urban cities in which the right of ways are clenching tight in every aspect.

The 3M brand composite conductor consists of high temperature aluminium zirconium (Al-Zr) strands covering a stranded core of aluminium oxide fiber-reinforced composite wires. Both of the composite core and the outer Al-Zr strands contribute to the overall conductor strength and conductivity. Having the strength and stiffness of steel but lighter in weight, the composite core contains 3M metal matrix composite wires that contains aluminium oxide fibers. Visually, the composite wires appear as traditional aluminium wires but exhibit mechanical and physical properties far superior to those of aluminium and steel. Stranded with a temperature resistant Al-Zr in the outer strands, this conductor is able to operate at high temperatures.

It had been proven that 3M Drake conductor is more reliable in providing higher ampacity with lesser sag compared to the ACSR Zebra conductor. The power per phase improvement using 3M Drake conductor is about 25%. Thus, the objective had been achieved.

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