

Conductor sag comparison for 132 kV overhead transmission line improvement in Malaysia

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ABSTRACT

This paper presents conductor sag comparison for 132 kV overhead transmission line improvement in Malaysia. Increasing industrialization and population growth around the world demands higher electricity supply. Power generation has yet to decline but transmitting sufficient electricity to consumers is worrisome due to scarce land space occupied by rapid urbanization. Hence reconductoring method was chosen to improve existing 132 kV overhead transmission line in Malaysia. A group of selected conductors were chosen for comparison where the high temperature low sag conductor stood out the most producing up to 40% sag reduction. This paper focuses on providing conductor alternatives to improve maximum sag of lowest conductor to ground for 132 kV transmission line in Malaysia in accordance to her climate and geographical factor.

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1. INTRODUCTION

The importance of electricity heightened along rapid urbanization all around the world due to industrialization development and increasing human population including Malaysia. Other than that, most people could not avoid from consuming electricity in our daily routine either for necessity or to fulfil unnecessary desires. Thus in order to ensure sufficient electricity is provided to every nook and cranny of a country to continue its growth, development of power generation should not be neglected. Generated from power substation, electricity is transmitted from one place to another through Overhead Transmission Line (OTL). Although power generation has been steadily increasing and improved in Malaysia [1], the means to transmit electricity has become worrisome. The reason behind this cause is due to scarce land space that had been occupied by huge industrialization and population growth. This scenario limits new construction of OTL that consumes wide land space in order to provide sufficient Right-Of-Way (ROW). Before the scenario worsens, studies have to be taken to evaluate other means necessary of improving existing OTL to transmit sufficient electricity to the consumers should the time arrives [2].

OTL systems are required in order to transmit electricity from one place to another where their size greatly depends on its respective voltage ratings. The simplest idea of increasing electricity transmission capabilities can be done by constructing new OTL systems which would be ideal to be constructed on new terrain far from human population. Nevertheless, the cost for such development would be expensive and it also requires huge land space to maintain its ROW. The same goes to the idea of replacing old OTL

systems to new ones of higher voltage rating [3]. Hence, the best solution to increase electricity transmission capabilities to avoid unnecessary cost and land space consumption would be the modifications of existing OTL systems. There are three types of OTL systems typically used in Malaysia known with voltage ratings of 132 kV, 275 kV and 500 kV. The 132 kV OTL in Malaysia becomes the focus of this study because it has the potential to be upgraded into 275 kV or even into 500 kV voltage systems. Figure 1 represents typical 132 kV OTL dimension used in Malaysia [4].

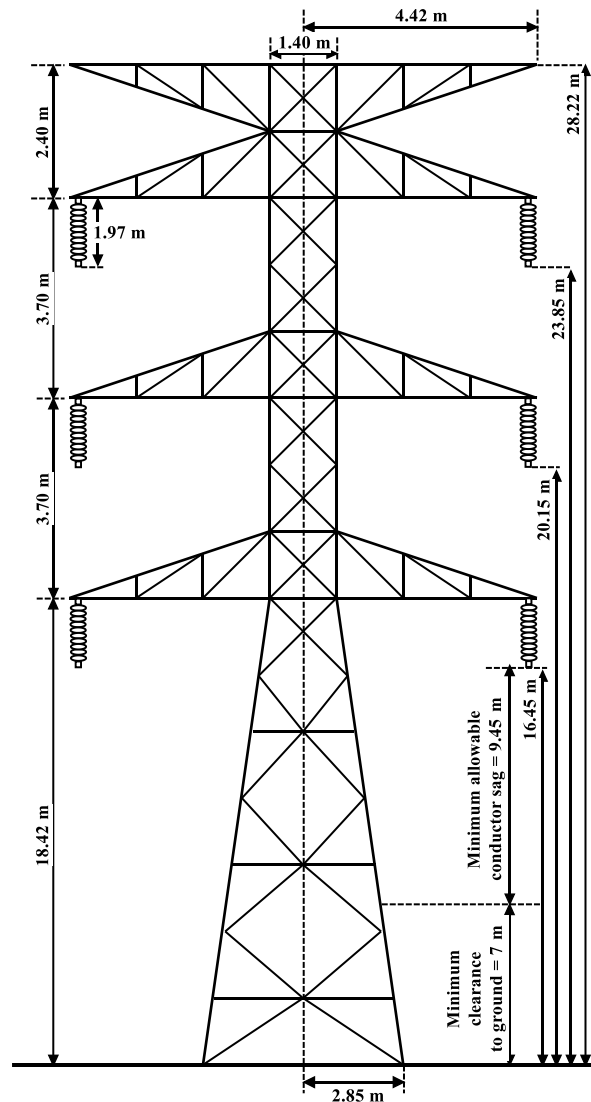


Figure 1. Typical 132 kV OTL dimension used in Malaysia [4]

OTL systems have four major parts namely the tower structure itself, cross-arms, insulators and conductors. These four major parts of existing OTL systems can be modified to improve its capabilities. The main objective of these modifications is to provide sufficient electrical clearances for the OTL to operate at higher capabilities while maintaining its ROW. Electrical clearances that need to be achieved are between the maximum sag of lowest conductor to ground, conductor phase-to-phase and conductor phase-to-structure [5]. The tower structure itself can be modified through reinforcement of a leg member or its foundation [6]. Such implementations are crucial when considering physical modifications of existing OTL towers to provide sufficient mechanical strength and supports. Cross-arms and insulators can both be modified into composite cross-arms that eliminates the use of insulator hence increasing electrical clearances [7-9]. All of these modifications require physical alterations that would sum up a huge number of expenses leaving conductor modification as an alternative.

Modifying existing conductors can be done by either restringing or reconductoring where the first is usually applied when faulty calculation existed while the latter is used to replace aged conductors with better performance conductors. Normally, conventional conductors are used to its maximum life span averaging between 40 to 50 years [10]. According to [11] there is the risk of sag exceedance and failure possibility on aged conductors due to annealing of aluminium layers in conjunction with repeat thermal cycling on the steel core of aged ACSR conductors. Thus by applying the reconductoring method, not only that existing OTL system can be used for an additional 50 years or more, but it can also be operated at higher capabilities when old conductors are replaced with better performance conductors. In addition to that, minimal to zero tower structure modification are required while still providing sufficient electrical clearances, maintaining ROW and cost effective when compared to building a new OTL system [12, 13].

In this paper, a group of conductors of different types were compared with existing conductor used in 132 kV OTL system in Malaysia. Conductors of similar diameters and strandings were chosen to evaluate the conductor sag that they will produce. The conductor sag calculation used in this paper accommodates Malaysia's climate specifically the wind speed and ambient temperature to further evaluate conductor sag improvement by reconductoring method specifically in this country.

2. RECONDUCTORING METHOD

Generally reconductoring method is performed by replacing old conductors with new ones of better characteristics depending on the objectives [14]. In this case, the objective of reconductoring is to provide increased maximum sag of lowest conductor to ground clearances. This can be achieved by using conductors that provides lesser sag when operated at the same operating current. In order to apply reconductoring method, choosing proper conductor is vital in the process. There are varieties of conductor selection available in the market commonly known as Aluminium Alloy Conductor (AAC), All Aluminium Alloy Conductor (AAAC), Aluminium Conductor Steel Reinforced (ACSR), Aluminium Conductor Composite Reinforced (ACCR) and others. Each group consists of numerous conductors which inherit different characteristic parameters usually known by their codename, conductor diameter and conductor stranding.

Conductor replacement with approximately the same cross-sectional area of similar conductor weight or by High Temperature Low Sag (HTLS) conductors can improve conductor sag without structure modification [15]. In Thailand, a series of HTLS conductors were compared with 1272 MCM ACSR for 230 kV OTL system that provides up to 15% conductor sag improvement [16]. In the UK, AAAC conductor is predicted to provide 20% increase in conductor system life compared to ACSR conductor [17]. A series of HTLS conductors were also compared with ACSR 450/75 conductors that measures up to three times increased thermal ratings while maintaining similar conductor sag [18]. HTLS conductors are currently in favour when intended to be used for reconductoring due to its ability to produce low sag while being operated at high temperature. In this study, conventional conductors including a type of HTLS conductor were chosen to be compared with existing ACSR conductor used in 132 kV OTL system in Malaysia in terms of conductor sag.

In Malaysia, the ACSR Batang conductor is commonly used for 132kV OTL system. Comparison was made between selected few conductors within those commonly group of conductors available in the market to determine which conductor is suitable to replace ACSR Batang. The conductors used for comparison of each group are chosen based on similar characteristics of conductor diameter and stranding as compared to ACSR Batang. Several conductors are also chosen with smaller and bigger conductor diameter and stranding to further evaluate the effects of these characteristics.

A good conductor should be able to perform better in terms of conductor strength-to-weight ratio, ampacity and sag. Strength-to-weight ratio of a conductor determines its ability to withstand gravitational and wind force before reaching its breaking point. High value of strength-to-weight ratio will produce low conductor sag. A conductor with the ability to provide higher ampacity is always favoured but transmitting higher electricity produces more heat and when combined with ambient temperature, conductor will elongate more resulting in higher sag. Thus in order to choose the best conductor to replace ACSR Batang while providing sufficient electrical clearances and maintaining ROW, the conductor sag characteristics of selected conductors are focused in this study.

3. CONDUCTOR SAG CHARACTERISTICS

A conductor that is strung from two points of tower supports will have sag due to gravitational force pulling the weight of the conductor to the center of the earth [19]. Sag is the distance measured vertically from the lowest conductor to the span length. Unless stated otherwise, sag is usually referred to the midpoint of the span where uniformly flat ground surface is assumed [20].

There are three common terms when characterizing sag which are everyday sag, maximum allowable sag and maximum sag at maximum operating temperature. Everyday sag occurs during normal daily operations of OTL systems where current supplied is not at its optimum. Maximum allowable sag is a criterion that should not be violated when operating OTL to ensure safety clearance from conductor to ground is secured. Its value is dependent on the type of OTL systems and tower structures where at least 7 m of height is required for typical 132 kV OTL system [21]. Maximum sag at maximum operating temperature determines the effectiveness of conductors in providing low sag when operated at its maximum capabilities. Figure 2 represents the first two of these sag characteristics while the third varies depending on the type of conductors [22].

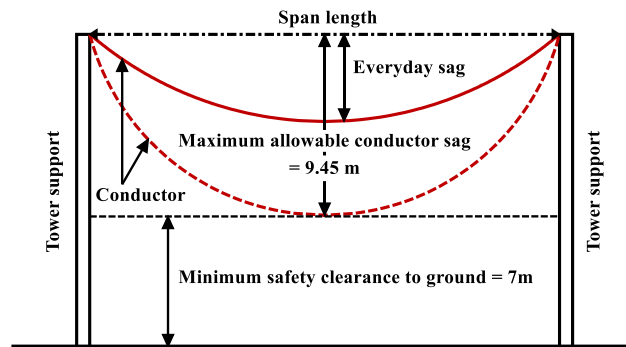


Figure 2. Sag characteristics and 132 kV minimum safety clearance to ground [22]

4. CONDUCTOR SAG CALCULATION

A conductor strung with supports only at its ends takes the shape of a catenary curve. Typically, lines that are spread across non-mountainous country have catenary curve that resembles almost like a parabola. In addition, there are no significant differences when comparing conductor sag calculated by using catenary and parabolic equation for lines shorter than 500 m span length. Hence, parabolic equation is used in this study with span length of 300 m to determine the maximum sag at maximum operating temperature. Sag, S is derived by (1) [23] while arc length of conductor in a level span l , is derived by (2) [24]:

$$S = \frac{wL^2}{8T} \quad (1)$$

$$S = \frac{wL^2}{8T} \quad (2)$$

Where L is span length (m), w is either vertical force in still air, or resultant force with wind, per unit length of conductor in the span length (N/m), and T is horizontal component of tension (N). The final untensioned conductor length equals the initial untensioned length plus any extension due to a change of temperature. Elastic stretch is deducted and change of temperature extension is added. Thus the change of state formula is as (3) [24]:

$$\frac{L^3}{24} \left[\left(\frac{w_1}{T_1} \right)^2 - \left(\frac{w_2}{T_2} \right)^2 \right] + \frac{L}{AE} (T_2 - T_1) + \alpha L (\theta_2 - \theta_1) = 0 \quad (3)$$

Where A is conductor cross-sectional area (m^2), E is effective modulus of elasticity (kN/mm^2), α is effective coefficient of expansion ($^{\circ}\text{C}$) and θ is temperature ($^{\circ}\text{C}$). Denomination 1 is for initial and 2 is for final. The length of conductor sag is affected by the mechanical properties of the conductor, its operating temperature and geographical factors such as wind speed and ambient temperature. Conductor mechanical properties are extracted from public accessible datasheet provided by worldwide companies.

Wind speed increases as the height increases above ground. Thus wind pressure used in tower designs should be increased for the upper parts of tall towers, one that is used for river crossings as

an example. This case should be implemented on towers reaching higher than 60 m tall. It is not practical to vary wind pressure along a span hence a single mean value should be used. Temperature changes provide significant impact upon conductor sag. It is considered as a standard practice to specify minimum and maximum conductor operating temperature at -5.6°C and 75°C respectively for countries with winter season. The minimum conductor operating temperature is the temperature where ice is usually formed on the conductor. Suruhanjaya Tenaga Electricity Regulations 1994 has provided guidelines for wind speed, minimum and maximum conductor temperature suitable to Malaysia's climate and geographical factors as shown in Table 1 [25].

Table 1. Sag calculation parameters complying with Suruhanjaya Tenaga Electricity Regulations 1994 [25]

| Parameters | Value |
|---|-------|
| Wind speed, m/s | 28.62 |
| Minimum conductor temperature, $^{\circ}\text{C}$ | 21 |
| Maximum conductor temperature, $^{\circ}\text{C}$ | 75 |

5. RESULTS AND DISCUSSION

The results of conductor sag calculated for all of the chosen conductors for comparison with ACSR Batang (reference conductor) are shown in Tables 2 to 5 according to their respective groups. Conductors are sorted by their conductor strandings and diameter in ascending order. The reference conductor has strandings of Aluminium/Steel (Al/St) at 18/7 with the diameter of 24.16 mm that produces 7.90 m conductor sag at 75°C operating temperature. Basically, conductors that produce lesser conductor sag than the reference conductor should be viable for reconductoring purposes in terms of increasing maximum sag of lowest conductor to ground clearance.

Table 2 represents the conductor sag calculated for ACSR conductor group that contains two different conductor strandings of Al/St at 18/1 and 24/7. None of the ACSR conductors with Al/St (18/1) strandings tend to produce lesser sag than the reference conductor. The closest conductor sag to the reference conductor would be ACSR Kingbird that has similar conductor diameter to the reference conductor producing -0.65% of sag reduction. The extra stranding of steel in ACSR Batang seems to provide better strength-to-weight ratio hence better sag.

Observing ACSR Brant, ACSR Peacock and ACSR Cuckoo, these three have the same stranding of (24/7) in the ascending order of conductor diameter with ACSR Peacock having similar conductor diameter as compared to ACSR Batang. All three of these conductors have lower conductor sag value as compared to the reference conductor. ACSR Peacock and ACSR Cuckoo have significant higher rated strength that contributes to this result. Interestingly, although ACSR Brant has slightly lower rated strength than ACSR Batang, it provides better conductor sag due to its lower value of other mechanical properties such as coefficient of expansion.

Table 2. ACSR conductor sag comparison with reference conductor

| Conductor types (with strandings) | Conductor diameter, mm | Conductor sag at 75°C operating temperature, m | Sag reduction, % |
|-----------------------------------|------------------------|--|------------------|
| ACSR Batang (18/7) | 24.16 | 7.90 | |
| ACSR Waxwing (18/1) | 15.45 | 9.49 | -20.06 |
| ACSR Pelican (18/1) | 20.68 | 8.71 | -10.24 |
| ACSR Kingbird (18/1) | 23.90 | 7.95 | -0.65 |
| ACSR Brant (24/7) | 19.62 | 6.49 | 17.79 |
| ACSR Peacock (24/7) | 24.19 | 6.22 | 21.31 |
| ACSR Cuckoo (24/7) | 27.72 | 6.09 | 22.91 |

Table 3 shows the AAC conductor sag comparison with the reference conductor. AAC conductors consist of only aluminium strands. Two types of AAC strandings are chosen at (37) and (61) for comparison. Without having any steel strands to increase its strength-to-weight ratio, all of the AAC conductors fail to provide better conductor sag as compared to ACSR Batang. Viewing the characteristics of AAC Mistletoe, AAC Verbana and AAC Arbutus with (37) aluminium strandings that are sorted in increasing conductor diameter, AAC Verbana is the one that has similar conductor diameter as the reference conductor and produces -22.48% sag reduction. AAC Arbutus with bigger diameter compared to ACSR Batang only shows a slight improvement of conductor sag at -21.26% sag reduction. The same goes for AAC Flag and AAC

Ulac both with (61) aluminium strandings that failed to provide better sag reduction compared to the reference conductor.

Table 3. AAC conductor sag comparison with reference conductor

| Conductor types (with strandings) | Conductor diameter, mm | Conductor sag at 75°C operating temperature, m | Sag reduction, % |
|--------------------------------------|------------------------|---|------------------|
| ACSR Batang (18/7) | 24.16 | 7.90 | |
| AAC Mist letoe (37) | 21.77 | 10.22 | -29.40 |
| AAC Verbana (37) | 24.43 | 9.68 | -22.48 |
| AAC Arbutius (37) | 26.04 | 9.58 | -21.26 |
| AAC Flag (61) | 24.48 | 9.39 | -18.88 |
| AAC Ulac (61) | 26.10 | 9.33 | -18.12 |

Table 4 represents AAAC conductors sag comparison with reference conductor. Comprised of aluminium alloy stranding, all of the conductors selected for this AAAC type conductor provide better conductor sag as compared to the reference conductor. AAAC Elm is the only conductor for this type found with aluminium alloy stranding (19) that has smaller conductor diameter and other characteristics when compared to ACSR Batang, except for its coefficient of expansion. Although AAAC Elm strength-to-weight ratio is smaller by a small margin, its significant smaller value of other characteristics is what contributes to its lower conductor sag. Looking at the AAAC trio with aluminium alloy strandings (37) which are AAAC Poplar, AAAC Upas and AAAC Yew, all of their rated strength is significantly higher as compared to ACSR Batang. Although AAAC Yew has higher value of characteristics in general, it tends to produce much lower conductor sag due to its doubled rated strength than the reference conductor.

Table 4. AAAC conductor sag comparison with reference conductor

| Conductor types (with strandings) | Conductor diameter, mm | Conductor sag at 75°C operating temperature, m | Sag reduction, % |
|--------------------------------------|---------------------------|---|------------------|
| ACSR Batang (18/7) | 24.16 | 7.90 | |
| AAAC Elm (19) | 18.80 | 5.81 | 26.47 |
| AAAC Poplar (37) | 20.09 | 5.39 | 31.72 |
| AAAC Upas (37) | 24.71 | 5.30 | 32.96 |
| AAAC Yew (37) | 28.42 | 5.11 | 35.34 |

Table 5 shows ACCR conductors sag compared to the reference conductor. ACCR conductor type relies on aluminium composite as its core surrounded by aluminium-zirconium wires to boost its efficiency. There are two types of ACCR strandings used for comparison which are (26/7) and (26/19). All of the ACCR conductors listed in this comparison provide significant sag reduction between 36-40%. Nevertheless, both ACCR Grosbeak and ACCR Drake conductors have larger diameter and weight compared to reference conductor which leaves ACCR Hawk and ACCR Dove as the most suitable replacement to avoid structural modification.

Table 5. ACCR conductor sag comparison with reference conductor

| Conductor types (with strandings) | Conductor diameter, mm | Conductor sag at 75°C operating temperature, m | Sag reduction, % |
|--------------------------------------|------------------------|---|------------------|
| ACSR Batang (18/7) | 24.16 | 7.90 | |
| ACCR Hawk (26/7) | 21.60 | 4.98 | 36.91 |
| ACCR Dove (26/7) | 23.90 | 4.98 | 37.02 |
| ACCR Grosbeak (26/19) | 25.50 | 5.02 | 36.44 |
| ACCR Drake (26/19) | 28.60 | 4.79 | 39.41 |

It is clear that conductors within the same group tend to produce lesser sag when they have bigger number of conductor strandings and larger conductor diameters. Among all of the conductor groups chosen for the comparison, only AAC conductor types are not suitable to be used for replacement of ACSR Batang conductor. In terms of reducing conductor sag while maintaining similar conductor diameter to avoid structural modification, ACSR Peacock, AAAC Poplar and ACCR Dove are the best choices amongst their

conductor groups. Though, there are other aspects that need to be calculated such as ampacity and costs before making the final decision.

6. CONCLUSION

In order to make use of reconductoring technique, only the conductors with lesser conductor sag should be chosen to provide sufficient electrical clearances while maintaining ROW. ACCR conductor type shown to provide the best conductor sag followed by AAAC conductor type and a few of higher rated strength ACSR conductor type. The AAC conductor type should be avoided when intended to improve existing 132 kV systems in Malaysia that are using ACSR Batang in terms of conductor sag.

It is clear that AAAC and ACCR conductor types provide significant conductor sag reduction up to more than 30%. ACSR Brant, Peacock and Cuckoo are the three ACSR conductors that provide better conductor sag as compared to ACSR Batang because these three have more strands. AAC conductors provide inferior conductor sag as compared to AAAC conductors due to the aluminium material enforcement in AAAC conductors.

Nevertheless, other conductor abilities such as its ampacity, maximum operating temperature and cost have to be analysed before finalizing conductor selection. Some conductors provide better sag along with higher ampacity while some do not while some conductor permits to allow maximum operating temperature up to 120°C or more. The ability to be able to operate at such high temperature allows for even higher ampacity which can be found inherited by HTLS conductors such as ACCR conductors.

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