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Design and Simulation Sag Tension of a 20kV Power System with 150kV Tower Infrastructure in Marahaban City with Monte Carlo method

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***Abstract*— Rumpiang Bridge is a vital object and requires special handling for voltage installation; therefore, a construction that is capable of spanning a wide area is needed, where the construction obtained is the 150 kV HV construction, and for the cable span, it is simulated using the Monte Carlo method for the analysis of cable crossing deflection in Barito Kuala, with three types of cables, namely ACSR, AAAC, and AAACS. The simulation was carried out 1000 times by considering random variations of ±10% in cable weight and tensile force and ±5% in the crossing length. The results show that ACSR and AAAC cables have low average deflections, 3.24 meters and 3.26 meters, respectively, with standard deviations of 0.33 meters and 0.32 meters, indicating stable and consistent mechanical performance. While the AAACS cable shows a higher average deflection of 4.72 meters and a standard deviation of 0.48 meters, indicating a greater variation in deflection due to its physical characteristics. All three cables meet the technical requirement of maximum deflection <30 meters, but ACSR cable is recommended as the primary choice due to its combination of low deflection and high stability, which provides a greater safety margin in extreme crossing environmental conditions.**

Keywords—MV 20 KV, HV 150 kV, MonteCarlo, Sag Cable

I. INTRODUCTION

Rumpiang Bridge is one of the vital infrastructures in South Kalimantan which connects Marabahan City with Banjarmasin City in the Trans Kalimantan Road network. [1], [2]. In addition to supporting the mobility of people and goods, this bridge is also used to distribute electricity networks by installing 20 kV underground medium voltage cables with a cross-sectional area of 150 mm²[3], [4], [5]. In addition to supporting the mobility of people and goods, this bridge is also used to distribute electricity networks by installing 20 kV underground medium voltage cables with a cross-sectional area of 150 mm² has the potential to accelerate the degradation of bridge structures, as expressed by [6] The bridge exhibits restricted integration with road infrastructure and substantial utilities on long-span structures. Consequently, employing bridge frameworks for extensive electrical cable installations is less technically viable and may jeopardize the bridge's operational safety. Previous research and executed projects suggest solutions such as the use of underwater cables and the construction of overhead lines. Nevertheless, regarding cost-effectiveness, overhead lines are deemed more suitable for this project due to their additional load capacity and ease of maintenance.

Based on the identified issues, the researcher examined the effectiveness of the cabling route and developed a 20kV MV system utilizing a 150kV HV construction. [7], [8], [9], [10], [11] Based on the research, the author supports the development of a new distribution network that does not rely on bridge structures, specifically through the use of High Voltage Overhead Transmission Lines at 150 kV to facilitate the distribution of medium voltage networks at 20 kV using cables with a cross-sectional area of 150mm²[12], [13]. This system is referred to as a Hybrid system, which integrates 150 kV pole construction with 20 kV cabling [14], [15], In previous research, the concept of multi-utility tower design was referenced, which has been implemented in several transmission projects across Southeast Asia. The use of 150 kV standard towers significantly enhances the structure's capacity to withstand mechanical loads, allows for extensive spans and cable pulls, and, importantly, facilitates the future expansion of electrical loads or the addition of new loads.

In the design of this system, the selection of conductor type is a critical aspect to ensure mechanical and electrical reliability. The three primary types of conductors commonly used in distribution networks are ACSR (Aluminium Conductor Steel Reinforced), AAAC (All Aluminium Alloy Conductor), and AAACS (All Aluminium Alloy Conductor Steel Reinforced). ACSR conductors are widely utilized in extreme environments where high tensile strength is required [16], AAAC is selected for areas with high corrosivity, such as coastal regions, due to its corrosion resistance. AAACS is the optimal choice for areas requiring a combination of high mechanical strength and resistance to humid weather. The selection of this type of cable will be further analyzed in the context of the environmental characteristics of the Barito River.

Furthermore, considering the extreme geographical conditions along the Barito River route, the analysis of sag and tensile stress in the conductors becomes crucial. This study employs a Monte Carlo simulation approach to model the variability of environmental conditions such as wind speed, air temperature, and rainfall load on conductor behavior[15], [17], [18], [19], [20]. The Monte Carlo method has been demonstrated to enhance the accuracy of reliability predictions for electrical systems, as evidenced by a study that applied this simulation to distribution lines

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in subtropical regions [21], [22], [23]. By simulating thousands of potential operational conditions, this approach provides probabilistic estimates of the maximum deflection of the conductor, critical stress, and the risk of failure in the distribution system due to external factors.

By integrating a structural design approach based on HV 150 kV, selecting optimal conductors according to local conditions, and conducting reliability simulations using the Monte Carlo method, this research aims to produce a 20 kV electrical distribution network design that not only meets national technical standards but is also adaptable to future environmental challenges.

II. METHODS

The methodology employed is the Monte Carlo method, which is capable of analyzing the technical aspects of electrical distribution networks under various factors and extreme conditions, as implemented in the Rumpiang bridge project over the Barito River. This probabilistic simulation technique allows for the modeling of uncertainties arising from environmental factors such as wind speed, temperature, rainfall load, electrical load fluctuations, sag, and tension. It operates by calculating thousands to millions of potential scenarios based on relevant probability distributions, thereby providing a more realistic estimate of maximum conductor deflection and tensile stress, as well as the probability of system failure. This method assists designers in determining a more efficient and rational safety margin, thereby avoiding the excessive designs often associated with traditional deterministic methods. Research by Silva et al. (2022) and Kumar and Gupta (2021) has demonstrated that the Monte Carlo method enhances the accuracy of system failure predictions and reduces design costs by up to 30% more effectively than conventional approaches, making it an essential tool in the design of more reliable and economical electrical distribution networks.

A. *The currently installed electrical system*

Currently, the electricity supply to the city of Marabahan relies solely on a single feeder from the Marabahan substation located in the Cerbon district. The existing distribution network utilizes a 20 kV Medium Voltage Cable (SKTM) installed on the Rumpiang Bridge structure. However, the geographical conditions and the limited mechanical support capacity of the bridge hinder the expansion of the distribution network, thereby affecting the reliability of the power supply.

Fig. 1. State SKTM 20kV

Furthermore, the condition of aging cables and the lack of backup routes heighten the risk of power outages during disturbances or maintenance. Therefore, the construction of a new distribution network is essential to enhance service quality and reliability the electrical system in the city Marabahan. Furthermore, to execute the project, several field data are required, including

The social conditions of the community surrounding the construction site of the 20 kV river crossing tower are considered to be quite favorable. The socialization activities and land acquisition for the tower foundation and right-of-way have been successfully completed, and all payments to the relevant parties have been settled.

In relation to the river crossing path, adjustments have been made to ensure the safety and security of navigation on the Barito River, taking into account the types of vessels that pass through. Consequently, the minimum clearance distance between the lowest point of the conductor sag and the water surface of the river at high tide has been established at 33 meters. This requirement is based on the Technical Consideration Letter from the Barito Kuala Transportation Agency number 560/85/Dishub-6/2024 dated June 12, 2024, and the Transportation Agency of Pulang Pisau number 552/199/Dishub-PP/IX/23 dated September 12, 2023.

From an environmental perspective, this region is situated in the equatorial zone at an elevation ranging from 0 to 100 meters above sea level. According to data from the Central Statistics Agency (BPS) in 2023, extreme temperatures vary between 28 and 36 °C, with normal temperatures falling between 21 and 28 °C, an annual average of 24 °C, and a daily average below 30 °C. The average annual rainfall is approximately 320.3 mm, humidity levels are at 93%, and wind speed is recorded at 2.07 m/s. This area also experiences a high frequency of lightning strikes, averaging 267 days of thunderstorms per year. The pollution level is classified as moderate at 31 mm/kV. When selecting materials and protective layers for equipment, the humid tropical climate must be taken into account. Certain exceptions to standard regulations may apply if the equipment is fully enclosed, but the materials used must still be appropriate for the environmental conditions.

In the design planning of the 20 kV river crossing tower, various technical and non-technical factors are considered as part of the risk mitigation efforts for public safety and river navigation. These factors include the span distance between towers, soil strength at the construction site, wind speed, tensile strength of the conductors used, and the required clearance distance of the lowest conductor from the water surface, as approved by the Barito Kuala and Pulang Pisau Transportation Agency.

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B. *Specifications Tower SUTM*

The tower utilized for the medium voltage overhead transmission line (SUTM) is designed for a rated voltage of 24 kV. It can withstand mechanical loads of up to 70 kN, ensuring structural stability under wind loads, conductor loads, and other specific loads. Its resistance to power frequency voltage in wet conditions reaches 65 kV, while its impulse voltage resistance due to lightning strikes is designed to withstand up to 170 kV.

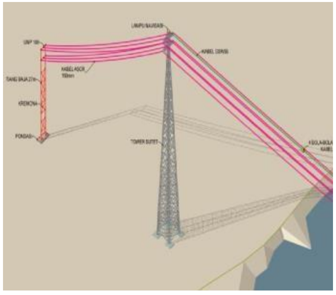

Fig. 1. Tower SUTT 150kv 40 Meter

The type of tower utilized is a high-tension special type, available in two height variants: 40 meters, which is designed for 150kV SUTT construction, accommodating long spans between towers. For electricity transmission, conductors are selected based on SPLN standards, specifically ACSR, AAAC, and AAACS types, with a cross-sectional area of 150 mm² in aluminum. These three conductors were chosen due to their high mechanical strength and reliable electrical current transmission capabilities, meeting the requirements for significant distances between towers.

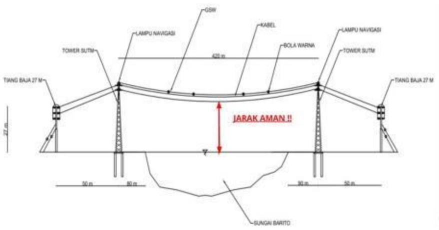

Fig. 2. Installation cable SUTT 150kV

In terms of the insulation system, this tower is equipped with silicone rubber housing tension insulators, specifically chosen for areas with moderate air pollution levels. The silicone material excels in resisting contamination and maintaining electrical insulation performance over the long term. Furthermore, to address the high frequency of lightning strikes at the installation site, an EGLA (Externally Gapped Line Arrester) type lightning arrester has been installed. The purpose of this type of arrester is to protect the system from disturbances caused by lightning, whether from direct or indirect strikes.

From the perspective of the foundation, the tower employs a bore pile type. This type of foundation is selected to provide optimal structural stability, particularly in areas with unstable soil conditions or low bearing capacity. By utilizing bore piles, the tower structure can effectively withstand both vertical and horizontal forces, thereby enhancing the overall technical lifespan of the installation.

C. Cable Sag

Sag refers to the vertical distance between the highest point of a cable's trajectory and its lowest point, typically occurring at the midpoint of the span. This phenomenon is influenced by the weight of the cable, tension, temperature, and environmental factors such as wind. In High Voltage Transmission Lines, effective sag management is crucial to ensure that the minimum clearance to the ground, buildings, or other obstacles adheres to safety standards, as outlined in SPLN 121:1996 regarding High Voltage Construction. According to PLN standards, there is a commonly used formula for calculating cable sag [12], which serves as a benchmark in the analysis of cable trajectories in high voltage transmission systems. Equation 1 illustrates the formula for cable sag curvature.

$$D = \frac{w \,.\, s^2}{8T} \quad (1)$$

In this context, w represents the weight per unit length of the cable (N/m), s denotes the span distance between the towers in meters, and T indicates the horizontal tension in the cable (N). This formula illustrates the maximum sag occurring at the midpoint of the span due to the weight of the cable itself.

Subsequently, Equation 2 is employed to calculate the maximum span S_max and the allowable maximum deflection.

D_{max}:

$$S_{max} = \sqrt{\frac{8 \,.\, T \,.\, D_{max}}{w}} \quad (2)$$

This formula is the inverse of Equation 1, which is utilized to design the maximum safe span without exceeding the permissible slack limit. To determine the value of w, refer to Equation 3, which relates the weight per unit length of the cable (w) to the mass per unit length (m), as follows.:

$$w = m \,.\, g \quad (3)$$

In Equation 3, g represents the acceleration due to gravity (9.81 m/s²). Equation 2.8 is essential for converting the mass information of the cable into the weight force required in Equations 1 and 2. The interplay of these three equations is crucial for determining the design of the cable support structure and ensuring a safe distance between the cable and the ground or water surface.

D. Monte Carlo

$$i = mean.(1 + \epsilon) \quad (4)$$

This is a method for calculating the values of parameters that vary randomly by introducing a random variable ϵ that follows a specific distribution, which is used to represent uncertainty in the model and to obtain a more realistic distribution of outcomes. Subsequently, the average value of the deflection leads to the formulas presented in equations 4, 5, and 6.

$$W_i = W_{mean}.(1 + \epsilon W) \quad (5)$$

In Equation 4, the weight of the cable per unit length significantly impacts the strength and stability of the cable network, particularly in electrical or communication systems. In this equation, W_mean represents the average weight of the cable, while ϵW denotes a random variation that follows a uniform distribution U (−ΔW,ΔW), reflecting the uncertainty in cable weight due to production variations, environmental conditions, or other factors.

$$T_i = T_{mean}.(1 + \epsilon T) \quad (6)$$

In equation 5, tension refers to the force exerted along the cable, which is crucial for maintaining the cable's tautness and preventing excessive sagging. T_i represents the expected average tension. ϵT denotes a random variation that follows a uniform distribution U (−ΔT, ΔT), reflecting the uncertainty in cable tension due to temperature fluctuations, additional loads, or other external factors.

$$S_i = S_{mean}.(1 + \epsilon S) \quad (7)$$

In equation 6, the distance between poles refers to the length of the cable span between two support points or poles. S_i denotes the average distance between poles. ϵS represents a random variation that follows a uniform distribution U (−ΔS,ΔS), indicating irregularities in pole installation due to terrain contours, field conditions, or technical planning. Consequently, the final outputs in equations 1, 4, 5, and 6 yield the resulting formula 7

$$D = \frac{w_i \,.\, s^2}{8T_i} \quad (8)$$

From equation 7, if several possibilities are considered, it leads to equation 8, where D_(avg) represents the average result of the simulation and N denotes the number of iterations.

$$D_{avg} = \frac{1}{N}\sum_{i=1}^{N} Di \quad (9)$$

$$\sigma D = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Di - D_{avg})^2} \quad (10)$$

In equation 8, the values are substituted into equation 9, where σD is utilized to calculate the standard deviation of deflection in the Monte Carlo simulation. σD indicates the dispersion of deflection values Di relative to the average deflection Davg, while N represents the total number of iterations or simulation data. The calculation process begins by determining the average deflection, followed by calculating the difference of each deflection from the average, squaring each of these differences, summing all the squared results, dividing by the number of iterations, and finally taking the square root of the result. This formula is crucial as it aids in measuring the consistency or variability of deflection results in the simulation; a smaller standard deviation value signifies that the deflection values are closer to the average, and conversely.

III. RESULT AND DISCUSSION

A. Comparison of SAG and tension for AAAC, AAACS, and ACSR 150 mm² cables using the Monte Carlo method.

To ensure the reliability and safety of the 20 kV cable crossings in the Barito Kuala region, a technical analysis was conducted using the Monte Carlo simulation method. This analysis aims to evaluate the sag performance of three types of cables: ACSR, AAAC, and AAACS, taking into account random variations in cable weight, tensile force, and crossing span length. The simulation was performed 1000 times to produce a realistic sag distribution under field conditions, which can serve as a basis for decision-making in selecting the most suitable cable type for the project requirements. The sag values were obtained by inputting various parameters and probabilities, which were then simulated using Equation 10, resulting in a graphical representation fig.1

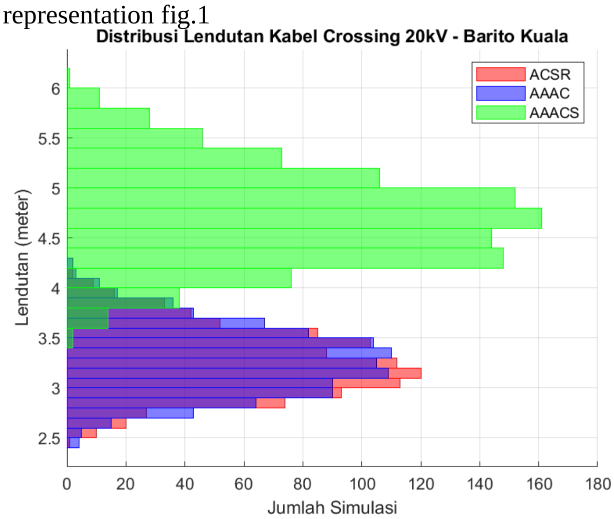

Fig. 3. Lendutan ACSR VS AAACS VS AAAC

The Monte Carlo simulation conducted for analyzing deflection in cable crossings at Barito Kuala involved three types of cables: ACSR, AAAC, and AAACS. This simulation, performed 1000 times, accounted for random variations of ±10% in cable weight and tension, as well as ±5% in crossing length. The results indicated that the ACSR cable exhibited an average deflection of 3.24 meters with a standard deviation of 0.33 meters, while the AAAC cable had an average deflection of 3.26 meters with a standard deviation of 0.32 meters. In contrast, the AAACS cable showed an average deflection of 4.72 meters with a standard deviation of 0.48 meters. The relatively small standard deviation values for ACSR and AAAC suggest that their deflection distributions are more concentrated around the mean, indicating a higher level of performance stability compared to AAACS. When comparing the distributions, ACSR and AAAC cables displayed very similar deflection characteristics. The histogram of deflection reveals that the distributions for these two cables nearly overlap within the range of 2.5 to 4 meters, suggesting that their mechanical performance under varying loads is quite comparable. Conversely, the AAACS cable exhibited a rightward shift in its deflection distribution, with a broader range of deflection between 3.5 and 6 meters. This shift is attributed to the higher weight and lower tension of the AAACS cable compared to ACSR and AAAC,

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resulting in greater deflection when subjected to variations in load and crossing length.

According to the simulation results, all three types of cables meet the technical requirements for the crossing project in Barito Kuala, which stipulate that the average deflection must be below 30 meters. While all cables satisfy this criterion, the performance of ACSR and AAAC can be regarded as superior due to their deflection values being significantly below the maximum limit, along with a small standard deviation indicating consistent performance under various simulated random conditions. The technical criteria not only require compliance with the maximum numerical limits but also take into account long-term stability, considering environmental factors at the crossing site such as strong river currents, soft soil, and significant fluctuations in water levels.

After evaluating the overall results, ACSR cable emerges as the most suitable choice for the 20kV SUTM project with a 150kV construction in Barito Kuala. With the lowest average deflection and minimal performance variation, ACSR offers greater safety margins and long-term mechanical stability, which are crucial for maintaining the reliability of the electrical system in extreme locations. AAAC cable also presents a viable alternative due to its nearly equivalent performance to ACSR. Meanwhile, although AAACS cable meets the criteria, it requires more careful consideration as its higher deflection values may increase the risk of deformation under extreme conditions. Based on these comprehensive considerations, ACSR cable is recommended for use in the cable crossing project in Barito Kuala.

IV. CONCLUSION

Based on the results of the Monte Carlo simulation conducted on three types of cables: ACSR, AAAC, and AAACS, it can be concluded that all cables meet the technical requirements of the project, with average deflections significantly below the maximum limit of 30 meters. Both ACSR and AAAC cables demonstrate excellent performance, characterized by low average deflections and small standard deviations, indicating a high level of performance stability under varying load conditions and crossing lengths. The nearly identical deflection distributions of ACSR and AAAC further reinforce that both possess very similar mechanical characteristics, making them highly suitable for the conductor needs in Barito Kuala. Conversely, while the AAACS cable still meets the requirements, its higher average deflection and standard deviation values indicate greater sensitivity to changes in load conditions and an increased risk of deflection. Considering stability, safety margins, and long-term reliability, ACSR is recommended as the primary choice for the SUTM 20kV project with 150kV SUTT construction that requires long spans.

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