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Review of N-Bundled Conductors on Right-of-Way in Transmission Network Reinforcement in Electrical Systems

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ABSTRACT

Transmission line expansion has become one of the critical network planning strategies to ensure the continuous evacuation of power. Right-of-way (ROW) has posed significant challenges due to an increase in population and rural-urban development. This research therefore reviews various methodologies of investigating the effect of N-bundled conductors on right-of-way and power system parameters such as voltage, current, power and load. The review of technical literature reveals that the effects of transmission lines bundling of conductors on the right-of-way were not considered in most cases of the literature reviewed. The changes in the electrical power system parameters with changes in conductor area and bundling of conductors were not examined in most cases of the papers reviewed. Even the relationship between transmission line expansion and bundling of conductors was not studied in most cases. To that effect, this study therefore proposed solutions to the above-mentioned shortcomings observed in the area of transmission network expansion.

INTRODUCTION

Bundling of transmission lines is increasingly becoming the cost-effective methodology to be implemented due to right-of-way issues and also the increased cost of constructing new transmission lines (JICA Study Team, 2020). Many countries have stabilized their transmission grid system by bundling conductors, which improves the voltage gradient, surge impedance level of the transmission line, power delivery ratio, less impact on right-of-way, improved load carrying factor by the transmission line and improvement of the N-1 criteria. Many developed countries are already evolving into octa-bundled transmission line conductors for their super grid, which has tremendously improved the security in their power systems. In resolving the issues, many methods have been proposed, and this helps to further buttress the importance of bundling of conductors and right-of-way. Although the proposed existing methods have contributed in no small measure to the main bottleneck associated with these methods, but they did not consider bundling of conductors and right-of-way as part of a means of transmission network expansion planning. Meaningful contributions to knowledge have been made and documented by many power system researchers with respect to the study of transmission line design, collapse and stability.

This paper, therefore, presents a comprehensive review of the patterns in the current trends of bundling of conductors and transmission line expansion. The remainder of the paper is organized as follows: Section 2 presents the methodology of the approach. A comprehensive review of different approaches to transmission network expansion, bundling of conductors and right-of-way, is presented in section 3. The research gaps and proposed solutions are identified in section 4, while the study is concluded in section 5.

METHODOLOGY

The review of relevant research studies aims at providing sustainable solutions to right-of-way challenges using bundled conductors to eliminate bottlenecks of voltage deficit and overloaded transmission lines.

REVIEW OF SOLUTION APPROACHES TO TRANSMISSION NETWORK EXPANSION, BUNDLING OF CONDUCTORS AND RIGHT-OF-WAY ANALYSIS

Review of related work based on transmission network expansion with both bundling of conductors and right-of-way considerations

Significant contributions have been recorded by existing studies on transmission network expansion, considering both bundling of conductors and right-of-way. For instance, Munir et al. (2020) discussed the use of Lidar technology in detecting and extracting bundled conductors in a transmission line network. The author adopted the use of automated methods using a combined point and image-based technique. The research considered the use of bundled conductors. However, the research encountered errors from noise, which reduced the discussion of the optimized arrangement of multiple circuits of different voltage levels on the same tower. The author adopted the use of compact transmission lines using the evolutionary algorithm technique. The research considered the use of bundled conductors and right-of-way. However, the effect of bundling conductors on distance protective relays was not considered in the research.

Review of related work based on transmission network expansion with bundling of conductors and without right-of-way considerations

Significant contributions have been recorded by existing studies on transmission network expansion considering bundling of conductors without right-of-way. For instance, Shaikh et al. (2021) discussed the optimal parameter estimation of overhead transmission line considering different bundled conductors with the uncertainty of load modelling. The author made use of the Whale optimisation algorithm (WOA), the research examined different bundled conductors and their impact on transmission losses. However, the research requires a more detailed computational simulation to be widely accepted. Zadeh et al. (2010) discussed the mixed-integer linear programming approach, considering the impact of bundled conductors on transmission network expansion planning. The authors made use of a mixed-integer linear programming (MILP) model, examined transmission expansion planning using bundling of conductors. The research showed the efficacy of bundling conductors in terms of cost. However, the right-of-way was not considered in the research.

Villasana et al. (1985) discussed transmission network planning using linear programming. The research combines the use of linear programming and the network transportation model to evaluate points of overloading by the addition of new transmission lines and buses by re-stringing and bunding of old conductors. However, the impact the addition of the new lines would have on the right-of-way (ROW) was not stated in the research. Timascheff (1971) discussed fast calculation of gradients for the centre phase of a three-phase bundled conductor line with any number of sub-conductors. The authors made use of mathematical formulations to examine a fast method for computing gradients of bundles of conductors. However, the effect of bundling of conductors on the right-of-way (ROW) was not considered in the research. Shayeghi et al. (2010) discussed the effect of bundled lines on transmission network expansion planning considering network losses using decimal codification genetic algorithm. The research affirmed that bundled conductors have significant effect on transmission network expansion planning. However, the research used direct current (DC) power flow in its analysis instead of alternating current (AC) power flow analysis. Shaikh et al. (2021) discussed parameter estimation of ac transmission lines considering different bundle conductors using flux linkage techniques. The study affirmed that changes in the conductor area resulted in significant changes in inductance, capacitance and resistance. However, the impact that changes in conductor area would have on the right-of-way of the transmission line was not considered in the research. Abdulkareem et al. (2021) discussed a novel approach to determine an unbalanced current circuit on Nigerian 330 kV transmission grid for reliability and security enhancement. The paper affirmed that the upgrade of some 330 kV double circuit lines from double-bundled to quad-bundled conductors would improve power transfer capability. However, the right-of-way of transmission lines was not considered in the research. Jianwei and Jean-Louis (1998) discussed the overhead electrical transmission line galloping across a full multi-span 3 degrees of freedom model. The authors made use of mathematical formulations to examine the full-scale multi-span 3 degrees of freedom model in the prediction of galloping in transmission lines. The research paper was able to simulate all forms of galloping on both single and bundled conductors and proposed detuning and torsional damping devices. However, the effect of bundled conductors on the right-of-way was not considered in the research. Jalilzadeh et al. (2008) discussed transmission network expansion planning considering voltage level, network losses and number of bundled lines using genetic algorithm. The authors made use of genetic algorithm to examine the use of Decimal Codification based Genetic Algorithm (DCGA) to ascertain the electrical losses in Azerbaijan regional electric network. The authors considered the application of the DCGA on different voltage levels and numbers of bundled conductors. However, the effect of bundled conductors on the right-of-way was not considered in the research. Reichman (1959) discussed bundled conductor voltage gradient calculations. The authors made use of Maxwell coefficients of capacitance to examine the use of Maxwell coefficient of capacitance to discover charges on conductors that are bundled. The author considered the application of the DCGA on different voltage levels and numbers of bundled conductors. The research asserted that for all bundled conductors, a change in diameter, phase spacing, bundling spacing results in a responsive change in voltage gradient. However, the effect of bundled conductors on distance protective relays was not considered in the research. Dang et al. (2011) discussed the comparative study of grid validation methods for wind load computations of transmission line. The authors made use of Power Spectral Density (PSD) to predict the lift or drag force during the simulation of transient winds. The authors affirmed that PSD could confirm grid sensitivity caused by transient winds for both single and bundled conductors. However, the right-of-way of transmission lines was not considered in the research.

Al-hamouz (1988) discussed the combined finite element-charge simulation computation of monopolar corona on bundle wires. The research paper asserted that as the number of bundled conductors increases, corona power losses reduce. However, the right-of-way of transmission lines was not considered. Al-hamouz and Abdel-salam (1999) discussed the finite-element solution of monopolar corona on bundled conductors. To examine how bundled conductors affect corona current, the authors used finite element analysis iterative based method. The paper asserted that the corona current decreased with an increase in bundling of conductors. However, right-of-way of transmission lines was not considered. Acosta and Tavares (2017) discussed the method for optimizing the capacity and costs of overhead transmission lines by modifying their bundle geometry. The authors made use of heuristic and meta-heuristic algorithms to examine the cost and capacity optimization of transmission lines. The study affirmed that the circular shape of bundles were more efficient, as the electrical field of the phase conductor reduces. However, the right-of-way of transmission lines was not considered in the research.

McConnell (1976) discussed the modelling technology for bundled power transmission lines. The authors made use of mathematical formulations to examine the various ways of modelling bundled conductors to be constructed. The research paper affirmed that as the sub-span length of the spacers increases, the more stable the bundle. However, a number of factors were not considered in the research, such as different tower heights, number of spacers, compressive loads experienced by the spacers and right-of-way. Calero (2015) discussed the mutual impedance in parallel-line protective relaying and fault location considerations. The authors made use of mathematical formulations to examine the effect of mutual coupling on two parallel lines would have on distance protective relay schemes. The work affirmed that zero sequence mutual impedance cannot be eliminated even when the line has been transposed. However, the right-of-way of transmission lines was not considered in the research.

Mahdavi and Mahdavi (2011) discussed evaluating the effect of load growth on annual network losses in transmission network expansion planning, considering bundle lines. The impact of increased load on network losses when conductors are bundled was investigated using the Decimal Codification-based Genetic Algorithm by the authors. The paper affirmed that considering the effect of the increase in load would improve return on investment. However, the right-of-way of transmission lines was not considered in the research.

Review of related work based on transmission network expansion with right-of-way and without bundling of conductors considerations

Significant contributions have been recorded by existing studies on transmission network expansion considering right-of-way and without bundling of conductors. For instance, Henriques et al. (2019) discussed the optimization of routing and tower spotting of electricity transmission lines in decision-making. The authors made use of route guideline definition based on a raster-based least-cost path approach; vertex siting based on graph theory and dijkstra algorithm along the route guideline, which defines the final route of the transmission line and tower spotting based on dynamic programming to examine the novel methodology in transmission line routing and tower spotting. The research considered cost and right-of-way optimization in transmission line design and network expansion. However, bundling of conductors was not considered in the research.

Ranjan et al. (2023) discussed the mathematical simulation for right-of-way corridors for overhead transmission lines. The authors made use of mathematical formulations to examine the efficient use of available land to avoid compromising the right-of-way (ROW). The research affirmed that the right-of-way varies directly with span and sag of the transmission line. However, bundling of conductors was not considered in the research. Bamigbola et al. (2014) discussed the mathematical modelling of electric power flow and the minimization of power losses on transmission lines. The authors made use of classical optimization method (Differential

Calculus) to examine the power losses on transmission lines. The research affirmed that the classical optimization method yielded good results. However, bundling of conductors was not considered in the research.

Abd-elaal et al. (2018) discussed the review of transmission line systems under downburst wind loads. The authors made use of a research review of the impact of downburst wind on transmission line systems to examine the power losses on transmission lines using the classical optimization method. The authors researched various contributions of knowledge into the effects of downburst winds on transmission line systems. However, the transmission lines' bundling of conductors was not considered in the research.

Review of related work based on transmission network expansion without both bundling of conductors and right-of-way considerations

Significant contributions have been recorded by existing studies on transmission network expansion without considering bundling of conductors and right-of-way. For instance, Tziouvaras et al. (2014) discussed protecting mutually coupled transmission lines: challenges and solutions. The authors made use of mathematical formulation to examine the effects of transmission line coupling on transmission line distance protection. The research considered that changes to the orientation or point of termination of two separate transmission lines or two mutually coupled transmission lines will affect the accuracy of distance protective relays. However, bundling of conductors and right-of-way was not considered in the research.

Teegala and Singal (2016) discussed electrical power and energy systems optimal costing of overhead power transmission lines using genetic algorithms. The authors made use of Genetic Algorithm to examine the use of a cost assessment and technical optimization model in proposing a techno-economic solution for overhead transmission line expansion. The research developed a correlation-based cost and optimization model for an effective transmission line expansion plan. However, the effect of bundled conductors and right-of-way was not considered in the research. Rakpenthai and Uatrongjit (2016) discussed power system state and transmission line conductor temperature estimation. The authors made use of a state estimation technique using constrained non-linear optimization based on weighted least square criterion to examine how the weather environment factor affected the conductors. The research asserted that bus voltages and conductor temperature can be estimated using the method adopted. However, the bundling of conductors was not considered in the research.

Papadopoulos et al. (1990) discussed a new approach to the reduction of transmitted reactive power in power networks. The authors made use of mathematical formulation to examine the use of ground wires to improve the power factor of a transmission line. The research affirmed that the methodology is effective in the control of reactive power on transmission lines. However, the research methodology cannot be implemented on the full length of a transmission line. Also, bundling of conductors was not considered. Kalunta and Ngwu (2021) discussed the enhancement of transmission efficiency and voltage profile in the Bauchi axis of the Nigerian power grid using a VSC-HVDC system. The authors examined the effects of the integration of voltage source-controlled high voltage direct current (VSC-HVDC) into the expanded 41-bus Nigerian 330kV transmission grid network. The research affirmed that by the application of VSC-HVDC at Mambila and Jalingo stations, the voltage profile increased rapidly. However, the effect of bundled conductors was not considered in the research. Yan et al. (2010) discussed the numerical study on dynamic swing of suspension insulator string in overhead transmission line under wind load. The authors made use of ABAQUS finite element system to examine the dynamic swing angles of suspension string insulators in power transmission lines subjected to stochastic wind load. The research asserted that, to determine the insulator swing angle, a dynamic wind load factor must be applied. However, bundling of conductors and right-of-way was not considered in the research.

Acosta and Tavares (2020) discussed the optimal selection and positioning of conductors in multi-circuit overhead transmission lines using evolutionary computing. The authors made use of mixed-integer linear programming (MILP) optimization technique to examine the optimal placement of wires in a multi-circuit transmission line using the MILP optimization. The research affirmed that the use of a multi-circuit tower will lead to an increase in surge impedance loading of the line, cost reduction, right-of-way optimization and height of structure. However, the bundling of conductors was not considered in the research.

RESEARCH GAPS AND SOLUTION APPROACH

Research gaps

The review of studies revealed the following research gaps;

i. The effect of transmission line bundling of conductors on the right-of-way was not considered in most cases.

ii. The power system parameter changes associated with changes in conductor area and bundling of conductors are not considered for most cases.

iii. The relationship between transmission line expansion and bundling of conductors was not considered for most cases.

Solution approach

To effectively solve the effect of bundled conductors on the right-of-way of transmission lines, the following solutions have to be considered;

i. The use of optimization algorithms to demonstrate the advantages of N-bundled conductors.

ii. Evaluation of the changes in the electrical power system parameters as a result of N-bundled conductors within the right-of-way of transmission lines.

CONCLUSION

In this paper, a comprehensive review of studies, on various approaches proposed by different researchers for transmission network expansion with bundling of conductors and right-of-way considerations in power systems, has been presented. The review reveals that the effects of transmission lines bundling of conductors on the right-of-way were not considered in most cases of the literature reviewed. The changes in the electrical power system parameters with changes in conductor area and bundling of conductors were not also considered in most cases of the papers reviewed. Even, the relationship between transmission line expansion and bundling of conductors were also not considered for most cases. To that effect, this study proposed solutions to the above mentioned shortcomings observed in the area of the transmission network expansion.

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