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DESIGN AND DEVELOPMENT OF 123kV 13L CROSS-ARM WITH BRACING STRUCTURES FOR APPLICATION IN TRANSMISSION TOWERS

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By

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July 2021

Chairman : Associate Professor Mohamad Ridzwan bin Ishak, PhD
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In this study, experimental and numerical investigations have been conducted of the mechanical behavior of existing full-scale wooden 123 KV 13L cross-arms used in transmission towers. Two cases have been considered to be analyzed and tested accordingly. In the case of normal condition, standard load 7.98 KN, with 8 organized steps with angle Θ = 54.2º at YZ plan from Y-axis were applied. While Fr = 16 KN with 16 organized steps with angle Θ = 12.6 º at the horizontal plane, α = 17.57 º at the vertical plane was applied for broken wire condition. The numerical results of the simulation have proven that the experiments were confident for normal and broken wire conditions are 93 % and 98.2 % respectively. To improve the existing design of cross-arm structure, an integrated TRIZ–Morphological Chart–ANP approach was used to establish four (4) new concepts of cross arms of transmission towers. In a conceptual design phase, a solution was developed through employing the TRIZ model according to TRIZ 40 techniques. After precise analysis, the output of the selection process of the conceptual design was further validated, where conceptual design 2 was ranked optimal in all three processing scenarios. Bracket structure P1048 by UNISTRUT® has been followed as a guide to be modified through conducting some modifications by employing systematic exploitation of proven ideas or experience. The modified design of the structure of the bracket was analyzed by FEM using static structural tool data from analyzing process were used to specify the thickness of the bracket structure to be used in the final design. Finally, the improved 13L 123KV Cross-arm structure has been investigated with experimental and numerical load-deflection behavior for the whole structure. Two scenarios have been conducted broken and normal wire conditions. the experimental results showed that the maximum value deflection at the normal condition for tangential and radial deflection is 11.6 mm and 11.5 mm respectively. Numerical results of simulation have proven that the experiments were confident for broken and normal wire conditions are 98.7 % and 91.4 % respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN LENGAN MERENTAS DENGAN STRUKTUR PENYANGGA UNTUK MENARA PENGHANTARAN KUASA 123kV 13L

Oleh

SHARAF HUSSEIN KADHIM SHARAF

Julai 2021

Pengerusi : Profesor Madya Mohamad Ridzwan bin Ishak, PhD
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Dalam kajian ini, penyiasatan eksperimen dan berangka telah dijalankan ke atas tingkah laku mekanikal kayu berskala penuh 123 KV 13L silang lengan sedia ada yang digunakan dalam menara penghantaran. Dua kes telah dipertimbangkan untuk dianalisis dan diuji sewajarnya. Dalam kes keadaan biasa, beban standard 7.98 KN, dengan 8 langkah tersusun dengan sudut $\Theta = 54.2^{o}$ pada pelan YZ dari paksi Y telah digunakan. Manakala Fr = 16 KN dengan 16 langkah tersusun dengan sudut $\Theta = 12.6^{o}$ pada satah mengufuk, $\alpha = 17.57^{o}$ pada satah menegak digunakan untuk keadaan wayar putus. Keputusan berangka simulasi telah membuktikan bahawa eksperimen yakin untuk keadaan wayar biasa dan patah adalah masing-masing 93 % dan 98.2 %. Untuk menambah baik reka bentuk sedia ada struktur lengan silang, pendekatan TRIZ–Carta Morfologi–ANP bersepadu telah digunakan untuk mewujudkan empat (4) konsep baharu lengan silang menara penghantaran. Fasa reka bentuk konsep, penyelesaian telah dibangunkan melalui penggunaan model TRIZ mengikut teknik TRIZ 40. Selepas analisis yang tepat, output proses pemilihan reka bentuk konseptual telah disahkan lagi, di mana reka bentuk konseptual 2 diletakkan pada kedudukan optimum dalam ketiga-tiga senario pemprosesan. Struktur kurungan P1048 oleh UNISTRUT® telah diikuti sebagai panduan untuk diubah suai melalui melakukan beberapa pengubahsuaian dengan menggunakan eksploitasi sistematik idea atau pengalaman yang telah terbukti. Reka bentuk struktur pendakap yang diubah suai telah dianalisis oleh FEM menggunakan data alat struktur statik daripada proses menganalisis digunakan untuk menentukan ketebalan struktur pendakap yang akan digunakan dalam reka bentuk akhir. Akhir sekali, struktur lengan silang 13L 123KV yang dipertingkatkan telah disiasat dengan tingkah laku pesongan beban eksperimen dan berangka untuk keseluruhan struktur. Dua senario telah dijalankan keadaan wayar putus dan normal. keputusan eksperimen menunjukkan nilai pesongan maksimum pada keadaan normal bagi pesongan tangen dan jejari masing-masing ialah 11.6 mm dan 11.5 mm. Keputusan berangka simulasi telah membuktikan bahawa eksperimen yakin untuk keadaan wayar putus dan normal masing-masing adalah 98.7 % dan 91.4 %.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

ANP	Analytic Network Process
AHP	Analytic Hierarchy Process
BC	Boundary Conditions
DV	Distance Vector
DOF	Degree of Freedom
FEM	Finite Element Method
FSP	Fibre saturation point
FRP	Fibre-reinforced plastic
LSP	Laser Shock Peening
NR-TPU	Natural Rubber-Thermoplastic Polyurethane
NLP	Neuro-Linguistic Programming
TRIZ	Teoria Resheniya Izobretatelskikh Zadatch (a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature)
PDF	Probability Density Function
PSD	Power Spectral Density
USIT	Unified Structured Inventive Thinking
SCAMMPERR	(S) substitute, (C) combine, (A) adapt, (M) modify, (P) put to another use, (E) eliminate and (R) reverse, (R) Re-arrange
TII	Transmission Innovations Inc
TSLSP	Tamping Stress Laser Shock Peening
X-X bracing	X shape to X shape
XBX bracing	base to X shape

CHAPTER 1

INTRODUCTION

1.1 Background

A transmission line is primarily composed of transmission towers. Transmission towers construction must withstand the weight of the transmission conductor at a certain height from the level. Besides, the transmission towers must be prepared to sustain all forms of natural catastrophes. Hence, putting up a transmission tower requires broad participation of all three fundamental engineering principles (mechanical, civil, and electrical) concepts which are evenly relevant [1]. An electricity transmission tower comprises several sections. One of the major structures in an energy transmission tower is the cross-arm. Crossarms of the transmission tower help the transmission conductor. Normally, the substances used for cross-arms in transmission towers are timber, steel, and fiberglass [2].

In transmission towers, which are made up of wood, steel, concrete, and fiber enhanced polymers, there are four principal materials. Historically, the wood of Chengal (Neobalanocarpus), which was first commissioned in 1929, was used as a crucible in 1963 on 132kV suspension towers after proving successful performance in a 66kV tower. The wooden cross arm has been selected for its high mechanical strength and excellent arc calming performance during lightning strikes [3–4], and wood has been selected as one of the low-cost facilities, compared to the two other materials. In the late 1990s, though, it was found that matured Chengal cannot be found to produce good quality cross-arms easily any longer. Furthermore, it was found that after 24 years of service, the wood began to fail due to aging [5]. Much later in 2010, after only 14 years of service, a defective wood crossarm was found.

In general, wood is the first material in the transmission line used as the structure. Wood is a resourceful structural material and has long been used but it requires additional testing, as cross-arms are beams placed on a utility pole that takes loads from the transmission wires and moves to the pole [6][7]. Figure 1 shows the present cross structure that is used by TNB

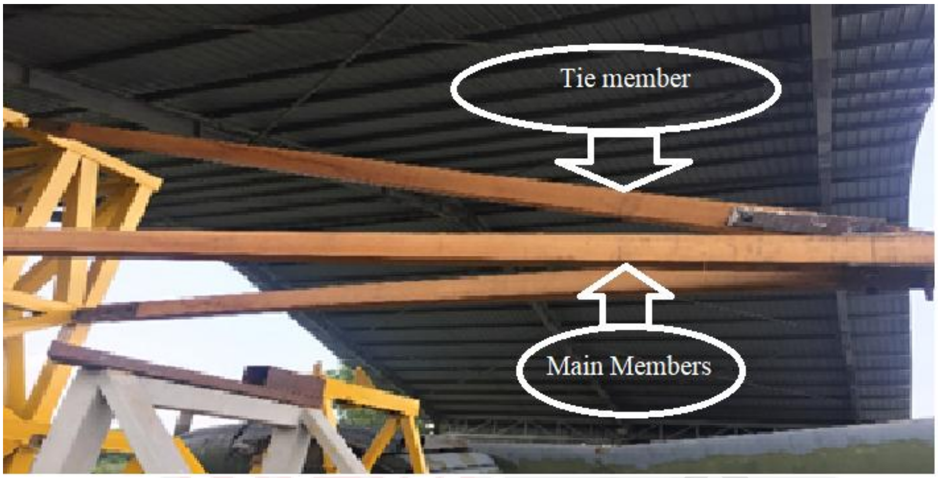

Figure 1.1 : Present cross-arm structure that is used by TNB

Around 22 distinct wood types, used to create cross-arms worldwide, were analyzed. The cross arms are composed of timber, asphalt, and composites of reinforced concrete. Many are constructed of timber since it is affordable and simple to reach [8].

Wood was known to be superior as a cross arm because of the arc-quenching property causing the arc to be quenched by lightning strikes [9]. However, after a direct lightning hit and other conditions, several cases were reported in the failed cross arm.

The first step to seeking an alternative of wood is the identification of a few products that have been selected: compacted wood stick, reinforced polymer/plastics fiberglass (FRP), and Silicon Rubber braced arms.

Additional properties including strong separation and corrosion tolerance are given for composite cross-arms. So, no painting is mandatory to save occasional repairs and associated job costs. In the course of a full-scale model of hollow filament-winding FRP elements. [10] built a 154 kV line post-typed insulation forearm, and checked for mechanical and electrical efficiency. Brian and Timothy [11] have researched the modification of the 132 kV tool with an independent cross arm to decrease the ROW of a current 132 kV transmission tower. All the following experiments on composite crossarms appropriate for stainless steel towers are performed to substitute the original steel cross arm, without altering tower configuration, to raise the voltage.

Transmission Inc. FRP Developments Inc, the third-larger utility in Canada, the British Columbia Hydro & Power Authority (BC Hydro) identified a need to replace the wooden and steel H-frame interfaces with something new. This need was made public and several recommendations and options were given to BC Hydro. The cross-arms method has been used and promoted by FRP Networking Technology Inc. After initial consultations and assessments, a 20-year cooperation agreement on new and cross-arms fiber-reinforced polymers (FRP), as well as for other products needed in the BC Hydro transmission system, was developed to undertake joint research and development between the BC Hydro and FRP TII. For h-frames, one for 138 kV, and one for wider geometries up to 287 kV[12], two new designs had been produced. In compliance with loading conditions, the larger cross-arm can be used with 340 kV boards. To gather expertise in field service, feedback incentives for line crews, and to determine field efficiency and ease of building, BC Hydro has developed and carried out a comprehensive third-party research program and has built several cross weapons.

In terms of price, wooden cross-arms need to replace the costliest maintenance from one team to the next (which could be quite expensive if only access from the helicopter is because of the rugged terrain) in between 25 and 40 years, depending on the environmental condition and initial timber. FRP cross-arms are capable of skipping up to 2 substitution times relative to wooden cross-arms. This saves so well of the total life-cycle expense forecast. The life cycle calculations here are rather easy. It should be simple to build a more complete diagram, jurisdictions, and service models [13].

In very short order, FRP TII transmission weapons may be manufactured to provide quality frames in large quantities appropriate for utilities. FRP Transmission Developments, Inc. The current lead period is up to three weeks. Cross FRP TII arms are chemically neutral and do not release contaminants. In environmentally sensitive settings, the FRP TII cross arms are highly important. Both conservation organizations used FRP TII networks in mountains, lakes, and similar regions. If cross arms are disposed of by FRP TII, they will go to general deposits [14], the preferred method is recycling. None can pollute the atmosphere through cross-arms. Theft is a concern with some transmission processes. The FRP TII Cross-arms were highly immune (gunshots) to bullet injury. When tested, several bullets bounced off. No structural loss exists also in large bullet damage on the arms of the cross of very close range [15].

1.2 Problem Statement

Cross-arms are the main structure of the transmission line constructed on a utility pole which takes up the load from the transmission wires and transfers it to the pole. The design of transmission towers must withstand the weight of the driver from the ground at a certain height. The transmission tower must also be able to sustain natural disasters of all forms. Therefore, a large participation of all three basic engineering concepts, which are equally applicable mechanical, civil, and electrical, is necessary for building a transmission tower [16]. There are many parts of a power transmission tower and cross-arm is one of the central components in a power transmission tower.

In the current cross-arm structure, the issue becomes crucial since it will affect electricity production and incur additional costs for reparation and maintenance. The failure of the crossarm that is being used at the transmission tower will be analyzed and developed.

The failure behavior and mechanical properties of the materials used in the cross arm are usually assessed with the coupons of the original material. Based on the previous research, fiberglass was used as an insulator in the transmission system according to previous research because it has a greater nonconductor strength [17]. Because of the inconsistency of a lot of conditions, however, many new cross-arms fail in a short period due to several reasons such as heavy rain, lightning, wind, and humidity in wet or hot conditions, and the material undergoes degradation leading to mechanical failure[18].

However, full-scale testing of the cross-arm structures hardly exists. Determination of properties of the full-scale structures will provide reliable data and identify failure behaviors critical to the structure. Moreover, few studies improved the design of the wooden cross-arm for optimal performance. In addition, very limited studies have been carried out on full-scale testing of the cross-arm structure.

The current problem is being forced by TNB is that the existing design of the cross-arm structure fails within a period for many reasons including mechanical, environmental, and other reasons. Based on previous reports, actual load-deflection under both normal and broken wire condition have not been conducted; only load deflection of full-scale cross-arm has been conducted until fracture point (fail). While in the current research, load-deflection behavior has been conducted under both situations in the limit of the elastic region of the structure. In normal conditions, loads have been applied in 8 organized steps with a maximum load of (7.98 KN), while in the broken wire condition, it has been applied in 16 organized steps with a maximum load of (16 KN).

Previous studies have mentioned that the numerical analysis was done of the coupon tests of the composite cross-arm structure and very limited studies carried out numerical analysis of the full-scale composite cross arm. While in current research, numerical analysis has been conducted on the full-scale wooden cross-arm to validate the results of a load-deflection test of both normal and broken wire conditions. Based on the previous explanation, there was no reliable data related to the full-scale wooden cross in both conditions. Thus, load-deflection data has been collected for further processing in the design of the cross-arm.

The existing cross-arm structure being used by TNB consists of the main member and two tie members. Nowadays, many new cross-arms fail in a short period due to several reasons such as heavy rain, the lightning, wind, and humidity in wet or hot conditions and all these factors lead to mechanical failure in the cross-arm structure [19][20]. The improved cross arm structure consists of the main member and two tie members along with bracing members thus bracket systems are needed to joint bracing members to the main body. In the current research, bracket structures have been designed, fabricated, and installed on the main body of the cross-arm structure. The design of bracket systems is based on concurrent engineering method, by using systematic exploitation of proven ideas of experience approach. Thus, they have been designed, analyzed, and fabricated accordingly.

In the current study, an improved design of cross-arm has been developed and tested accordingly. Similar to the previous design of the cross-arm structure, actual load-deflection under both normal and broken wire condition have not been conducted in the limit of the elastic region of the structure. In normal conditions, loads also have been applied in 8 organized steps with a maximum load of (7.98 KN). While in the broken wire condition, it has been applied in 16 organized steps with a maximum load of (16 KN). In the current research, numerical analysis using structural analysis tool in ANSYS software has been conducted on the full-scale wooden cross-arm to validate the results of the load-deflection test in terms of both normal and broken wire conditions. These tests have been carried out for both present and improved design. Data from both tests have been compared accordingly.

1.3 Research Objectives

The general objective of current research is to develop and design cross-arm structures to be applied in transmission towers. This scheme can be achieved in an effective way to satisfy the following:

1. To optimize the conceptual designs of the cross-arm structure with bracing members using the structural analysis method.
2. To optimize the conceptual designs of the cross-arm structure with bracing members using the structural analysis method.
3. To develop the bracket system of the improved cross-arm design.
4. To investigate experimentally and numerically the load-deflection behavior of the improved full-scale wooden cross-arm under normal and broken wire conditions.

1.4 Scope of Thesis

In this research, a wooden cross-arm will be used in a full-scale cross-arm structure to be fabricated and tested. To carry out the investigation load-deflection, a test is used as an indicator to specify the quality of the cross-arm structure.

To fabricate the improved full-scale cross-arm structure, bracket structure arms are developed in terms of functionality, analysis, fabrication, and assembly to be installed accordingly. In this work, load-deflection investigation has been carried out for both normal wire and broken wire conditions. Furthermore, the numerical investigation will be conducted for both normal and broken wire conditions for the existing cross-arm. Additionally, the numerical investigation will be carried for the improved cross-arm structure in both normal and broken wire conditions. Static structure tool in ANSYS software has been employed for the simulation process. In the conceptualization process, structural analysis software SKYCIV is used to analyze the proposed structure of the cross-arm in terms of deflection due to load

1.5 Research Questions

1. How to investigate the load-deflection behavior numerically and experimentally for the existing full-scale wooden cross-arm?
2. How the conceptual designs of the cross-arm with bracing members can be optimized using structural analysis software SKYCIV?
3 What are the procedures required for developing the bracket system of the improved cross-arm design?
4. How to investigate the load-deflection behavior of the numerically and experimentally improved full-scale wooden cross-arm?

1.6 Significance of Research

The findings of this study will benefit society considering that mathematics plays an important role in science and technology today. This project is considered a significant project because it mainly deals with real problems occurring in the wooden cross-arm in transmission towers. This study can be conducted in the future by using the improved structure of the wooden cross-arm instead of the old design used by TNB. In this study, a new perspective will be introduced to the design of the cross-arm design, and the new design consists of the main members, tie members, and bracing members where the bracing member will be connected to the main body by using a bracket structure. Moreover, a new design of bracket structures has also been developed. Thus, this design may be used in the future with different kinds of materials of the cross-arm structure. Thus, researchers who are working in the same area can use the proposed method to select the optimum design. The present study bridges the gap in the literature by employing the theories of load-deflection to be implemented on the cross-arm structure. Moreover, many researchers can use the same numerical model along with its governed equations to the different types of materials.

1.7 Thesis Outlines

This research has five chapters, and the following is a brief outline of the synopsis of each chapter. The first chapter begins with an introduction to the study with sub-sections of Background of the Study, Problem Statement, Research Objectives, and Research Questions, the Scope of the Current Research.

The second chapter is dedicated to Literature Review. It has nine sections that address principles relevant to the conceptual design of this research. Moreover, the chapter addresses the structure procedure which reviews different kinds of materials that have so far been used in the fabrication of cross-arm with its governed theories.

The third chapter is composed of five main parts. They show how the objectives of the study are achieved. The first part discusses how to investigate the load-deflection behavior of the existing wooden cross-arm. While the second part discusses how the optimum design of the proposed design of the cross-arm may apply a concurrent engineering approach. The third part presents the procedure of developing bracket structures used in connecting the bracing member to the main body of the cross-arm structure. The fourth part presents how load-deflection investigation improves the selected design of the crossarm structure of both normal and broken conditions. The final chapter shows the procedure of numerical investigation of the exiting and improved cross-arm of both normal and broken conditions.

In chapter four, the focus is on the research outcomes and discussion about the present study.

Chapter 5 concludes the outcomes of the current research. Recommendations for further researches related to the field of this study are also made and included in this chapter

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