A Literature Review on Structural Configuration, Design and Failure Analysis of Transmission Structures

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ABSTRACT

Transmission structures serve as the framework for supporting phase conductors and shield wires within a transmission line. Typically, transmission lines employ two primary types of structures: lattice structures constructed from steel angle sections and pole structures made from materials like wood, steel, or concrete. Furthermore, each of these structure types can be categorized as either self-supporting or guyed. The configuration of these structures can be classified into one of three fundamental types—horizontal, vertical, or delta—depending on how the phase conductors are arranged. The purpose of this paper is to conduct a literature review that covers the structural configuration, design, and analysis, as well as failure analysis of these transmission structures.

INTRODUCTION

Transmission towers play a crucial role in the nationwide distribution of power, necessitating the construction of more power stations in strategic locations. To enhance accuracy and efficiency, there is a growing network of interconnected systems. Inadequately planned transmission lines are vulnerable to failure during natural disasters, underscoring the importance of stability and thoughtful design. Compliance with both national and international regulations is imperative. During the planning and design phase, one must consider both the structural and electrical aspects of a transmission line. From an electrical perspective, insulation and maintaining safe clearances between power-carrying cables and the ground are paramount. A substantial portion, roughly 40%, of the total expenses associated with a transmission line is allocated to the construction of transmission line towers. Choosing the right tower design and implementing an appropriate bracing system are critical elements in creating a cost-effective transmission line tower. Electricity is the primary energy source for residential, commercial, and industrial use. With the rapid growth of industry and infrastructure, there is a rising demand for energy. Furthermore, electric power is increasingly utilized for rail transportation due to its cost-effectiveness, necessitating the installation of transmission line towers for transmitting Extra High Voltage (EHV) to areas in need.

LITERATURE REVIEW

Types of Towers

[1] Aditya Shrivastava et. al. (2021) In his paper "Review Paper Study on Steel Transmission Tower "described the types of towers based on their constructional features, which are in use on the power transmission lines are given below.

(1) Self-Supporting Towers
(2) Conventional Guyed Towers
(3) Chainette Guyed Towers
(4) Self-Supporting Towers: Self-supporting towers are compliant with Indian Standard (IS: 802) and various National and International Standards. They are constructed using tested, high-quality mild steel structural materials, or a combination of tested mild steel and high tensile structural materials conforming to IS: 2062 and IS: 8500 standards, respectively.
(5) Traditional Guyed Towers: These towers are designed as portal structures in 'Y' and 'V' shapes and have been utilized in some countries for extra high voltage (EHV) transmission lines, reaching up to 735 kV. These towers can have either internal or external guy wires for support.
(6) Guyed Towers, including guy anchors, require significantly more land compared to self-supporting towers. Therefore, this construction type is typically used in vast, unoccupied areas.

(7) Chainette Guyed Tower: This tower is akin to traditional guyed towers but is capable of accommodating double circuit lines.

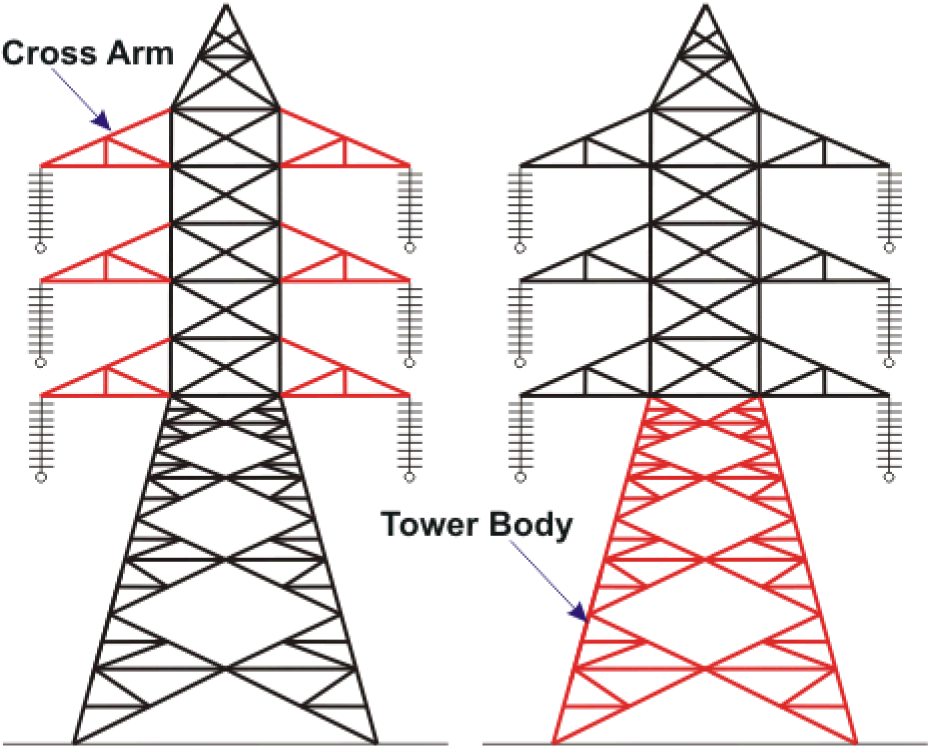

Figure 1Typical Transmission Tower details

Structure Configuration and Material

The cost of the structure typically constitutes 30 to 40% of the total expenditure for a transmission line. Consequently, the selection of an optimal structure plays a crucial role in designing a cost-effective transmission line. To determine the most suitable structure configuration and material based on cost, construction, maintenance considerations, and the effects of electric and magnetic fields, a structural analysis is usually carried out. Here are some key factors to take into account when assessing the structure configuration:

1. A horizontal phase configuration typically results in the lowest structure cost.

2. If right-of-way expenses are high, or the width of the right-of-way is limited, or the line closely follows other lines, a vertical configuration may result in a lower overall cost.

3. In addition to needing a wider right-of-way, horizontal configurations generally require more tree clearing compared to vertical configurations.

4. While vertical configurations are narrower than horizontal ones, they are also taller, which might be aesthetically undesirable.

5. In scenarios where minimizing electric and magnetic field strengths is essential, the choice of phase configuration can be a method for achieving this reduction. Generally, vertical configurations tend to exhibit lower field strengths at the right-of-way boundary compared to horizontal configurations. For single-circuit setups, delta

configurations typically yield the lowest field strengths, and for double-circuit configurations with reverse or low-reactance, similar reductions can be achieved. strength. phasing results in the lowest achievable

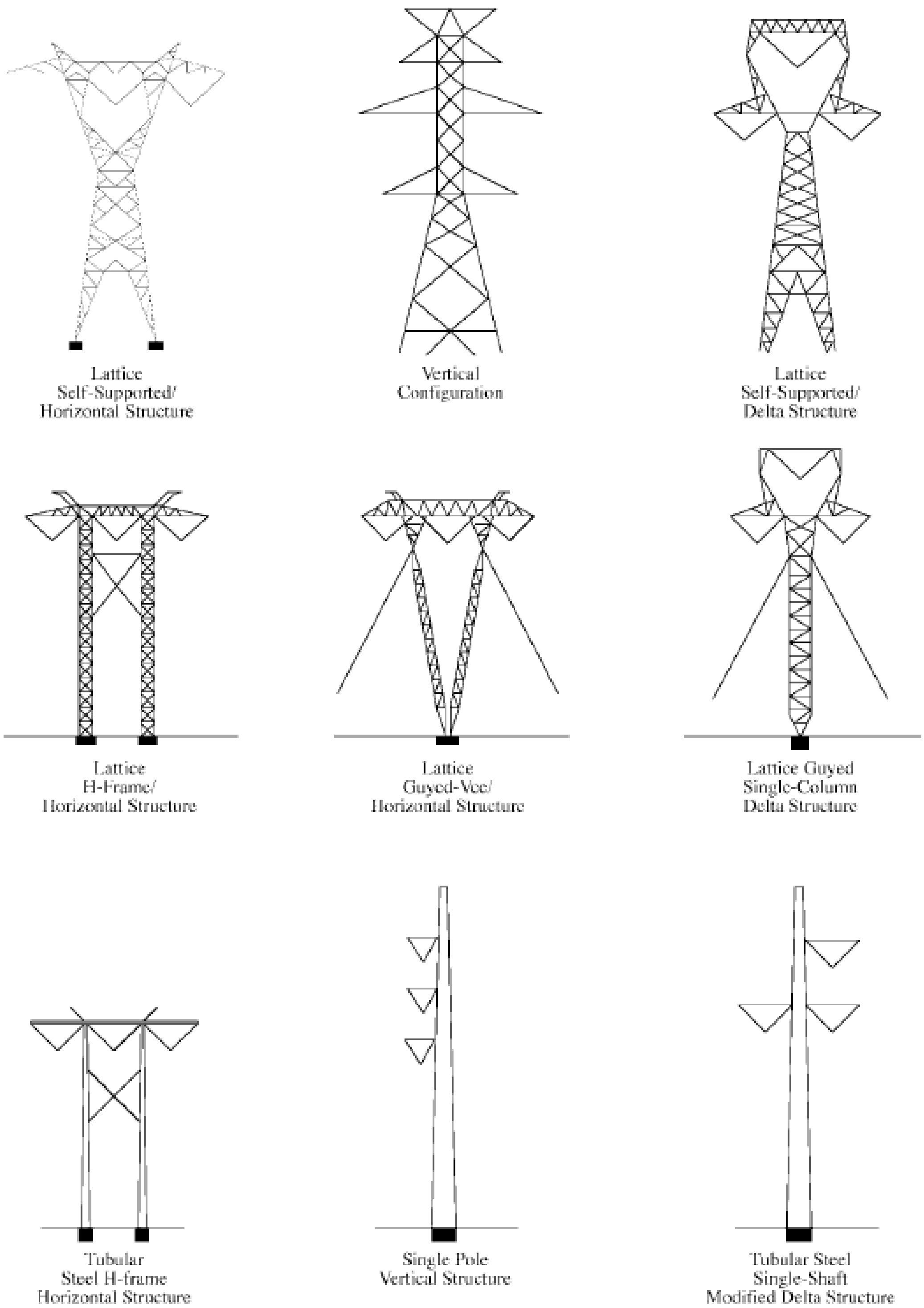

Figure 2 Types of transmission tower

Analysis and Design

[1] Natarajan and Santhakumar (1955) In the paper "Reliability-based optimization of transmission line towers" conducted studies on reliability-based optimization of transmission line towers. A suite of four standalone computer programs was created to address component reliability, perform reliability analysis, optimize designs, and automate the generation of failure modes. These programs were interconnected to facilitate cost-effective tower design while maintaining a specific level of desired reliability. The weight of the optimized tower, taking into account reliability as a constraint for tangent cover, is just slightly heavier, approximately 3 to 4%, compared to a tower designed using traditional methods.

[2] Elagaaly et al (1992) In the paper "3-Dimensional Study of transmission tower truss" conducted experiments on 3 dimensional trusses. The trusses were designed such that the target angle would fail first without significant deformations in the remaining members of the truss. Following After each test, the target angle was replaced to enable multiple tests within the same environment. Additionally, fifty individual angle members were tested as part of the truss. The results revealed six distinct buckling modes arising from the interplay of local, flexural, tensional, and torsional structural behaviours. The primary cause of member failures predominantly stemmed from local buckling, particularly in the vicinity of bolt holes. This research was centered on the investigation of a 230KV transmission line upheld by delta-type towers. It also took into account soil-structure interaction, encompassing two types of soil: medium sand and clay. The study involved an in-depth analysis of a 230KV transmission line upheld by delta-type towers. Soil-structure interaction was a central focus, with consideration given to two soil types: medium sand and clay. In order to emulate the behavior of the soil and concrete footing, linear elastic springs and rigid elements were employed. The assessment of structural dynamic characteristics revealed that, irrespective of the soil type, the first 10 lower natural oscillation frequencies remained consistent.

[3] Battista et al (2003) In the research paper entitled "An Analytical Numerical Model for Evaluating the Structural Behavior of Transmission Line Towers under Wind Forces," a comprehensive three-dimensional finite element model was created to study the dynamic interaction of transmission line towers when exposed to wind forces. The analysis placed significant focus on the examination of suspension rods, which consist of chains of insulators, as the pivotal component influencing the tower's response to wind flow. The structural framework of the tower, along with all related cables, was modeled using spatial frame elements.

[4] V. Lakshmi1, A. Rajagopala Rao (2004) In the paper "Analysis and design of 132 KvV tower under medium wind intensity zone" studied the performance of 21M high 132kV tower with medium wind intensity is observed The paper delves into the recommendations of IS 875-1987, addressing aspects like basic wind speeds, the influence of height above ground and terrain, design wind speed, design wind pressure, and design wind force in a comprehensive manner. The study involves an analysis of a transmission tower, evaluating both the tower's performance and the forces experienced by its vertical, horizontal, and diagonal members. Critical components within each of these three categories are identified. Subsequent chapters focus on assessing the tower's performance under abnormal conditions, such as localized failures. The document also provides a detailed discussion on load calculations, modeling, and analysis. Wind intensity is translated into point loads, which are then applied at the panel joints.

[5] M.V.R.Satyanarayana (2007) In the study titled "Evaluating the Reliability of 220kV Transmission Towers with the Application of IS Code," the wind load on the tower under Zone 2 conditions was computed. The tower's analysis was conducted under full load conditions using STAAD Pro 2007. Securing land for power transmission lines has become increasingly challenging over the years due to various constraints, including high population density in urban areas, the complexities of obtaining forest clearances, and an emphasis on preserving natural environments. Hence, there is a pressing need to design more compact 110/132kV and 220kV transmission line tower structures in order to minimize their physical dimensions.

[6] M.Selvaraj, S.M.Kulkarni, R.Ramesh Babu (2012) In the paper "Comparative study of transmission tower using steel and FRP pultrude sections". Studied that power transmission line towers will have to be built with new design concepts using new materials, reduction of construction costs and optimizing power of delivery with restricted right of way. This paper discusses experimental studies carried out on a X braced panel of transmission line tower made from FRP pultruded sections. Mathematical model of individual members and members in the X-braced panel are generated using FEM software to study the analytical correlation with the experiments. The member stresses are monitored using strain gauges during full scale testing. Conclusions are drawn based on these studies.

[7] S.Christian Johnson , G.S.Thirugnanam (2013) In the paper "Analysis and Design of Transmission Tower with Isolated Footing In transmission line towers, the tower legs are typically embedded in concrete, which offers effective protection for the steel structure. However, the presence of defects and cracks in the concrete can create opportunities for water and salts to infiltrate, leading to corrosion and weakening of the tower leg. When ferrous materials undergo corrosion, transforming into ferrous oxide, they undergo a volumetric expansion compared to their original state. This expansion introduces strain on the chimney concrete, leading to the development of cracks. These cracks serve as pathways for water infiltration into the chimney concrete, intensifying the corrosion process and ultimately causing the deterioration of the concrete in the chimney. This form of corrosion, often observed in the stub angle just above or within the muffing, is a prevalent issue in regions with high salinity.
To effectively maintain and renovate electric power transmission lines while they are in operation, it is imperative to possess precise knowledge about the condition of their components. This information is vital for devising cost-efficient programs aimed at extending the operational life of these lines. The most comprehensive approach to assess the degradation of foundation concrete involves excavation. This technique provides insights into the extent and nature of corrosion damage, including potential microbial-induced corrosion. The research delves into the analysis of physical, chemical, and electrochemical parameters observed in transmission line tower stubs excavated from both inland and coastal areas. Furthermore, the study outlines a methodology for the restoration of these transmission tower stubs.

[8] F.Albermani and M. Mahendran (2014) In the paper "Upgrading of Transmission Towers Using of Diaphragm Bracing System" The paper titled "Enhancing Transmission Towers Through the Implementation of Diaphragm Bracing Systems" addresses the challenge posed by older transmission towers originally designed with tension-only bracing systems featuring slender diagonal members. These aging towers must now undergo upgrades due to the increased demand for power supply and the changing weather patterns worldwide, resulting in the need to support heavier loads. The failure of a single tower in the transmission line can swiftly propagate, leading to extensive damage incurring substantial financial losses. Therefore, the core objective of this research project is to develop efficient upgrade strategies utilizing diaphragm bracings.

The research focused on enhancing the strength of these towers by introducing various diaphragm bracing designs at the midpoint of the slender diagonal members. Analytical studies demonstrated that significant strength improvements could be achieved through the implementation of diaphragm bracings. These studies also examined the impact of different bracing types, including methods of connecting the internal nodes of diaphragm members and the positioning of diaphragms, utilizing the most efficient diaphragm bracing design, was effectively put into practice on an existing TV tower standing at a height of 105 meters. The paper offers a comprehensive account of both the analytical assessments and the experimental investigations, along with their respective findings.

[9] G.Visweswara Rao (2015) In the paper "Optimum Designs For Transmission Line Towers" A method for the development of optimized tower designs for extra high-voltage transmission lines is presented in the paper. The optimization process takes into account both the weight and geometry of the tower, achieved by regulating a selected group of essential design parameters. The design process also incorporates an element of uncertainty or fuzziness in defining these control variables. To facilitate this, a derivative-free nonlinear optimization technique is integrated into the program, which has been specifically developed for the configuration, analysis, and design of transmission line towers. The research presents intriguing findings from both precise (crisp) and fuzzy optimization approaches that pertain to the design of a standard double-circuit transmission line tower under various loading conditions.

[10] Falguni Patel et. al. (2016) In the paper " Performed evaluation investigate Clasping Examination of Cross section Transmission Pinnacle." Various kinds of untimely disappointments that were resolved sooner or later of full-scale giving a shot of transmission line towers at Pinnacle Testing and Exploration Station, Primary Designing Exploration Place, Chennai (CSIR-SERC) are examined, and the outcomes are referenced in detail. Because of the unpredictable burden conditions and the nonlinear exchange a portion of the enormous amount of primary added substances, right underlying examination of the LTT frameworks has been a difficult topic for a long time. Still these days there are a couple of holes among studies and business practice. This investigation gives a summary of studies results from current writing.

[11] Hadimani et. al. (2016) In the paper "Performed static and dynamic assessment of transmission line tower (X type of propping machine)" The investigation and displaying of pinnacle is executed the utilization of FE based absolutely ANSYS programming program. The model is made in CATIA and afterward imported to ANSYS workbench. The majority performing on the pinnacle mulled over are futile burden, live burden and dynamic hundreds (Seismic and wind). The existing tower stands at a height of 40 meters, accounting for ground clearance, the conductor's maximum sag, and vertical spacing between conductor strings. A comprehensive analysis, covering static and dynamic aspects, has been conducted using the Finite Element-based ANSYS software. This analysis encompasses static, modal, response spectrum, and wind assessments. The results include data on maximum deformation, combined loads, natural frequencies, and direct stress, which have been graphically represented.

[12] Gopi Sudam Punse (2017) In the thesis "Analysis and Design of Transmission Tower" . The analysis and design of a narrow-based Transmission Tower (using Multi Voltage Multi Circuit) is carried out in India, with the goal of maximising the use of electrical supply with limited ROW and an increasing population. Transmission Line Towers contribute to 28 to 42 percent of the total cable cost. The increased demand for power is frequently handled more cost-effectively by designing various light-weight transmission tower layouts. In this project, a battle has been waged to make the cable more cost-effective while keeping in mind the goal of providing the best possible electric supply for the defined area by identifying a unique transmission tower structure. The goal of this study is to increase the current geometry by using a 220KV and 110KV Multi Voltage Multi Circuit with narrow based Self Supporting Lattice Towers. STAAD PRO v8i was used to accomplish the analysis and design.

[13] Vikas Gahlawat (2018) In the paper " Analysis and Design of a 25 Meter Tall Steel Transmission Tower". The analysis and design of a steel truss tower used for electrical transmission systems is carried out in this paper under different gravity and lateral load categories. The tower is analyzed under various loading conditions before designing as per IS 800:1984. In order to plan the design process as accurately as possible, proper site survey data as well as environmental impact assessment data are collected using appropriate electronic and paper media prior to the design process. The relevant safety aspects of the design are considered in the design keeping in mind the sloping terrain of the site (Shimla). Non-linear imperfections in both the surroundings and the structural material are taken into account during the design process. The steel angles that were riveted together were chosen for their different purposes and load impacts. Geotechnical survey data is used to determine foundation details. The software tool used in the process was STAAD.Pro 2008. The load calculations were done manually, however, STAAD.Pro 2008 was used to obtain the analysis and design outputs. The goal is always to create the safest possible design while keeping costs in mind.

[14]N. Mahesh (2018) In the paper "Design & Estimation of Electric Steel Towe" This study presents the main analysis and design of a convergent electric steel tower using STAAD. This is done to ensure the maximum amount of electrical supply with LINE that is available while keeping in mind the growing population in the area. Electrical steel poles cost about 30-48 percent of the total cost of line construction. Due to the growth in demand, lightweight structures will be developed, which will have a lower load on the structure due to a reduction in dead weight. When examining the design and estimation of the tower, the chosen structure is decisive. A little analysis was done to make the electric tower more cost effective than the standard one. The best electric power supply for the required area is also considered in a single electrical steel tower. The structure can include multi-voltage circuits of 230 KV and 120 KV, as well as self-supporting towers that are created depending on the geometry. STAAD. Pro is used to assess and design an electrical steel tower, also known as a steel truss tower, for any load size or orientation. It is necessary to construct three-dimensional structures of tower elements. The new edition of the code is Design of Steel Structures as per Indian Standard Code IS: 800-2007 at Limit State. In this study, the foundation design of the electrical steel tower is also carried out using the Hansen method. In addition, the total cost estimate for the construction of the electric steel tower has been completed.

[15] Patil B.Y. (2019) In the paper "Design and Analysis of Transmission Line Tower using Staad-Pro" This research compares three types of bracings and focuses on estimating a feasible transmission line tower for various wind speeds by developing transmission line towers with hot rolled sections. 220 kV twin circuit self-supporting transmission towers with square bases are employed for this purpose. STAAD PRO is used to analyse this transmission tower, which is subjected to wind loads in Zones II, III, and IV. The load calculation for the analysis is performed in accordance with IS 802:1995. Finally, wind speed is used to compare the best transmission tower design utilising hot-rolled steel.

[16] Deepali Patel, Dr. Dipti Singh, Dr. Shilpa Pal and Sachin Tiwari (2020), In the paper "" an attempt has been made to make a 400kV double circuit's tension tower having deviation angle of 2-15° with X, K and mixed both bracings using STAAD.PRO. A mixed combination of K and X bracing is to be applied for least cost.

Rectangular base configuration cost is lesser than the Square configuration by 1.17%, but Rectangular base configuration is difficult to carry in practice and hence, practically Square Configuration is adopted.

[17] Anshu Kumar Pal (2020) In the paper "Comparative Analysis of Transmission Tower Using XX and XBX Bracing Systems in Different Wind Zones". Using STAAD Pro. V8i software, an improved steel bracing system is recommended in the construction of transmission line towers. According to IS 802 (Part-1 / Sec-I):1995, two bracing systems, XX and XBX, are being compared in all six wind zones of India, employing seven different load circumstances. STAAD Pro V8i software is used to model and analyse the structural behaviour of the tower for both bracing systems. In all wind zones of India, the XBX – bracing system was determined to be more cost-effective than the XX – bracing system.

[18] Yasaswini (2020) In the paper "Multi Voltage Multi Circuit Transmission Tower Design to Reduce Right of Way", A novel strategy for reducing the ROW width in MVMCT design is proposed in this research. The case study was carried out on multi-voltage multi-circuit towers (MVMCT) with three different voltage levels (400 kV, 220 kV and 33 kV). The study proved that the proposed design is not only technically superior but also cost effective. Compared to traditional wide-base towers, the right-of-way (ROW) width can be reduced from 48 to 40 meters, resulting in significant cost savings for transmission line projects. In addition, MVMCT increases transmission capacity while keeping electromagnetic fields (EMF) within permissible limits within the ROW. All stress levels fall within acceptable limits. By limiting the ROW, cost savings could range from 30 to 50%. Consequently, the implementation of MVMCT with a smaller footprint has the potential to be a disruptive development in India, offering economic benefits and mitigating legal concerns associated with land use.

[19] Anshu Kumar Pal, M. Suneel, P V Rambabu (2021), In the paper "in this study, 220 KV suspension type, and square based self-supporting transmission tower having double circuits. Two bracing systems viz. XX and XBX are being compared in all the six wind zones of India as per IS 802 (Part-1/Sec-I):1995. The towers are modelled and analyzed in STAAD Pro V8i. The XBX bracing was concluded to be more economical in comparison with XX bracing in all wind zones of India.

[20] P. Rajasekhar (2021) In the paper "Plan of transmission towers is offered in a viewpoint of facing high voltage sending conductors and covers to remain needing height starting from the earliest stage. For a similar reason a transmission tower is reproduced with comparable setting of tallness 49m and bringing a 220KV twofold circuit conductor, moved with STAAD Professional. The examinations from both underlying and electrical fields are seen in planning transmission line towers, for protected and financial angles. As per IS 800-2007, the breeze powers are a lot of conspicuous on the pinnacle, conductors and covers, other than oneself weight. This work is engaged in enhancing the transmission tower with utilizing the 'X' and 'K' bracings, and by fluctuating the areas, analyzed utilizing Static investigation. The aftereffects of utilizing 'X' propping to 'K' supporting are the appraisable decrease in the heaviness of the design by 6% and having the removal esteems enhanced.

Failure analysis –

[21] Raghavan Ramalingam {2017) In the paper "The Experimental investigations have revealed significant mismatches between analytical estimates and experimentally measured deflections of tower structures" The tension and deflection of the conductor and ground wire are affected by the maximum deflections and deflections of the cross arms, so accurate estimates of tower deflections under service loads are key. In this paper, a non-linear approach to the analysis of tower structures is presented to address existing disparities. This analysis takes into account the geometric non-linear characteristics of the mast, material non-linearity and buckling of the shoulder members under pressure. The nonlinear analysis successfully predicts the ultimate collapse load of the tested towers to failure. However, it should be noted that even after using a non-linear analysis, there are still differences in deflection values. This highlights the need to incorporate additional parameters to minimize the error rate in analytical deflection predictions.

[22] Hemant Patil et al (2018) In the paper "Failure analysis on 400kV S/C horizontal configuration tower by conducting nonlinear finite element analysis using NE-NASTRAN software" Both geometric and material non linearity's have been included in the analysis. It was predicted that the nonlinear analysis forces are higher compare to linear analysis force. Further the remedial measures have been suggested for the in stability encountered in the structure.

[23] Swarup Sontakke et. al. (2021) In the paper " Literature Review on Failure Analysis Transmission Tower Design" This article examined how failure of "MD" (300 -600 Dev./D.E.-00) NT +9M Body Extension 220 Kv Multi – Circuit Transmission Tower design. The poor design Transmission Tower Structure directly related with load behaviors on each component elements of transmission tower Structure. Failure were observed that during testing load applied on transmission tower structure at That were observed MD type tower withstood load up to 50 %, while reaching near 75% load, belt member item no. 562 of +9M B.E & Center plate item no. 563 buckled, subsequently other item no. 560,543,544,535,536 & 537 got damaged/ failed. Data were collected from failure analysis of physical testing and previous reason of failure transmission tower with the help of study journal research paper based on the failure transmission tower design. Also government and NGO studies on tower failure. After analyzing all the causes of failure, the project recommends using the finite element method, practical prototype testing of the tower Using this method, the design of the tower can be easily modified and updated. Using this method of Testing & FEM will result in saving time and tooling costs. Theoretical and practical implications of the results are discussed. Different types of premature failures and reasons were discussed. The study shows that different types of faults are useful for understanding the behavior, carrying capacity. During the literature review and after analyzing all the causes of failure, the Project is recommended to use the finite element method, practical prototype testing of the tower Using this method, the design of the tower can be easily modified and updated. Using this method of testing and FEM results will save time and tooling costs.

[24] N.PrasadRao, G.M.Samuel Knight, S.J.Mohan, N. Lakshmanan(2022) In the paper “Failure of transmission line towers in testing” The towers are vital components of the transmission lines and hence, accurate prediction of their failure is very important for the reliability and safety of the transmission system. When an outage occurs, direct and indirect losses are high, apart from other costs associated with power interruptions and litigation. Various types of premature failures observed during full-scale testing of transmission line towers at Tower Testing and Research Station, Structural Engineering Research Centre, Chennai are presented. The malfunctions that were observed during testing are studied and the reasons are discussed in detail. The effect of non-triangulated hip brace pattern and isolated hip braces associated with cant in "K" and "X" braced panels on tower behavior is studied. The tower elements are modeled as beam column and plate elements. Different failure types are modeled using finite element software and analytical and test results are compared with different code provisions. The universal finite element analysis program NE-NASTRAN is used to model the elastoplastic behavior of the towers. The importance of redundant element design and connection details in the overall tower performance is discussed.

[25] P.Sethupathi et. al. (2022) In his paper “Failure analysis of transmission line towers” *During* full scale testing of transmission line towers at the Tower Testing and Research Station, Structural Engineering Research Centre, Chennai Indian, numerous sorts of early failures were detected. The model was developed and evaluated using finite element software. This research demonstrates that a nonlinear static analysis is required to comprehend the structure's behaviour, likely load bearing capability, design flaws, and instability.

Failure analysis of transmission towers

[26] N. Prasad Rao; G.M. Semuel Knight; S.J. Mohan; N. Lakshamanan (2016), *“Studies on failure of transmission line towers in testing;.:-* Different forms of early failures discovered during full scale testing of transmission line towers at Tower Testing and Research Station, Structural Engineering Research Centre, Chennai are described in this research on towers. Failures identified during testing are investigated and the causes are described in depth. Different types of failures are modeled using finite element software and the analytical and the test results are compared with various codal provisions. The general Fem analysis programme NE- The effect of nontriangulated hip bracing pattern and isolated hip bracings connected to elevation redundant in „K‟ and „X‟ braced panels on tower behaviour are studied. The tower members are modelled as beam column and plate elements.

[27] F. Albermani; S. Kitipornchai; R.W.K. Chan, ELSEVIER (2018) The main objective of this paper is to present the results of a full-scale pushover test of a 40-meter telecommunication tower under limit load. A detailed description of the studied tower was presented, emphasizing the geometric imperfections of selected structural elements. Experiment results were provided that included axial forces in tower members as well as observed node displacements as a function of external loading. For a typical set of communication equipment, a comparison of wind loading based on existing standards with loading based on experimental breaking force was investigated. The key result was that the overall load capacity of the structure was determined by the buckling resistance of the legs. In addition, the predicted buckling strengths of the tower legs consisting of round solid bars (based on standards) were lower than the experimental axial compressive forces.

[28] Dharmender Panth, IIT-BHU, Varanasi, U.P., India, Reasons For Failure Of Transmission Lines And Their Prevention Strategies, Volume-2, Issue-1, Jan.-(2021):- Transmission line pylons, although designed to code provisions, can fail during the mandatory testing required in many countries, resulting in massive damage to the power system. The various types of premature failures that are observed during various full-scale transmission line mast tests and their results are discussed in detail. The importance of design assumptions and connection details in the overall performance of the masts was studied. The importance of secondary element design and connection detail in the overall performance of the tower was studied. Nonlinear finite element analysis is useful for understanding system behavior and for predicting the failure pattern and ultimate load. Based on the test results, the importance of fault studies is emphasized. The need to implement various failure prevention strategies in transmission line towers was also clearly highlighted.

[29] Rao NP, Knight GS, Mohan SJ, and Lakshmanan N (2022). Studies on failure of transmission line towers in testing. Engineering Structures,. :- Different types of premature failures observed during full scale testing of transmission line towers at Tower Testing and Research Station, Structural Engineering Research Centre, Chennai are presented. Failures that have been observed during testing are studied and the reasons discussed in detail. The effect of nontriangulated hip bracing pattern and isolated hip bracings connected to elevation redundant in „K" and „X" braced panels on tower behaviour are studied. The tower members are modelled as beam column and plate elements. Different types of failures are modelled using finite element software and the analytical and the test results are compared with various codal provisions. The general-purpose finite element analysis program NENASTRAN is used to model the elasto-plastic behaviour of towers. Importance of redundant member design and connection details in overall performance of the tower is discussed.

REFERENCES

1. Arya, S., & Er. Sindhu, A. R. (2020). Analysis and Design of Transmission Tower with Isolated Footing. Journal of Science and Technology, 35-42.
2. B. Bharath Kumar Reddy, K. Rasagnya, & V. Sanjay Gokul. (2016). A Study on Analysis of Transmission Line Tower and Design of Foundation. International Journal of Engineering Development and Research , 2214-2224.
3. CH. Prasad Babu, & N. Vikram. (2020). DESIGN OF TRANSMISSION TOWER AND ITS FOUNDATION. IJARIIE, 364-375.
4. Heera Lal Bhardwaj, Ajit, & Yogesh Kaushik. (2015). Analysis and Design of Four Leg Steel Transmission Tower using Staad.Pro. International Journal of Advanced Engineering, Management and Science (IJAEMS) , 7-13.
5. Julius O Onyeka, & Ochonogor Hycent Ifechukwudeni. (n.d.). Towards Sustainability in Infrastructure development Structural Design of a 330kV Transmission Line Tower in Warri, Nigeria.
6. N, B. B., & Banavekar, S. M. (2020). ANALYSIS AND DESIGN OF TRANSMISSION. JETIR December 2020, Volume 7, Issue 12, 8.
7. N. Mahesh, & V. Ranga Rao. (2017). DESIGN & ESTIMATION OF ELECTRIC STEEL TOWER. International Journal of Civil Engineering and Technology (IJCIET), 646-652.
8. P.Vishnu Priya. (2021). Analysis and Design of Transmission Tower. International Journal of Scientific Research in Engineering and Management (IJSREM), 1-4.
9. Patil B.Y, Prof. Upase K.S., & Prof. Hamne A. A. (2020). Design and Analysis of Transmission Line Tower using Staad-Pro. International Journal for Scientific Research & Development, 11-13.
10. Sujeeth M Banavekar, & Bhavyashree B N. (2020). ANALYSIS AND DESIGN OF TRANSMISSION TOWER USING STAAD.Pro V8i. Journal of Emerging Technologies and Innovative Research (JETIR), 572-579.
11. Trishit Chandra, & Sanjay Sengupta. (2019). Dynamic Analysis of Telecommunication Tower for Optimum Model Combination and Elemental Discretization. International Journal of Engineering and Advanced Technology (IJEAT), 2229-2237.
12. Vikas Gahlawat, Er. Sumit Kumar, & Yogesh Kaushik. (2015). Analysis and Design of a 25-Metre-Tall Steel Transmission Tower. International Journal of Engineering Technology, Management and Applied Sciences, 32-35.
13. Yasaswini, S. V. N. L. Lalitha, & Shefali Talati. (2016). Multi Voltage Multi Circuit Transmission Tower Design to Reduce Right Of Way. Indian Journal of Science and Technology, 1-7.
14. Gopi Sundam Punse. "ANALYSIS AND DESIGN OF TRANSMISSION TOWER". International Journal of Modern Engineering Research (IJMER), ISSN: 2249–6645, Volume 4, Issue 1, Jan. 2014

15. Anshu Kumar Pal, M. Suneel, & P V Rambabu. (2019). Comparative Analysis of Transmission Tower using XX and XBX Bracing Systems in Different Wind Zones. International Journal of Recent Technology and Engineering (IJRTE), 56-61.
16. Hsein -Yang Yeh and Samuel C.Yang. Building of composite transmission tower. Journal of Reinforced Plastics and Composites 16(5):414-424:1997
17. Hsien-Yang Yeh, Hsien - Liang Yeh, Simple failure analysis of the composite transmission tower, Journal of Reinforced plastics and composites, Vol.20 No.12/2001
18. ASCE Manuals and Reports on Engineering Practice No.104, Recommended practice for Fiber-Reinforced polymer products for overhead utility line structures..
19. Marisa Pecce, Edoardo Cosenza, Local buckling curves for the design of FRP profiles, Journal of Thin Walled structures Vol.37 (2000) 207-222
20. John Tomblin & Ever Barbero, Local Buckling Experiments on FRP Columns, Journal of Thin Walled Structures Vol.18 (1994) 97-11
21. Al-Bermani FGA and Kitipornchai S 1992 *Eng. Struct.***14(3)**139-51.
22. Albermani F, Kitipornchai S, Chan RWK 2009*Eng. Fail. Anal.* **16**1922
23. Rao NP, Knight GMS, Lakshmanan N and Iyer NR 2010*Eng. Fail. Anal.***17**1127-41.
24. Kitipornchai S, Al-Bermani FGA and Peyrot AH 1992*J. Struct Eng ASCE***120(8)**2281-7.
25. Kroeker D 2000*Structural analysis of transmission towers with connection slip modelling* MS thesis, University of Manitoba.
26. Ungkurapinan N, Chandrakeerthy SRDeS, Rajapakse RKND and Yue SB 2003*Eng. Struct.***25**779-88.
27. Rao NP, Knight GMS, Lakshmanan N and Iyer NR 2012*Pract. Period. Struct. Des. Constr. ASCE.***17(2)**65-73.
28. Mattiasson K 1983*On the corotational finite element formulation for large deformation problems* During thesis, Chalmers university of technology.
29. Jayachandran SA Kalyanaraman V and Narayanan R 2004 *Int. J. Struct. Stab. Dyn.***4(1)** 1-19.
30. Crisfield, MA 2000 *Non-linear Finite Element Analysis of Solids and Structures, Volume 1: Essentials* John Wiley & Sons, Chichester.