Performance Analysis of an Overhead Power Transmission Line Tower

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Abstract

One of the main reasons for overvoltage-related power system outages is the back flashover (BF) mechanism, which is brought on by lightning strikes directly on towers and overhead cables. In this thesis, analysis and design of a narrow-based transmission tower are carried out with the goal of providing the area's growing population with the best possible electric supply given the available ROW. In India, an overhead transmission line may be used to transmit or distribute electricity. This paper's goal is to transmit the most power possible at a given power factor, over a certain distance, and with a given level of voltage regulation. This study uses friction dampers subjected to wind excitations to control vibration and evaluate performance on a transmission-tower line system. The tower construction is appropriately rigged to allow for the most representative application of the external loads and to imitate tower design conditions.

Keywords:- Transmission Line, Mechanical Design, Electrical Design, Transmission Efficiency, Transmission Line Tower.

1. INTRODUCTION

One of the key factors that contribute to transmission line overvoltage's and potential outages is lightning. The coordination of protection and insulation measures in power systems is greatly aided by analyses of lightning strikes to transmission towers. When a tower top or an above ground wire is struck by lightning, the surge current splits to reach nearby towers via the ground wires and descends the tower structure to the earth. In this case, the tower surge impedance, which results in reflection waves at the top and bottom of the tower, will have a significant impact on the overvoltage's. A rearward flashover will occur if the voltage between the phase conductor and the cross arm is higher than the Critical Flashover Voltage (CFO) (BF). According to estimates, 40% to 70% of transmission system outages are attributable to BFs, which have a significant impact on system performance.

These accidents generally take place in areas with high soil resistivity, high ground flash densities, and high terrain. Back flashovers may be decreased by a number of reasons, including the installation of overhead ground wires, proper insulator string and tower structural sizing, and low tower footing resistance values. India has a sizable population spread out over the nation, which necessitates a sizable transmission and distribution system to meet the country's need for power. Additionally, the distribution of the main resources used to generate electricity, such as coal and hydropower, is highly uneven, which raises the need for additional transmission infrastructure. A transmission line is an integrated system made up of one subsystem for each type of support structure, a conductor subsystem, a ground wire subsystem, and a ground wire subsystem. Transfer line mechanical supports are a major component of the line's cost and are crucial for the efficient transmission of power. They are created and built in a broad range of forms, styles, dimensions, arrangements, and materials. Transmission line supporting structures typically fall into one of three categories: guyed, pole, or lattice. EHV transmission lines are often supported by steel lattice towers. The cost of towers makes up between 25% and 50% of the cost of a transmission line, therefore even the best tower design won't result in significant savings.

A transmission line tower's cost-effective design is greatly influenced by the choice of the ideal form and the appropriate type of bracing system. The user sets the tower's height, and the structural designer is responsible for creating the general layout, member details, and joint details. A transmission network's function is to move electric energy from generating units to various sites before it is delivered to the distribution system, which in turn supplies the load. The fundamental components of a transmission system are a conductor, an insulator, and a support. Constants used in the electrical design of the transmission line include resistance, inductance, and capacitance. Transmission lines come in two varieties: AC transmission lines and DC transmission lines. The levels of the transmission voltages are 66 kV, 132 kV, 230 kV, and 500 kV. Utilizing a three phase, three wire

AC system is the best strategy for transmission systems. Electric loads that have a power factor of less than one can have negative impacts, and power factor correction (PFC) is a strategy to mitigate these effects.

An electrical power transmission utility may use power factor correction to increase the stability and effectiveness of the transmission. Shunt capacitors are hence frequently employed in power factor correction applications. A prominent type of electrical power infrastructure that is utilized extensively around the world for energy supply is the overhead transmission tower-line system. The transmission tower-line system is susceptible to large wind excitations because of its low damping, making it a high-rise structure. Strong wind loadings may cause a transmission tower-line system to vibrate excessively, leading to structural damage or failure that results in incidents such member fracture, member buckling, and tower collapse.

There have been numerous reports of tower failure under wind loading worldwide. Numerous theoretical, experimental, and field measurement investigations have been conducted over the past 20 years to reduce the transmission tower-line system's dynamic reactions. There are now two main categories in which performance evaluation and control methods and strategies fall. The first method is the traditional one, created by making the structure stiffer while allowing for a high level of wind excitations. The alternate strategy involves installing vibration control systems to prevent structural breakdown.

2. LITERATURE REVIEW

BALAJI PATIL et.al (2020) Heavy electrical transmission cables are carried by transmission line towers at a suitable and safe height above the ground. They must bear not only their own weight but also all natural factors such severe winds, earthquakes, and snow loads. As a result, for a secure and cost-effective construction, transmission line towers should take into account both structural and electrical requirements. This study focuses on developing a transmission line tower with hot rolled sections and comparing three types of bracings to estimate a feasible transmission line tower for various wind speeds. 220 kV twin circuit self-supporting transmission towers with square bases are utilized for this purpose. STAADPRO is used to analyses this transmission tower while subjecting it to wind loads for Zones II, III, and IV. The analysis's load calculation is done in accordance with IS802:1995. The best transmission tower design employing hot-rolled steel is then evaluated for wind speed.

Juliana Maciel Maia Be¸ca et.al (2019) In order to increase the transmission line capacity, the purpose of this work is to offer uprating strategies on a 230 kV transmission line. It also includes a comparison of uprating techniques, which emphasizes the significance of the reconductoring process. A computer programmer that is frequently used by electric power companies to build and optimize new transmission lines will be utilized to validate the methodology, which will result in considerable increases in the conductor heights. Introduce a competitive option as well to boost the transmission capacity of active lines. In order to assess the advantages that the strategies might provide at low voltage, we also show certain study cases that were conducted on actual lines.

Aye Aye Maw (2019) Electric power transmission and distribution are both possible with an overhead transmission line. This paper's goal is to transmit the most power possible at a given power factor, over a certain distance, and with a given level of voltage regulation. Presented is the design and analysis of a 160km long, three phase, 50Hz overhead line that provides 150MW at 230kV, 0.9 power factor lagging. For various spans with poles at equal heights, the mechanical design incorporates different types of towers, spans, ground clearance, tension, and sag. Additionally, electrical design includes the selection of a conductor, percentage voltage regulation, and transmission line efficiency. The power factor shunt capacitor bank can be modified to improve system performance.

R. J. Araújo et.al (2017) One of the main reasons for overvoltage-related power system outages is the back flashover (BF) mechanism, which is brought on by lightning strikes directly on towers and overhead cables. An overvoltage results from the injected current that flows through the structure of a tower when lightning strikes it. A BF will occur if the critical flashover voltage (CFO) of the insulator strings is exceeded by the voltage between the phase conductor and cross arms. There are many models that have been developed for the computation of the tower surge impedance, which is a crucial parameter in the estimation of overvoltage. This study compares the measured and computed surge impedances of a thin cylinder with a specially constructed, reduced-scale transmission tower. The computations have taken into account several models. Along with several techniques for measuring tower surge impedance, this article also provides a brief survey of related literature.

3. METHODOLOGY

The calibration of all instruments before to the test is necessary to assure the accuracy and dependability of all measuring devices and, consequently, the validity of the tests. A 600 kN capacity Universal Testing Machine is used to systematically calibrate load cells used for tower testing. The highest anticipated load to be imposed during tower testing is the limit at which load cells are calibrated. The tower construction is appropriately rigged to allow for the most representative application of the external loads and to imitate tower design conditions. When creating a rigging arrangement, the impact of any variation in the inclination of the rigging wires with respect to the directions taken into account in the design is taken into account. As shown in Fig. 1, the calibrated load cells are secured to the cross arm using rigging wires that are as near the test tower as possible to prevent frictional losses from having an impact on the load cells during testing. For applying loads at various places of the tower construction, the electrically operated winches are connected to the control panel and are controlled by a remote from a centralized control room.

Fig.1. Rigging arrangement of composite tower test bed

Fig.2 Calibrated load cells attached to the on the tower composite cross arm

During the testing, weights are imparted to the cross arm of the tower using a pulley block system and flexible steel ropes, with electrical winches controlling the tension.

Tower Testing Procedure

To demonstrate that all the bolts and nuts are properly tightened, the prototype composite tower is carefully inspected. The tower is constructed to be square and plumb. Each member is examined for the presence of any obvious flaws. On the transverse and longitudinal face, four graduated metallic scales are fixed at the levels of the cross-arm’s peak, top, middle, and bottom. An optical theodolite is used to measure these scales in relation to the plumb line. The precision of the tower deflection measurements is 5 mm. Table 3 shows the deflections at the cross-arm levels in the longitudinal and transverse directions at various stages of loading for all test circumstances.

Bolt Slip test

The play between the bolts and the holes must be reduced as much as feasible across the entire construction. Bolt take-up testing is done first. All vertical and transverse loads are simultaneously increased throughout this test to a maximum of 50% of the reliability condition loads. For a minute, the loads on the tower are held. Readings of deflection are taken under both loaded and unloaded situations. After then, the loads on the tower are cut down to zero or as close to zero as possible. For this zero loading, the deflection measurement is once more taken. The permanent deflection on the composite tower distinguishes the two zero loading systems. The results obtained during the bolt slip test that have zero loads are taken into consideration as the initial readings for further tests.

Tests under Security Conditions

All transverse and vertical loads are first increased to approximately 100% in this situation (all conditions involving longitudinal stresses in addition to transverse and vertical loads). Then, longitudinal loads are raised by 50%, 75%, 90%, and 95% of the final loads, respectively. It is made sure that the transverse and vertical loads at all stages of loading are equal to or greater than the values for the corresponding step of the longitudinal load. The loads are maintained for a minute at each stage, and the deflections are recorded. Then, all loads are raised to 100%. At this last step of 100% loading, the tower is watched for two minutes while deflections are recorded. Following each test, the loads are reduced, and deflection measurements are made under no load conditions, which are listed in Table 3.

Tests under Reliability Conditions

At all sites, the transverse and vertical loads are applied as simultaneously as feasible in stages of 50%, 75%, 90%, and 95%. Every phase maintains a two-minute waiting period, while the final 100% loading observes a five-minute waiting period. The tower is continuously monitored for any obvious indication of failure or deformation throughout the process of loading under all tests. For each level of loading, the deflections are measured; their values are listed in Table 2.

Table 1. Tower deflection under security condition.

	Deflection in mm			
Load %	Peak	Top cross arm	Middle cross arm	Bottom cross arm
Initial reading	0	0	0	0
50	30	30	20	20
75	95	65	60	60
90	160	110	90	80
95	180	130	110	100
100	210	150	130	120

Table 2. Tower deflection under reliability condition.

	Deflection in mm			
Load %	Peak	Top cross arm	Middle cross arm	Bottom cross arm
Initial reading	0	0	0	0
50	20	130	100	80
75	50	130	100	80
90	80	135	105	85
95	160	140	110	90
100	170	140	110	90

Strain Measurements

Three rosette strain gauges (16 Nos. with 48 channels) are installed on the crucial members of the composite tower as shown in Figure 3 in order to analyses the structural performance of the composite tower under mechanical stress.

The 64 channel MCE 1000 DAQ system is linked to the lead wires of the strain gauges, and Lab View software is used for data gathering with a sampling rate of 300 samples per second. Before the tower was ever loaded, the strain gauges indicated zero. Prior to the actual test, the load cycle test is performed with 25% of the design loads. Till the entire loading is achieved under each loading condition, the loads are applied incrementally through the load cell. Through a DAQ system, the strain fluctuations in relation to changes in load magnitude are continuously monitored.

Fig. 3 (a) Three rosette strain gauges mounted on the leg member;(b) On the cross-arm members

4. DATA ANALYSIS

Without any obvious signs of failure, the composite tower successfully resisted the recommended design loads as per IS: 802. The maximum deflection at the apex of the tower is 210 mm under security conditions and 170 mm under reliability conditions, according to Figs. 4 and 5. One of the leg components developed a crack near the top of the cross arm when the stress was increased to 31.885 kN (3 times the design loads), suggesting the first obvious signs of failure.

When composite towers are utilized in place of steel towers, the Right of Way (ROW) required for a typical 66 kV tower is effectively reduced by around 17%. Additionally, the weight of composite towers is reduced to 10500 N as opposed to 24000 N for steel towers. As demonstrated in Fig. 6, the height of the composite tower was lowered by roughly 16% when compared to steel towers.

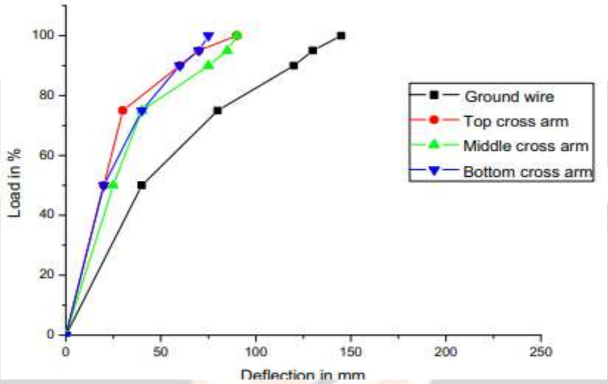

Fig.4 Load Vs. Deflection (Reliability condition)

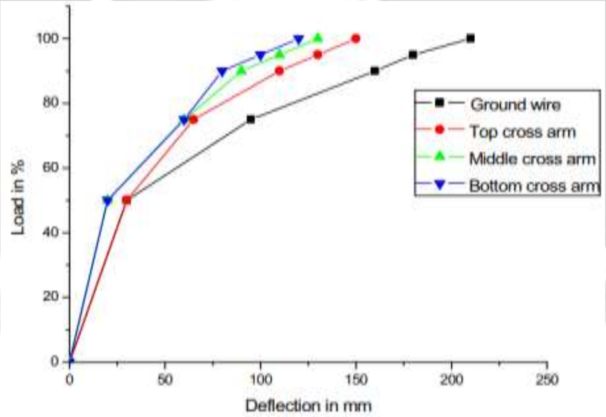

Fig.5 Load Vs. Deflection (Security condition)

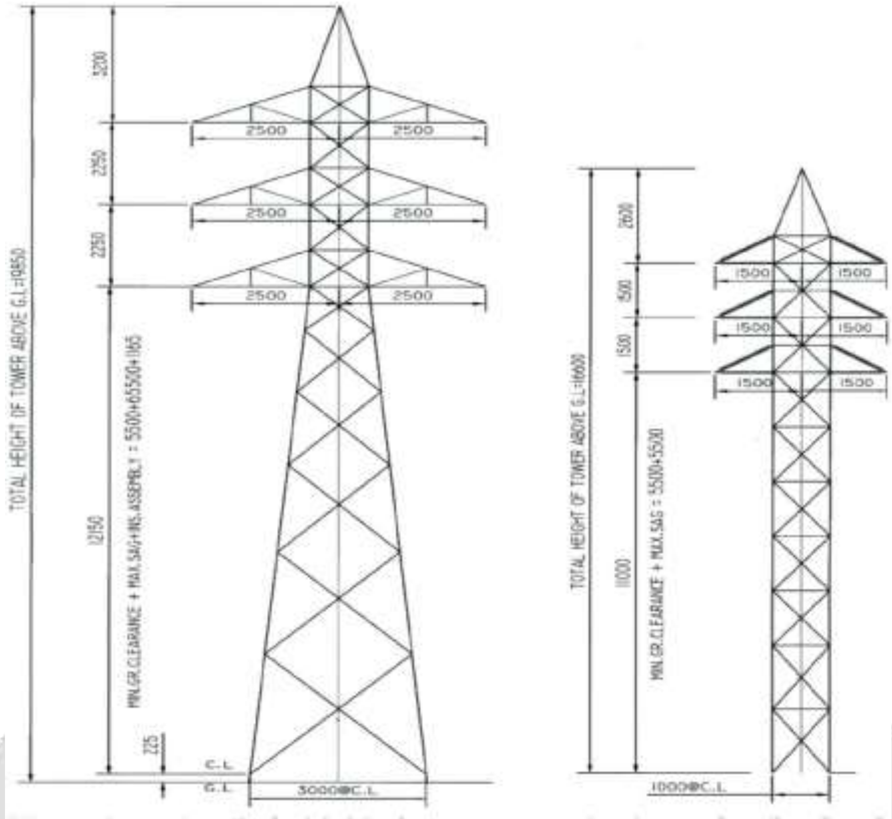

Fig.6 (a) Conventional steel tower; (b) Proposed tower with composite members

5. CALCULATION OF POWER TRANSMISSION LINE

The distance between level supports on the high voltage overhead transmission line varies. The strongest air pressure in Myanmar's central areas is 66 kg/m2, and the temperature at that time is 28 °C.

The Thaton-Mawlamyine power transmission line provided the data below, which were used to create a shunt capacitor bank for power factor adjustment. A bank of shunt capacitors of the proper size is fitted in this design calculation. Current load is 150 MW at kW.

Present kVA1 = 166.67MVA

Present kVAR1= 72.649MVAR

Present Power Factor = 0.9

Desired Power Factor = 0.95

Voltage = 230kV

If power factor is raised to 95%,

Desired kVA Demand,

kVA2 = Present load/ Desired power factor = 150/0.95 = 157.895MVA

The KVAR at the two power factor values is used to calculate the size of the capacitor needed to achieve this.

$kVAR = \sqrt{(kVA^2 - kW^2)}$

At 90% power factor,

$\text{kVAR1} = \sqrt{(\text{kVA1}^2 - \text{kW}^2)} = \sqrt{(166.67^2 - 150^2)}$

$= 72.649\text{MVAR}$

At 95% power factor, $\text{kVAR2} = \sqrt{(\text{kVA2}^2 - \text{kW}^2)}$

$= \sqrt{(157.895^2 - 150^2)} = 49.303\text{MVAR}$

Capacitor rating = kVAR1(Uncorrected) − kVAR2(Corrected)

$= 72.649\text{MVAR} - 49.303\text{MVAR}$

$= 23.346\text{MVAR}$

Table 3 Results of Sag, Tension and Ground Clearance (GC) for Transmission Line

Types of Conductor (ACSR)	Tower Height (m)	Span (m)	Tension (kg)	Sag (m)	GC (m)
346.4mm^2 (DUCK)	20	344	2209	7.8	9.75
	58	678.35	2104	31.71	23.84
	58	643	2109	28.43	27.12
374.7mm2 (GROSBEAK)	20	344	2237	8.6	8.95
	58	678.35	2186	34.18	21.37
	58	643	2188	30.68	24.87

Table 4 Results of Voltage Regulation and Transmission Line Efficiency for 0.9 Power Factor

Type of Conductor (ACSR)	Current (A)	V drop (kV)	Diameter (mm)	V.R (%)	Line ~ (%)
346.4 2	418.37	18.366	24.21	13.8	95.18
374.7 2	418.37	17.927	25.15	13.45	95.44

Table 5 Result of Transmission Line Performance for After Power Factor Correction

Types of conductor (ACSR)	power factor					
	0.9 (Lagging)			0.95 (Lagging)		
	V drop (kV)	V.R (%)	Line i (%)	V drop (kV)	V.R (%)	Line ~ (%)
346.4 mm2	18.37	13.8	95.18	14.36	10.8	95.57
374.7 mm2	17.93	13.5	95.44	13.96	10.5	95.81

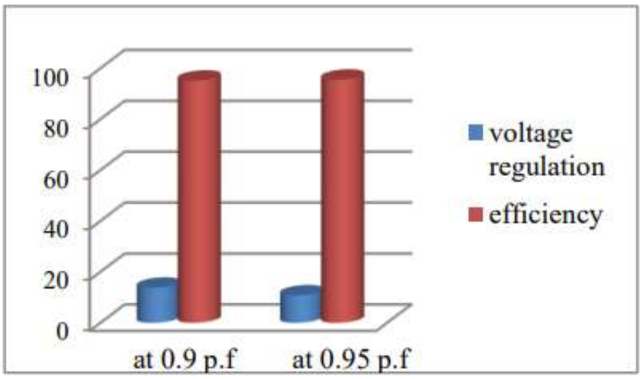

Figure 7. Results from 346.4mm^{2}ACSR(DUCK) Conductor

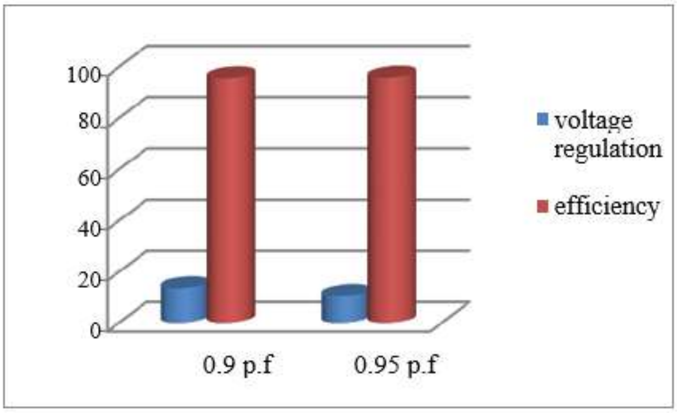

Figure 8. Results from 374.7mm2ACSR(GROSBEAK) Conductor

6. CONCLUSIONS

The coordination of protection and insulation measures in power systems is largely dependent on analyses of lightning strikes to transmission towers. India has a sizable population spread out over the nation, which necessitates a sizable transmission and distribution system to meet the country's need for power. In this study, the voltage regulation and transmission efficiency are computed for the transmission line's line conductor and tower. Depending on the installation area, overhead transmission lines need that maximum clearances be respected to preserve safety. This study examines the viability of suppressing the dynamic responses of a transmission tower-line system under wind excitations using passive friction dampers. For applying loads at various places of the tower construction, the electrically operated winches are connected to the control panel and are controlled by a remote from a centralized control room.

7. REFERENCES

1. Balaji patil et.al (2020) design and analysis of transmission line tower usingstaad-pro e-issn: 2395-0056 p-issn: 2395-0072
2. Juliana maciel maia be¸ca et.al (2019) a performance analysis of uprating techniques on a 230 kv overhead transmission lines
3. Aye aye maw (2019) performance analysis of overhead transmission line design issn: -2319–7560
4. R. J. Araújo et.al (2017) performance of transmission line tower models used for electromagnetic transient studies: comparisons with experimental results
5. Ali, s.s.s.; razman, m.r.; awang, a.; asyraf, m.r.m.; ishak, m.r.; ilyas, r.a.; lawrence, r.j. Critical determinants of household electricity consumption in a rapidly growing city. *Sustainability* 2021, *13*, 4441.
6. Asyraf, m.r.m.; ishak, m.r.; sapuan, s.m.; yidris, n.; ilyas, r.a.; rafidah, m.; razman, m.r. Evaluation of design and simulation of creep test rig for full-scale cross arm structure. *Adv. Civ. Eng.* 2020, *2020*, 6980918.

7. Zhu, j.j.; schoenoff, m.s. Effects of natural sunlight on fiberglass reinforced polymers for crossarms. In proceedings of the ieee rural electric power conference (repc), memphis, tn, usa, 6–9 may 2018; volume 2018-may, pp. 101–105
8. Selvaraj, m.; kulkarni, s.; babu, r.r. Analysis and experimental testing of a built-up composite cross arm in a transmission line tower for mechanical performance. *Compos. Struct.* 2013, *96*, 1–7.
9. Yang, x.; li, n.; peng, z.; liao, j.; wang, q. Potential distribution computation and structure optimization for composite cross-arms in 750 kv ac transmission line. *Ieee trans. Dielectr. Electr. Insul.* 2014, *21*, 1660–1669.
10. Rawi, i.m.; ab kadir, m.z.a. Investigation on the 132kv overhead lines lightning-related flashovers in malaysia. In proceedings of the international symposium on lightning protection, xiii sipda, balneario camboriu, brazil, 28 september–2 october 2015; pp. 239–243.
11. Asyraf, m.r.m.; ishak, m.r.; sapuan, s.m.; yidris, n.; shahroze, r.m.; johari, a.n.; rafidah, m.; ilyas, r.a. Creep test rig for cantilever beam: fundamentals, prospects and present views. *J. Mech. Eng. Sci.* 2020, *14*, 6869–6887.
12. Asyraf, m.r.m.; ishak, m.r.; razman, m.r.; chandrasekar, m. Fundamentals of creep, testing methods and development of test rig for the full-scale crossarm: a review. *J. Teknol.* 2019, *81*, 155–164.
13. Rawi, i.m.; rahman, m.s.a.; ab kadir, m.z.a.; izadi, m. Wood and fiberglass crossarm performance against lightning strikes on transmission towers. In proceedings of the international conference on power systems transient (ipst), seoul, korea, 26–29 june 2017; pp. 1–6.