ANALYSIS AND DESIGN OF 110KV/220KV MCMV KLB TYPE TRANSMISSION TOWER.

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ABSTRACT

Transmission towers are critical components in the development of power transmission infrastructure, accounting for approximately 45% to 60% of the total construction cost of transmission lines. Therefore, optimizing tower design is essential for achieving cost efficiency while maintaining safety and reliability in accordance with CBIP Manual 323. This study focuses on the structural design and analysis of a transmission tower intended for the upgradation of an existing 110 kV double-circuit line to a multi-circuit 110 kV/220 kV configuration within the same Right of Way (ROW), addressing the growing energy demands of Kerala without requiring additional land—a key advantage in densely populated areas. Various tower base configurations—wide, narrow, and semi-narrow—were considered based on site-specific constraints. The design process accounted for all critical load components including self-weight, conductor and accessory weights, tension effects, and environmental influences, in compliance with IS 802 Part 1 (2015). A detailed structural model of the tower was developed using STAAD.Pro software, with preliminary member sections assigned and subjected to calculated loads under different design scenarios. The final tower configuration was derived based on structural safety and performance, and a general arrangement drawing was prepared. The proposed tower design enables Kerala State Electricity Board Ltd. (KSEBL) to enhance its transmission capacity from 140 MW to 740 MW per line segment, contributing toward the state's strategic goal of increasing overall transmission capacity from 6000 MW to 10,000 MW by 2030. This approach ensures cost-effective infrastructure development without the need for additional land acquisition, offering a scalable solution for future transmission upgrades in urban and constrained environments.

Key words: Multi-Circuit Tower, Right of Way (ROW), STAAD. Pro Analysis, Transmission, CBIP manual

INTRODUCTION

The rapid growth in electricity demand, driven by increased urbanization, industrialization, and the adoption of electric vehicles, has placed immense pressure on existing power transmission networks. In densely populated regions like Kerala, India, where acquiring additional land is both costly and challenging, there is a critical need for innovative solutions that enhance transmission capacity within existing Right of Way (ROW) constraints. One such solution is the upgradation of existing transmission lines using multi-circuit transmission towers capable of supporting higher voltage levels without expanding the physical footprint of the infrastructure. Transmission towers are among the most capital-intensive components of a power transmission line, contributing approximately 45% to 60% of the total project cost. Therefore, optimizing their structural design can lead to significant cost savings while improving operational efficiency and reliability. At the same time, tower designs must comply with national standards such as IS 802 (Part 1):2015 and guidelines outlined in the CBIP Manual 323 to ensure structural safety under various loading conditions, including wind, seismic, and environmental loads.

This study investigates the manual and software-assisted modeling, analysis, and design of a 220 kV multi-circuit transmission tower intended for the upgradation of existing 110 kV lines. Using STAAD. Pro for simulation and design validation, the study explores different tower base configurations, structural member selections, and load conditions as per Indian standards. The resulting tower design supports a significant increase in transmission capacity—from 140 MW to 740 MW per line—without requiring additional land acquisition. This makes it a practical and sustainable solution for power utilities like the Kerala State Electricity Board Ltd. (KSEBL), which aims to increase the state's total transmission capacity to 10,000 MW by 2030.

OBJECTIVES

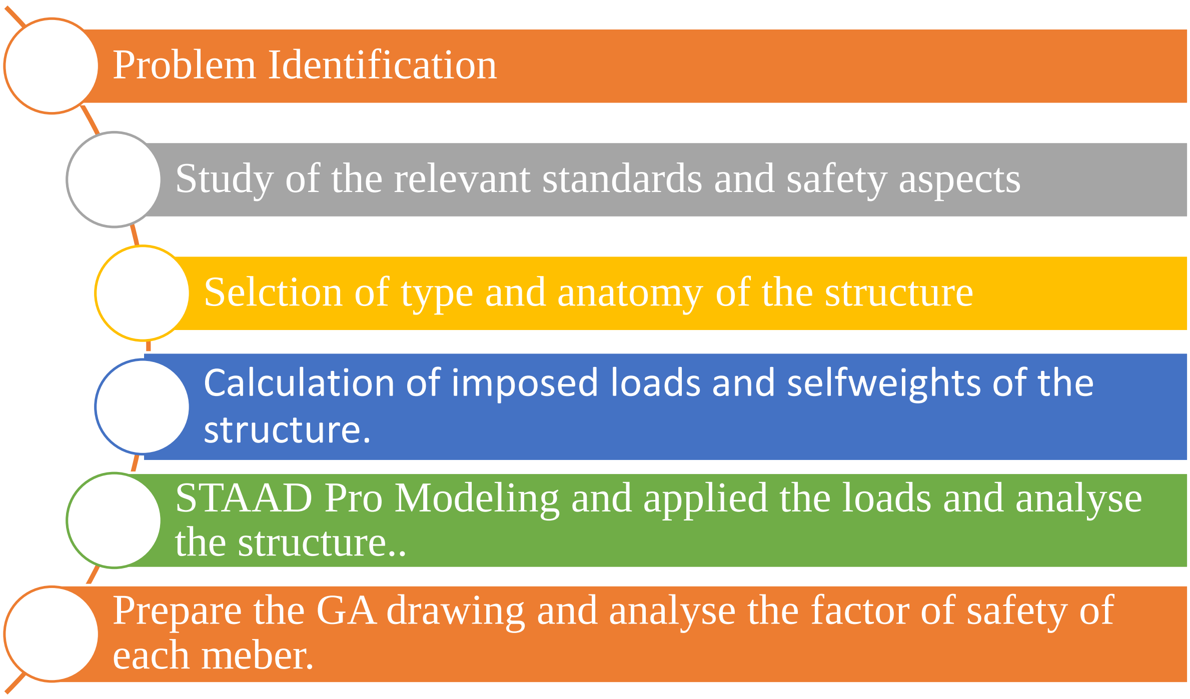
To understand the design standards and safety requirements applicable to transmission tower design.

To explore optimization techniques and determine the appropriate type of tower based on functional and structural considerations.

To analyze various loads acting on transmission towers, including imposed loads, wind loads on conductors and tower bodies, tension forces, and load combinations as per IS 802 (Part 1): 2015.

To study the selection of tower members using STAAD Pro software and evaluate the factor of safety for each member through structural analysis.

METHODOLOGY



LOAD ANALYSIS

The following calculations are required as per IS 802 before the load calculations.

1. **Tower height calculation for 110kV/220kV MCMV KLB type transmission tower;**

   Ground Clearance (m)+ Max Sag of conductor (m) + Sag Error (m) (IS 802 part 1-2015) + Height of Max Extension (m)+ Vertical Separation of Conductor (m) for each phase R, Y, B+ Height of Top Conductor Attachment (m) + Height of EarthWire from Top Conductor (m) - (Ground Clearance - Min Sag Difference) + Height of EarthWire or Insulator Attachment

   Reductions: -
   Min Sag at 10 deg, No Wind, 2/3rd of Min Sag

   6.1m+7.63m+0.15+2x3.2m (110kV phase to phase clearance) +7.5m (inter circuit clearance 110kV nad 220kV)+2x5.5 (220kV phase to phase clearance) +7.8m (Height of earth wire from top 220kV circuit =55.58 m
   Reduction 3.1m (min sag) , 2/3x2.4=1.6m.
   Height of the tower =55.58-1.6 m =53.98m.
2. **Tower base width** shall be fixed as per the client requirement based on the site constraints which is to be installed.
   The 110kV/220kV MCMV KLB type transmission tower shall be proposed to semi narrow based type 10m x10m as the fixed base width.
3. **Calculation of loads over the transmission tower as per IS 802 part 1-2015.**
   As per the code various load combinations Reliability requirement, security requirement, safety requirement, cascading requirement.
   Reliability requirement.
   The reliability of a transmission tower refers to its ability to consistently perform its intended function throughout its design life without structural failure. According to IS 802 (Part 1):2015, the reliability load cases must consider the prevailing climatic conditions, including everyday temperature and 100% wind intensity. Wind loads should be evaluated in oblique directions at angles of 0°, 30°, and 45° to account for the most critical load scenarios.
   The following wind data are considered.
   Basic wind speed for Zone 2 as per IS 802 part 1-2015 for Kerala = 39m/s
   Risk coefficient k1 (IS 802 part 1-2015) = 1.1
   Risk coefficient k2 (IS 802 part 1-2015) = 1
   Design wind pressure Pd (IS 802 part 1-2015) = 59.56Kg/m2
   Wind pressure on conductor = PdxCdcxGc
   Where: Pd= Design wind pressure
   Cdc= Drag coefficient
   Gc= Gust response factor
   Wind pressure on insulator = PdxCdixGc

   As per IS 802 part1-2015, The drag coefficient for tower is 1 and insulator is 1.2.

Gust response factor depend on the height of the conductor/insulator and available in the table IS 802part1-2015.

Reliability condition under 0° wind obligation is calculated and given below. Annexure 1.

Security Requirement.

Focuses on the ability of the tower to withstand extreme, rare, or unexpected events (e.g., natural disasters, sabotage) without catastrophic failure.

Withstanding extraordinary loads like cyclonic winds, earthquakes, or explosions. Preventing systemic failures in extreme scenarios.

The sample calculation is attached as per IS 802 part 1-2015 is attached Annexure-2.

Safety requirement

Pertains to the protection of people, property, and the environment from harm associated with the tower's operation or failure.

Safe clearance from the ground, buildings, and vegetation. Stability against collapse to avoid endangering life or infrastructure. Use of corrosion-resistant materials to prevent hazardous failures.

The sample calculation is attached as per IS 802 part 1-2015 is attached Annexure-3.

Cascading requirement.

Focuses on preventing a single failure in the tower or line from triggering a series of failures (cascading events) in the transmission network.

Incorporating redundancy in design to prevent chain failures. Ensuring system stability and controlled fault isolation. Avoiding systemic power outages due to localized issues

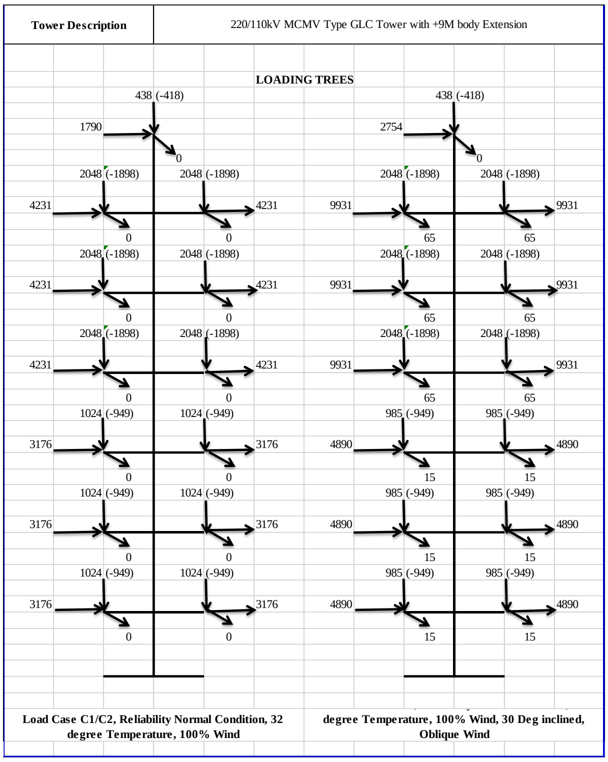
The sample calculation is attached as per IS 802 part 1-2015 is attached Annexure-4.

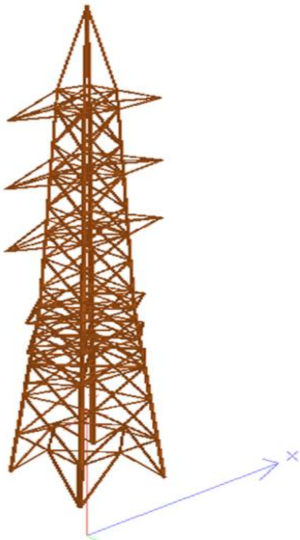
Load tree and STAAD Pro

The load combinations were calculated as per the relevant standards, and separate load trees were prepared for each case. A STAAD Pro model was developed using tentative angle sections, and the calculated loads from the load trees were applied at the respective load points. The structure was analyzed under each load case in STAAD Pro. In the post-processing stage, the displacement of each node was verified against the allowable limits. If any displacement exceeded the permissible value, the corresponding angle section was revised to a higher size, and the analysis was repeated until all nodal displacements were within acceptable limits.

Once the structure satisfied the displacement criteria, the STAAD output was reviewed to examine the internal forces in each member. The capacity of each member was calculated, and the factor of safety (FOS) was checked. If the FOS exceeded the minimum required value, the section was optimized by replacing it with a lower configuration to ensure efficient use of material. Sample load trees and STAAD outputs are provided in the annexures.

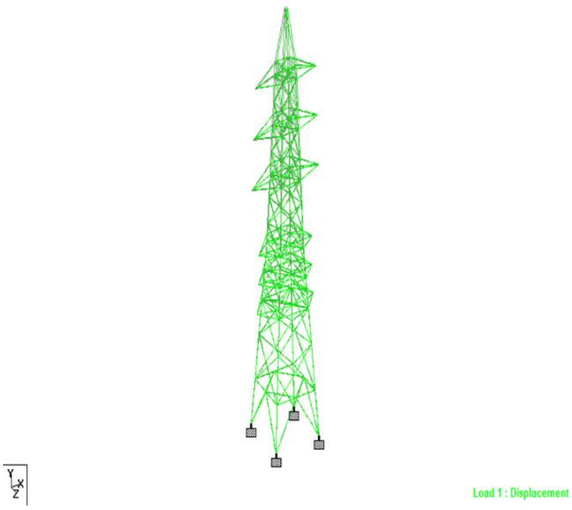
The load tree are drawn from the result obtained through Staad pro and are given below

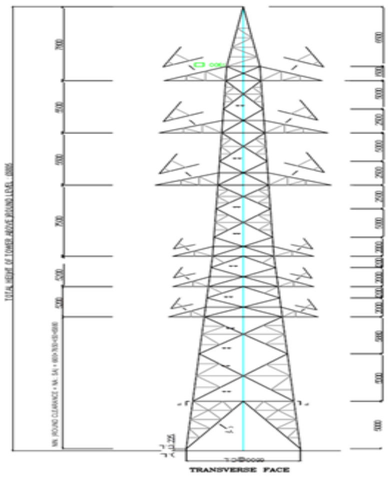




Tree Model

STAAD Pro 3D Model





Displacement pattern after analysis.

Tower design after load calculation

Annexure-1

Tower Description	220/110kV MCMV Type KLB Tower with +9M body Extension									
LOAD CALCULATIONS										
For Earthwire		**GSW 7/3.15 HTGS**			**For Conductor**	**CKT 1**	**CKT 2**	**For Insulator**	**CKT 1**	**CKT 2**
						Panther ACS	**ACSR Panthe**			
Number Ne		1			Number Nc	1	2	Number Ni	1	2
Diameter De (m)		0.00945			Diameter Dc (m)	0.021	0.021	Diameter Di (m)	0.255	0.255
Weight We (kg/m)		0.428			Weight Wc (kg/m)	0.974	0.974	Weight Wi (kg)	50	50
Tension Te (kg)		2506.74			Tension Tc (kg)	4414.23	4414.23	Length Li (m)	1.53	2.915
Spans	**CKT 1**		**CKT 2**		**Wind Pressure (kg/m^2)**	**CKT 1**	**CKT 2**	**Line Deviation**		
	NC	**BWC**	**NC**	**BWC**	EarthWire Pe	165.82	165.82	Angle Min	ϕ1	0
Normal Span Sn (m)	335				Conductor Pc	130.97	138.42	Angle Max	ϕ2	14
Wind Span Swn (m)	752	201	335	201	Insulator Pi	156.74	175.96	Wind	Sin^2 Ω1	0.9832
Max Wt Span Swt1(m)	1000	1000	1000	600	Angle of Wind Incidence (degree)			Direction	Sin^2 Ω2	0.9828
Min Wt Span Sw2(m)	-1000	-576	-1000	-600	θ	0		Factors	Sin^2 Ω3	1.000
Reliability Requirement								**Normal Condition**		
Wind Direction						0		**All Intact Wires**		
Everyday Temperature (32 degree)						100%	Wind			

For Earthwire		**GSW 7/3.15 HTGS**			
Transverse Loads		**CKT 1**		**CKT 2**	
Wind Load on Earthwire	Ne*De*Swn*Pe*Sin^2 Ω	1179		525	
Load Due to Deviation	2*Ne*Te*sin ϕ2/2	611		611	
	Total	**1790**		**1136**	
Vertical Loads		**Max**	**Min**	**Max**	**Min**
Weight of Earthwire	Ne*We*Swt	428	-428	428	-428
Weight of Hardware		10	10	10	10
	Total	**438**	**-418**	**438**	**-418**
Longitudinal Loads		**0**	**0**	**0**	**0**
For Conductor		**Panther ACSR**		**ACSR Panther**	
Transverse Loads		**CKT 1**		**CKT 2**	
Wind Load on Conductor	Nc*Dc*Swn*Pc*Sin^2 Ω	2069		1948	
Wind Load on Tension Insulator	0.5*Ni*Li*Di*Pi*Cos θ	31		131	
Load Due to Deviation	2*Nc*Tc*sin ϕ2/2	1076		2152	
	Total	**3176**		**4231**	
Vertical Loads		**Max**	**Min**	**Max**	**Min**
Weight of Conductor	Nc*Wc*Swt	974	-974	1948	-1948
Weight of Tension Insulator & Hardware	Ni*Wi	50	25	100	50
	Total	**1024**	**-949**	**2048**	**-1898**
Longitudinal Loads					
Wind Load on Tension Insulator	0.5*Ni*Li*Di*Pi*Sin θ	0		0	
	Total	**0**		**0**	

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Annexure-2

Tower Description	220/110kV MCMV Type KLB Tower with +9M body Extension

LOAD CALCULATIONS

For Earthwire		**GSW 7/3.15 HTGS**		
Number Ne		1		
Diameter De (m)		0.00945		
Weight We (kg/m)		0.428		
Tension Te (kg)		2126.74		
Spans	**CKT 1**		**CKT 2**	
	NC	**BWC**	**NC**	**BWC**
Normal Span Sn (m)	335			
Wind Span Swn (m)	335	201	335	201
Max Wt Span Swt1(m)	960	576	1000	600
Min Wt Span Sw2(m)	-1000	-576	-1000	-600

For Conductor	**CKT 1**	**CKT 2**
	Panther ACS	**ACSR Panther**
Number Nc	1	2
Diameter Dc (m)	0.021	0.021
Weight Wc (kg/m)	0.974	0.974
Tension Tc (kg)	3782.2	3782.2
Wind Pressure (kg/m ^2)	**CKT 1**	**CKT 2**
EarthWire Pe	124.37	124.37
Conductor Pc	98.2275	103.815
Insulator Pi	117.555	131.97
Angle of Wind Incidence (degree)		
ɵ	0	

For Insulator	**CKT 1**	**CKT 2**
Number Ni	1	2
Diameter Di (m)	0.255	0.255
Weight Wi (kg)	50	50
Length Li (m)	1.53	2.915
Line Deviation		
Angle Min	ɸ1	0
Angle Max	ɸ2	15
Wind	Sin^2 Ω1	0.9832
Direction	Sin^2 Ω2	0.9828
Factors	Sin^2 Ω3	1.0000

Security Requirement	
Wind Direction	0
Every day Temperature (32 degree)	75% Wind

Broken Wire Condition

For Earthwire		**GSW 7/3.15 HTGS**							
Transverse Loads		**CKT 1**				**CKT 2**			
		Intact		**Broken**		**Intact**		**Broken**	
Wind Load on Earthwire	Ne*De*Swn*Pe*Sin^2 Ω	394		236		394			236
Load Due to Deviation	2*Ne*Te*sin ɸ2/2 (NC) & NC/2 for BWC	555		277.5		555			277.5
	Total	**949**		**513.5**		**949**			**513.5**
Vertical Loads		**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
Weight of Earthwire	Ne*We*Swt	411	-428	247	-247	428	-428	257	-257
Weight of Hardware		10	10	10	10	10	10	10	10
Total		**421**	**-418**	**257**	**-237**	**438**	**-418**	**267**	**-247**
Longitudinal Loadds	Ne*Te*Cos ɸ1/2	**0**		**2127**		**0**		**2127**	

For Conductor			**Panther ACSR**				**ACSR Panther**			
Transverse Loads			**CKT 1**				**CKT 2**			
			Intact		**Broken**		**Intact**		**Broken**	
Wind Load on Conductor		Nc*Dc*Swn*Pc*Sin^2 Ω	691		415		1461		876	
Wind Load on Tension Insulator		0.5*Ni*Li*Di*Pi*Cos ɵ	23		11.5		98		49	
Load Due to Deviation		2*Nc*Tc*sin ɸ2/2 & NC/2 for BWC	987		493.5		1975		987.5	
		Total	**1701**		**920**		**3534**		**1912.5**	
			Intact		**Broken**		**Intact**		**Broken**	
Vertical Loads			**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
Weight of Conductor		Nc*Wc*Swt	935	-974	561	-561	1948	-1948	1169	-1169
Weight of Tension Insulator & Hardware		Ni*Wi	50	25	25	13	100	50	50	25
		Total	**985**	**-949**	**586**	**-548**	**2048**	**-1898**	**1219**	**-1144**
Longitudinal Loads			**Intact**		**Broken**		**Intact**		**Broken**	
Wind Load on Tension Insulator	NC & BWC	0.5*Ni*Li*Di*Pi*Sin ɵ	0		0		0		0	
Conductor Tension	BWC	Nc*Tc*Cos ɸ1/2	0		3782		0		7564	
		Total	**0**		**3782**		**0**		**7564**	

Annexure-3

Tower Description	220/110kV MCMV Type KLB Tower with +9M body Extension									
LOAD CALCULATIONS										
For Earthwire		**GSW 7/3.15 HTGS**			**For Conductor**	**CKT 1**	**CKT 2**	**For Insulator**	**CKT 1**	**CKT 2**
						Panther ACS	**ACSR Panthe**			
Number Ne		1			Number Nc	1	2	Number Ni	1	2
Diameter De (m)		0.00945			Diameter Dc (m)	0.021	0.021	Diameter Di (m)	0.255	0.255
Weight We (kg/m)		0.428			Weight Wc (kg/m)	0.974	0.974	Weight Wi (kg)	50	50
Tension Te (kg)		1106.43			Tension Tc (kg)	2285.17	2285.17	Length Li (m)	1.53	2.915
Spans	**CKT 1**		**CKT 2**		**Wind Pressure (kg/m^2)**	**CKT 1**	**CKT 2**	**Line Deviation**		
	NC	**BWC**	**NC**	**BWC**	EarthWire Pe	0.00	0.00	Angle Min	ϕ1	0
Normal Span Sn (m)	335				Conductor Pc	0.00	0.00	Angle Max	ϕ2	15
Wind Span Swn (m)	335	201	335	201	Insulator Pi	0.00	0.00			
Max Wt Span Swt1(m)	960	576	1000	600						
Min Wt Span Sw2(m)	-1000	-576	-1000	-600						
Safety Requirement								**Maintenance Condition**		
Wind Direction										
Everyday Temperature (32 degree)						0%	Wind			
For Earthwire							**GSW 7/3.15 HTGS**			
Transverse Loads							**CKT 1**		**CKT 2**	
							NC	**BWC**	**NC**	**BWC**
Wind Load on Earthwire					Ne*De*Swn*Pe		0	0	0	0
Load Due to Deviation					2*Ne*Te*sin ϕ2/2		289	145	289	145
					Total		**289**	**145**	**289**	**145**
Vertical Loads			OLF				**NC**	**BWC**	**NC**	**BWC**
Weight of Earthwire			2		Ne*We*Swt		822	493	856	514
Weight of Hardware			2		5	kg	10	10	10	10
					Total		**832**	**503**	**866**	**524**
Longitudinal Loads										
For Broken Wire			2	*	**Ne*(0.5*Te)*Cos ϕ1/2**		**830**	**1106**	**830**	**1106**
For Intact Wire			1.5	*	**Ne*(0.5*Te)*Cos ϕ1/2**					
For Conductor							**Panther ACSR**		**ACSR Panther**	
Transverse Loads							**CKT 1**		**CKT 2**	
							NC	**BWC**	**NC**	**BWC**
Wind Load on Conductor					Nc*Dc*Swn*Pc		0	0	0	0
Wind Load on Tension Insulator					0.5*Ni*Li*Di*Pi		0	0	0	0
Load Due to Deviation					2*Nc*Tc*sin ϕ2/2		597	299	1193	597
					Total		**597**	**299**	**1193**	**597**
Vertical Loads						OLF	**NC**	**BWC**	**NC**	**BWC**
Weight of Conductor					Nc*Wc*Swt	2	1870	1122	3896	2338
Weight of Tension Insulator & Hardware					Ni*Wi	2	100	50	200	100
Weight of Lineman and Tools					1500	N	153	153	153	153
Additional Load at Crossarm Tips					3500	N	357	357	357	357
					Total		**2480**	**1682**	**4606**	**2948**
Longitudinal Loads										
For Broken Wire			2	*	**Nc*(0.5*Tc)*Cos ϕ1/2**		**NC**	**BWC**	**NC**	**BWC**
For Intact Wire			1.5	*	**Nc*(0.5*Tc)*Cos ϕ1/2**		**1714**	**2285**	**3428**	**4570**

Annexure -4

Tower Description	220/110kV MCMV Type GLC Tower with +9M body Extension									
LOAD CALCULATIONS										
For Earthwire		**GSW 7/3.15 HTGS**			**For Conductor**	**CKT 1**	**CKT 2**	**For Insulator**	**CKT 1**	**CKT 2**
						Panther ACSR	**ACSR Panthe**			
Number Ne		1			Number Nc	1	2	Number Ni	1	2
Diameter De (m)		0.00945			Diameter Dc (m)	0.021	0.021	Diameter Di (m)	0.255	0.255
Weight We (kg/m)		0.428			Weight Wc (kg/m)	0.974	0.974	Weight Wi (kg)	50	50
Tension Te (kg)		1106.43			Tension Tc (kg)	2285.17	2285.17	Length Li (m)	1.53	2.915
Spans	**CKT 1**		**CKT 2**		**Wind Pressure (kg/m^2)**	**CKT 1**	**CKT 2**	**Line Deviation**		
	NC	**BWC**	**NC**	**BWC**	EarthWire Pe	0.00	0.00	Angle Min	ϕ1	0
Normal Span Sn (m)	335				Conductor Pc	0.00	0.00	Angle Max	ϕ2	15
Wind Span Swn (m)	335	201	335	201	Insulator Pi	0.00	0.00			
Max Wt Span Swt1(m)	960	576	1000	600						
Min Wt Span Sw2(m)	-1000	-576	-1000	-600						
Anticascading Condition								**Maintenance Condition**		
Wind Direction										
Everyday Temperature (32 degree)						0%	Wind			
For Earthwire							**GSW 7/3.15 HTGS**			
Transverse Loads							**CKT 1**		**CKT 2**	
							BWC		**BWC**	
Wind Load on Earthwire					Ne*De*Swn*Pe		0		0	
Load Due to Deviation					1*Ne*Te*sin ϕ2/2		144		144	
					Total		**144**		**144**	
Vertical Loads							**BWC**		**BWC**	
Weight of Earthwire			1		Ne*We*Swt		411		428	
Weight of Hardware			1		10	kg	10		10	
					Total		**421**		**438**	
Longitudinal Loads										
For Broken Wire			1	*	**Ne*(Te)*Cos ϕ1/2**		**1106**		**1106**	
For Conductor							**Panther ACSR**		**ACSR Panther**	
Transverse Loads							**CKT 1**		**CKT 2**	
							BWC		**BWC**	
Wind Load on Conductor					Nc*Dc*Swn*Pc		0		0	
Wind Load on Tension Insulator					0.5*Ni*Li*Di*Pi		0		0	
Load Due to Deviation					1*Nc*Tc*sin ϕ2/2		298		597	
					Total		**298**		**597**	
Vertical Loads							**BWC**		**BWC**	
Weight of Conductor					Nc*Wc*Swt	1	935		1948	
Weight of Tension Insulator & Hardware					Ni*Wi	1	50		100	
					Total		**985**		**2048**	
Longitudinal Loads										
For Broken Wire			1	*	**Nc*(Tc)*Cos ϕ1/2**		**BWC**		**BWC**	
							2285		**4570**	

Conclusions

The transmission tower is a critical component of power infrastructure, supporting extra high-tension conductors to transmit electricity reliably under varying climatic conditions and complex loading scenarios. In transmission projects, towers typically account for 45% to 60% of the total project cost, making optimized tower design essential for cost-effective implementation. Each transmission tower is uniquely designed based on several factors, including conductor configuration, base width, voltage level, terrain, wind zone, reliability requirements, span length, and deviation angles. The 110 kV/220 kV MCMV transmission tower presented in this study is specifically designed to upgrade the existing 110 kV double circuit line without requiring additional right-of-way (ROW). This innovative solution enables an increase in transmission capacity from 140 MW to 740 MW using the same corridor.

In a densely populated state like Kerala, where land acquisition for new transmission corridors is highly challenging, this design offers a practical and scalable solution. It addresses the growing electricity demand driven by the proliferation of electric vehicles, increased use of air conditioning, and modern household appliances. This tower serves as a key enabler in achieving the state's goal of enhancing transmission capacity from 6,000 MW to 10,000 MW by 2030, making it a significant step toward sustainable and future-ready power infrastructure.

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