Comparative Study of Downburst Loading Against Normal Wind Loading on Transmission Tower

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Abstract – *Transmission towers and lines are the components mainly responsible for the power supply to normal households. But these are very vulnerable to the localized High-Intensity Wind (HIW) events like "Downburst". If any of the towers are caught by this HIW event then it may lead to cascade failure of the whole transmission line and loss of millions of money. The electric industry mainly facing this problem around the globe. When this event takes place, its critical parameters play an important role to consider the heavy loading on the towers. The characteristics of the downburst events are Jet Diameter (D_j), Jet Velocity (V_j), Polar coordinates (r, θ) of the events concerning the tower center. This paper mainly focuses on the comparison of loading due to downburst events and the normal wind loading as per the IS code recommendations on the transmission tower. This work has been done on a 30m tall self-supporting tower which is considered to be located in the wind zone-V, with a basic wind speed of 50 m/s.*

Key Words: **Transmission Tower, Downburst event, High-Intensity Wind (HIT), Conductors, Wind Load, Self-Supporting Tower**

1. INTRODUCTION

In the late '70s, the great researcher T. T. Fujita had come across some strange pattern of destruction after the heavy wind in his aerial survey over the crop field. He was also investigating the reasons behind the aircraft accidents during the take-off and landing and discovered an event, later which had been termed as Downburst Event. A downburst event can be explained as "A strong sinking current of the thunderstorm which generates an outward propagation of damaging winds on or near the ground" [1].

After this discovery, many researchers try to identify and simulate the behavior of downburst events as these events have a higher probability to cause the failure of transmission lines. Fujita had performed the following observation projects to understand downburst events:

1. Northern Illinois Meteorological Research on Downbursts (NIMROD), 1978
2. Joint Airport Weather Studies (JAWS), 1982
3. Microburst And Severe Thunderstorm (MIST), 1986.

The Downburst has been classified based on its horizontal extend as "Microburst and Macroburst". If the damaging horizontal extent of the downburst is greater than 4 km with the possible approx. speed of 60 m/s, then it classifies as Macroburst. Otherwise, if its horizontal extent is less than or equal to 4 km with the possible approx. speed of 75 m/s. These may exert the loading on the many structures such as towers, buildings, etc. The towers are mainly categorized as "Guyed Tower and Self-Supported Tower". In the "Self-Supported Towers" the exerted loads are transferred and resisted by its members only. On the other hand, in guyed towers, the exerted loads are supported by attached Guys which are anchored at the ground.

In September 1996 a downburst was responsible for the failure of the 19-transmission tower, which costs the loss of 10 million USD to Manitoba Hydro Company, Canada. This event excites the investigation and research work in this field. The event was simulated by using the Computational Fluid Dynamics (CFD) models in Fluent 6.0 Commercial software based on an impinging jet theory and the numerical model considered based on Reynolds Averaged Navier-Stokes (RANS) equations, then the results of which compared with laboratory experimental work [2]. Components of the transmission line like conductors, earth wire, insulator, and the tower were modeled by using the Finite Element Modeling. The scaling procedure for the CFD data of jet diameter, velocity, and position of the event concerning the tower center to simplify the loads on the transmission towers. The variation of peak axial forces associated with the normal wind load and downburst was identified to encounter the importance of the event while analysis [3].

The readily available results of CFD data were used to show the time and space dependency of downburst simulation by considering the different characteristics. It had been found that the quasi-periodic vortex rings were formed and this propagates radially. The time and space dependency provide more efficient results than the scale dependency of the simulation [4]. As we have been aware of the characteristics parameters of the events but it becomes absolutely important to identify the critical parameters which influence the loading on the tower systems. A finite element genetic algorithm optimized technique had been developed to identify the critical characteristics parameters of the downburst event, which is also capable of extracting the maximum axial forces in the tower members [5]. For this, many permutations and combinations of D_j, r/ D_j, and θ were required. The radial distance (r) between the downburst center and the tower center was recognized by considering the ratio of r to the D_j. The range of these parameters was considered as below: Jet Diameter: 250 – 2000 m, ratio r/ D_j: 0 – 2.2, and θ: 0^0 – 90^0 and these vary with the interval step of 250 m, 0.2, and 15^0 respectively [6].

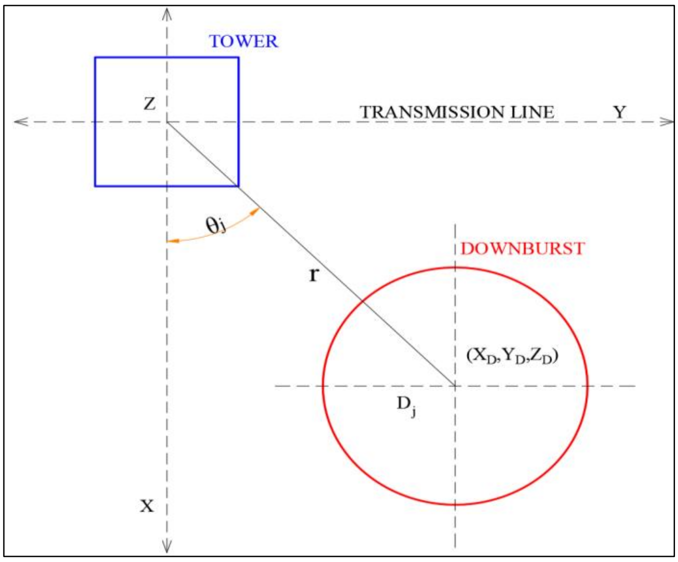

Fig -1: Horizontal projection of transmission line and downburst [3]

From all these analyses and investigation work it has been seen that downburst may lead to generate symmetrical and asymmetrical load cases. If the downburst configuration with projection angle 0^0 or 90^0 then this is a symmetrical loading case. As these may not create any oblique loading neither on the transmission tower nor conductors. If the downburst configuration with the projection angle is in between the above-stated configuration then it may be considered as an asymmetrical load case [7]. To simplify and calculate the downburst loading on transmission tower M. M. Darwish and A. A. El Damatty (2017) suggested three approaches:

1. Constant Reference Velocity at 10-m Height
2. Constant Reference Velocity at Top of the Tower (at Ground Wire Level)
3. Constant Jet Velocity

From the above discussion, it is clear that in any design code there is no provision of considering downburst loading or not having any dedicated procedure for the same. But it becomes essential to consider the downburst loading along with the stipulated design procedure. If the transmission tower is considering on the Indian territory, then it should be obligatory to use the respective IS codes for design and analysis [8-9]. D. B. Sonowal et al. (2015) adopted the method of IS code procedure to analyze and design a 220 kV single circuit transmission tower [10]. In this paper, an attempt was made to compare the performance of the transmission tower by considering conventional IS codal provisions and the approach developed by researchers to simulate downburst loading on the transmission tower.

2. TRANSMISSION TOWER AND PARTS

For this study, a 30 m tall latticed self-supporting tower having the 6m x 6m square base is considered and the same was modeled in the relevant design software. The properties of the transmission tower, transmission line, conductors, and earth-wire

Table -1: Characteristics of Transmission Tower & Line

Parameters	Description
Line Voltage	220 kV (AC)
No. of Circuit	Single Circuit
Tower Geometry	Square-based (6 x 6 m)
Cross Arm	Pointed
Tower Type	Self-Supporting Pratt trussed
Insulator Length	2500 mm
Geographic Parameters	
Return Period	50 Years
Wind Zone	V
Terrain Category	II
Basic Wind Speed	50 m/s

Table -2: Characteristics of Conductors & Earth-wires [9]

Characteristics	Description
Conductors	
Material	Aluminum Conductor Steel Reinforced (ACSR)
Code Name	Panther
Conductor size	30/7/3 mm
Conductor Area	2.6155 cm^2
The overall diameter of the conductor (d)	21 mm
Weight of the conductor (w)	0.973 kg/m
Bearing strength of the conductor (UTS)	9130 kg
Modulus of elasticity Final (E)	0.787 x 10^6 kg/cm^2
Earth-Wires	
Material	Galvanized Steel
Stranding/Wire Size	7/3.15 mm
Total Wire Area	54.55 mm^2
Overall diameter (d)	9.45 mm
Weight of Wire (w)	428 kg/km
Minimum UTS	5710 kg

Modulus of elasticity Final (E)	19361 kg/mm^2

The above-mentioned values were used for further investigation and Evaluation of loading on the transmission tower.

3. MODELING OF THE TOWER AND ITS PARTS

3.1 Transmission Tower

The tower was modeled by using the STADD Pro. Vi8 software and then checked for the designed members. Again the same model was developed with the transmission line in the SAP 2000 v21 software and the steel sections were considered for the main leg ISA 200 x 200 x 25, horizontal bracings 130 x 130 x 10, diagonal bracings ISA 110 x 110 x 8, cross arm bracings ISA 90 x 90 x 12 following Indian Standards. Single angle back-to-back configurations were used for all the considered sections.

The height of the tower body was assumed as 15.3 m, cage height 12.25 m, the peak portion 2.45 m, and the cross-arm width considered as 3.31 m with a pointed configuration at the end. The structure has 3 cross arms on each side having a clear height of 4.9 m between two consecutive cross-arm endpoints. At the top point of the peak portion, the earth wire was attached within the span length.

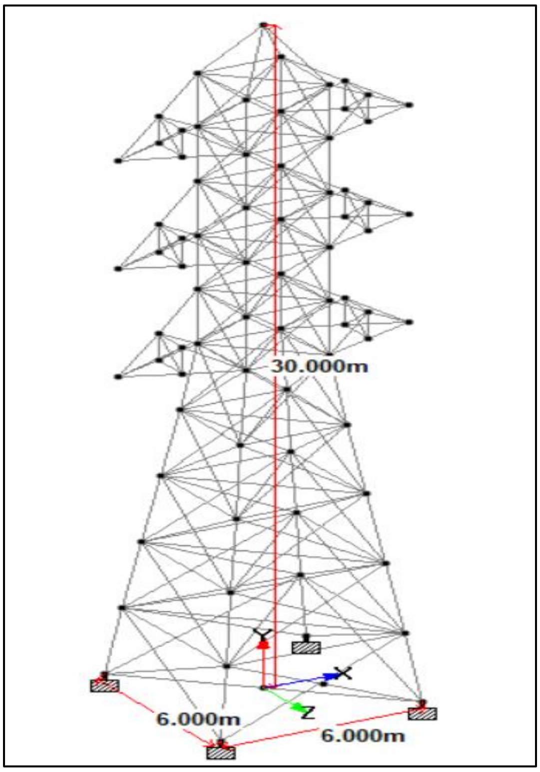

Fig -2: Modeled Self-Supporting Tower

3.2 Insulators

The cross arms are mainly used to support the insulators, which have a high resistance to the current supply. Insulators are suspended vertically downward at the endpoint of cross arms so they tend to move in the vertical plane. It has been designed with rotational freedom consideration in the corresponding direction. These insulators were simulated by considering the springs in X and Y direction i.e., along with and across the transmission line. These insulators were incorporated in SAP 2000 v21 software with some stiffness and the transmission line was attached to it. Stiffness for the insulators in the X and Y direction can be calculated by using the expressions enlisted in literature [3]. The stiffness values are:

$$K_X = 2.2371\ N/mm$$

$$K_y = 2.2061\ N/mm$$

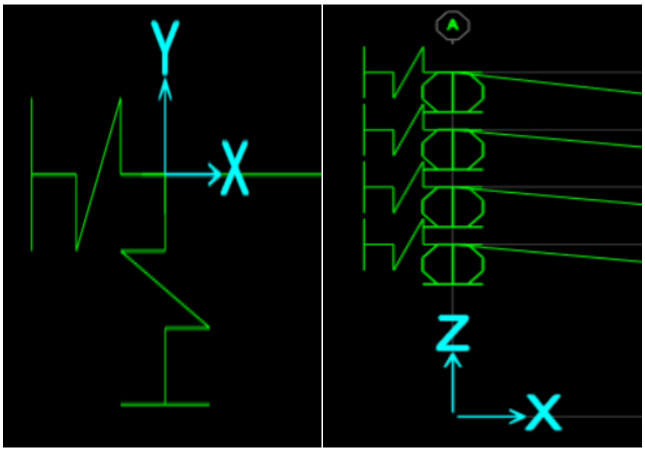

Fig -3: Spring Model for Insulators

3.3 Transmission Line

As discussed earlier the transmission line is composed of the conductors and the earth wire which were attached at the insulators and peak point respectively. The span of the transmission line was 320 m. All the properties of these wires explained earlier, based on that the end tension and the sag in the transmission line were calculated by using IS code provisions and implemented for modeling in the SAP 2000 v21 (fig. 4). Due to the large span, these wires are subjected to heavy wind loading, so which leads to the failure of the tower.

4. LOADING ON THE TOWER AND TRANSMISSION LINE

In this paper, an attempt was made to compare the axial loading in the member of the transmission tower when it is subjected to the normal wind loading and downburst loading.

4.1 Sag and Tension for Conductors & Earth-wire

These components have a large length so due to their self-weight these tend to form a hyperbolic shape and sags vertically downward. This sag depends on the tension in the cable and it leads to exert the external force on the cross arms. While calculating the sag and tension the wind variation and temperature variation were considered. The temperature was considered as -18^{0}C minimum, 32^{0}C every day, and 55^{0}C maximum temperatures. Then all the required values were calculated as per "IS 5613 Part 2, Sec 2 -1985" by using the following equations (Table 3):

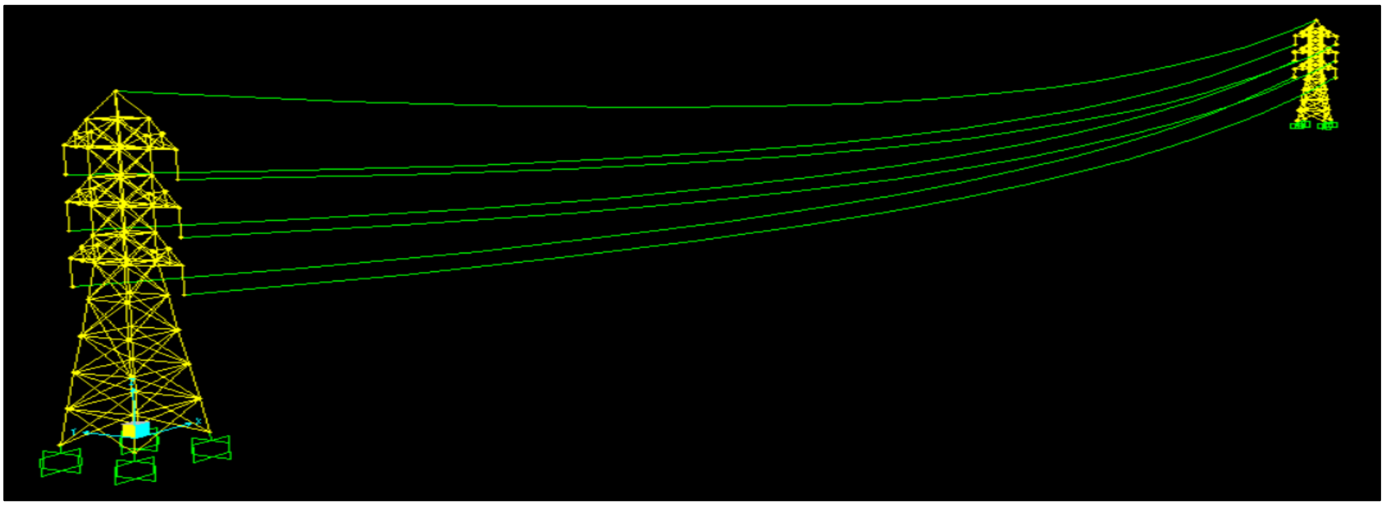

Fig -4: single spanned transmission tower with conductors and earth-wire

$$f_2^2 * [f_2 - (K - \alpha Et)] = \frac{l^2 \delta^2 q_2^2 E}{24}$$

$$Sag = \frac{q\delta l^2}{8f_1}$$

Where, $K = f_1 - \frac{l^2 \delta^2 q_2^2 E}{24 f_1^2}$

$q = Load\ Factor$

$\delta = \frac{Weight\ of\ Conductor\ (\frac{kg}{m})}{Area\ of\ Conductor\ (cm^2)}$

Table -3: Sag and Tension for the wires by using IS code

Loading Conditions	CONDUCTORS		EARTH-WIRE	
	Tension (kN)	Sag (m)	Tension (kN)	Sag (m)
At Worst Load (50% UTS)	44.783	8.084	28.008	9.89
At -18 ⁰C Without Wind & With Ice Load	31.149	8.893	34.481	8.034
At 0 ⁰C Without Wind & With Ice Load	33.023	8.388	35.573	7.787
At 0 ⁰C Without Wind & Without Ice Load	18.633	6.557	24.40	2.208
At 32 ⁰C Without Wind	22.682	5.387	20.982	2.561
At 55 ⁰C Without Wind	26.714	4.574	26.846	2.001

4.2 Loading According to IS Code Provision

This section deals with the calculations done by using "IS 802 Part 1, Sec 1 – 2015". Wind loading was considered as the key design factor while analyzing and designing the transmission tower. The factors required to calculate loading on the tower panel as well as node point were considered earlier [Tables 1 & 2]. The design pressure P_d exerted on any structure due to 50 m/s wind is 793 N/m². This pressure was used to calculate the load on the conductor, earth-wire, tower panels at different heights.

Wind load on the Tower panel can be determined by the equation:

$$F_{WT} = P_d C_{dt} G_T A_e$$

Wind load on the Conductors and Earth-wires can be determined by the equation:

$$F_{WC} = P_d C_{dc} L D G_c$$

Wind load on the insulator String can be determined by the equation:

$$F_{WI} = P_d C_{di} G_I A_I$$

All these wind loads were computed and applied to the tower modeled in the software. The wind load on the insulator and conductors were applied at the cross-arm tip, the vertically downward loads were also applied for the live load consideration, the load due to earth wire was applied at peak point, and the panel load was applied at the respective panel. The drag coefficient and gust response factor for these loading were extracted from the IS code.

Table -4: Wind loading due to different parts of the tower

Tower Member	Load (kN)
Top Conductor	11.099
Middle Conductor	10..794
Lower Conductor	10.105
Earth wire	6.159
Insulator	0.777

4.3 Sag & Tension Due to Downburst

Whenever the cables are tied in between two supports and subjected to the in-plane loading then it took the curve shape which is known as catenary. Sag for this case needs to be computed by using the extensible catenary method. This method used some hyperbolic equations, which are capable to compute the sag at any point on the cable but here it was used to compute the maximum sag at the mid-span of the cables i.e., L/2 distance. An iterative approach was considered in the equations [11]:

$$C_L^i = 2C * Sinh(L/2C)$$

$$S_L^i = C * \{Cosh\left(\frac{L}{2C}\right) - 1\}$$

Where, $C_L^i = Cable\ Length\ at\ i^{th}\ iteration$
$S_L^i = Sag\ at\ i^{th}\ iteration$
$C = Constant\ (= T_0/w)$
$T_0 = horizontal\ Tension$

Table -5: Cable Sag by the extensible catenary method

Tower Member	**Sag (m)**
Conductor	21.174
Earth-wire	20.76

4.4 Downburst Loading on the Tower

As we discussed in an earlier section, the parameters of downburst lead to different loading on the transmission line and the tower. If the basic downburst speed is greater than 40 m/s then it shows the adverse effect on the structure, so the considered basic wind speed according to the code and solved by using the method of the constant reference velocity at 10m.

For this study, the chosen critical parameters values were, $D_j = 1000$ m, $\frac{D_j}{r} = 1.6, \theta = 30^0$ taken out from the literature which was found to be critical for the cross-arm members of the tower. As the projection angle for the downburst was 30⁰ so the forces generated in the longitudinal and the transverse directions at the tip of the cross arms, which was an asymmetric loading configuration. Due to the non-linear behavior of the cables, it became necessary to consider the downburst loading on cables as a uniformly distributed load (W). This can be calculated by following equations [7]:

$$W = 0.5 * \rho * D * V^2 * C_d$$

Where, $\rho = Air\ Density$
$V = Basic\ Wind\ Speed$
D = Projected Perpendicular Dimension of Cable to Wind Flow
$C_d = Drag\ Coefficient$

After obtaining the load, sag, and pretension these values were incorporated in the software to obtain the longitudinal reaction at cross arms due to conductors and the transverse reactions can be evaluated by considering the following equation:

$$R_{trans} = 0.5 * W * L + \frac{WL}{8}$$

Axial forces in the tower members can be then determined by applying these transverse and longitudinal forces on the joint where the conductors were attached to the tower.

5. RESULTS AND DISCUSSION

The procedure was adopted to get the axial forces in the tower members. As we know that the tower is a latticed spaced structure and the designed to resist the heavy axial loads acting on it. For modeled structure, the axial force in main components was considered as the comparison parameter. Chart 1 shows the comparison of peak axial forces generated in the respective members viz. main leg, diagonal bracing, horizontal bracing, and cross arm bracing under the action of wind events considered here i.e., IS code method and the downburst loading.

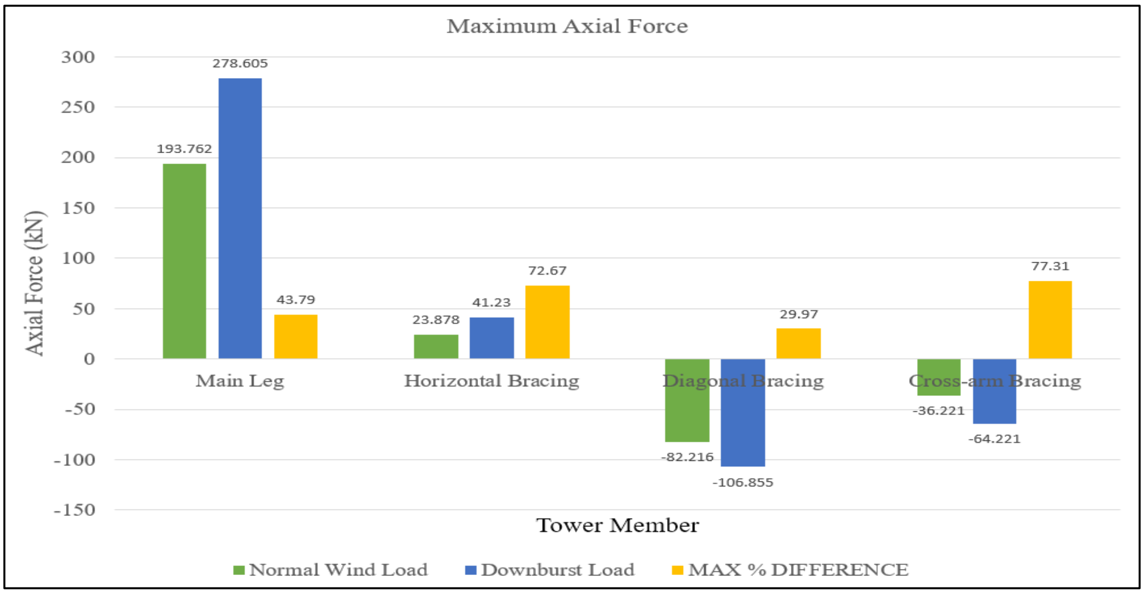

Chart -1: Maximum Axial Force in the Tower Member

This study had been worked out to get the idea about how downburst loading differs from loading obtained by using the regular codal provision for the Indian territory. The maximum expected difference in the axial forces in the members was way beyond the imaginations. This selected downburst event was an asymmetric one which leads to the failure of different tower members. The section provided for the main leg exhibits the highest axial forces and the difference is also very high. As other members also show the difference but that was in the small range.

6. CONCLUSIONS

In this paper, it has been seen that the adopted critical parameters for the downburst events mainly lead to the failure of the transmission towers, but if cross arms got failed then there may be chances of the cascade failure of the whole transmission line and it will be the huge loss to our economy.

The downburst loading exerted on the tower shows the difference in the axial forces which were in the range of 29.97% to 77.31%. These differences were found in Diagonal Bracings and Cross-Arm bracing of the Transmission tower. But the maximum axial forces were generated in the leg members of the transmission tower. This might be a very high range of divergence from the conventional method and this is enough to attract attention to this event. Although to date, there haven't been any traces of downburst events in India, comparing these results it becomes important to improvise the method and incorporate some provisions to consider the downburst event for analysis and design of the transmission tower structures.

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