

Conductive Cables Vibrations Effect On Lattice Steel Transmission Towers

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Abstract

Nowadays, the power industry prefers using overhead lines instead of burying cables due to cost requirements. In spite of that, a problem lies in the fact that many of the existing older transmission systems are built with minimal or no consideration of dynamic effects. Moreover, demands require taller and more slender towers that may be subjected to heavier dynamic loads, and may undergo larger responses. Consequently, the study of the overhead power line failure and its consequences on the supporting towers is essential, especially when being located close to wind farms with risks of severe vibrations. This is a fact when considering the economic costs of failure of transmission lines, as well as the cascade failure that may happen to adjacent transmission towers. This research aims to study the effect of heavier wind loading on the response of the conductive cables and subsequently the lattice steel tower-cable system. This was achieved by creating a finite element model using computer software (ADINA) and (SAP2000). It is shown that many improvements can be made in current design methods promoting a reliability-based design procedure on designing the transmission line systems near wind farms.

Keywords: Transmission towers; Stability; Risks; Vibrations; Conductive cables; Wind farms

Introduction

The process of transporting electricity over long distances to consumers is called electric transmission [1]. Electric transmission facilities are usually required for some alternative wind energy facilities, such that if no existing suitable transmission facilities are available, new transmission lines and associated facilities will be required. Transmission lines consist of transmission towers which are the main supporting unit in the transmission line system that carries the conductors. Conductors carry electricity to and through the electric grid, at a sufficient safe height from the ground and keep them separated from each other [2,3]. Shield wires lie on top of the transmission tower to protect the whole system from lightning strikes so that the strike can flow to earth by the easiest and shortest path. The electric insulators isolate the electric current in the conductor and therefore no current would flow from the conductor to earth through the transmission tower. An insulator can take either an I-shape connected to the transmission tower cross arm in one point, or V-shape connected to the cross arm in two points [4,5].

There are several different kinds of transmission structures. Transmission structures can be single-poled or multi-poled, single-circuited carrying one set of transmission lines or double-circuited with two sets of lines. Showing an image of an existing transmission line [6,7]. Transmission towers, as the main support, usually vary in shape and height. The structural systems may generally be single pole towers, constructed of either wood or steel, ranging from 50-70 feet tall. The supporting systems for lower voltage lines however, are typically constructed of wood or steel pole systems. Towers for higher voltage lines are generally constructed from lattice steel towers where the common factor in all transmission line designs is the conductor that connects each tower together. This conductor, strung under tension to prevent ground contact, is the source of the most significant structural load (Figure 1).

Failure of transmission towers may occur due to accidental loads such as conductor or insulator breakage or failure in any other component of the system, this can also take place due to extreme conditions such as thunder or ice storms or tornadoes [8]. The consequences of a single failure may cause a cascade failure for the whole

system, as was observed as an example in Hurricane Katrina in 2005, over 1.7 million people lost power due to the storm in the golf states, and to return power back it was going to take more than numerous weeks, said by the power companies. The total losses for this hurricane exceeded 100 billion dollars and over 34 billion in insured losses [9]. Moreover, according to a study conducted by Lawrence Berkeley National Laboratory researchers [5], the electric power outages and shutdowns cost the US nation about 80 billion dollars yearly, 73% are losses in the commercial sector and 25% in the industrial sector and the rest are losses in the residential sector [10-12].

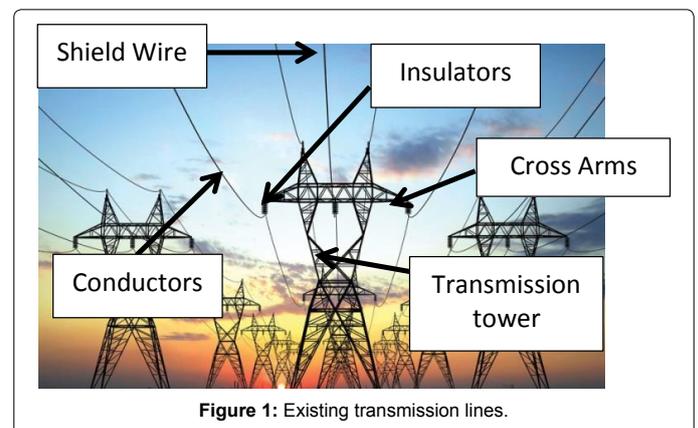


Figure 1: Existing transmission lines.

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Received February 09, 2019; **Accepted** February 20, 2019; **Published** February 25, 2019

Citation: Ghazal T, Elkassas E, El-Masry MI (2019) Conductive Cables Vibrations Effect On Lattice Steel Transmission Towers. J Steel Struct Constr 5: 151.

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Literature Review

The purpose of this review is to provide researchers with a summary of the previous work accomplished to be a helpful tool for researchers' future work. McClure and Tinawi constructed a numerical model using the finite element software (ADINA) to be able to determine the transient dynamic loads due to broken conductor scenario. The results were compared to full scale models to validate the ADINA software and to make sure that this software can be used accurately as it was the first time to use it to predict dynamic loads due to broken conductor on transmission lines. Kempner constructed a scale model (scale 1:23) for the broken conductor scenario. The effect of structure collapse on adjacent towers was studied, not only the dynamic loads effect on undamaged towers. He measured the forces on the surviving towers when the proceeding towers have failed, to be able to assess the dynamic containment load on the first surviving tower due to conductor failure. McClure and Lapointe studied the dynamic response of transmission lines due to shock loads such as sudden ice shedding on conductors or sudden failure of components of transmission line using the commercial software ADINA [8]. This effect was studied through a case study of a double circuit 120 KV line that suffered two tower failures during an ice storm occurred in the Lanaudiere region in Canada. Shehata described a numerical model to predict the structural performance of the transmission towers under downburst event loading, the authors transformed the wind velocities to forces [12]. A comparative study was made between the results of the tower exposed to downburst wind loads and normal wind analysis. The importance of considering high intensity wind loads when designing the transmission towers was described, due to the increase in axial forces in the case of downburst than normal wind load. Albermani and Kitipornchai used a nonlinear analysis technique for structural failure of transmission towers [4]. The results were confirmed by a full scale test results already determined. When the results were compared, it showed a close agreement with the nonlinear analysis prediction. It considered the effect of dynamic wind analysis on a guyed and a river crossing transmission tower due to the difficulty of studying the dynamic response of the structure by the traditional static equivalent method. Turbulent wind loading was calculated and the transmission line structure was created using Finite Element (FE) method. After that, the author compared the results of the dynamic wind loading with the equivalent static loading method. Pengyun et al. studied the dynamic response of power transmission towers under strong wind using finite element software and using the energy criteria, the results showed that the developed energy criteria might be used later for the examination of structural dynamic performance [10]. Aboshosha and Damatty created a numerical model that associated the data from the simulation of tornadoes wind field with three dimensional nonlinear analyses [2]. The authors recommended that the conductors and ground wires must be taken into considerations when designing and analyzing transmission lines subjected to tornadoes. It studied the dynamic behavior of transmission lines subjected to synoptic wind loads. The numerical model of the transmission line, subjected to the mean and fluctuating component of synoptic winds, was studied and validated experimentally [2]. The dynamic behavior of transmission lines was studied using four different types of towers. The peak responses of the towers increased when increasing the velocity.

Problem Definition

This research aims to study the effect of vibration of the conductive cables during wind loading on the pylon-cable system stability, by creating a finite element model using computer software such as

(ADINA) and (SAP2000). It is shown that many improvements can be made in current design methods promoting a reliability-based design procedure on designing the transmission line systems. Approximately 49% of transmission tower failures were due to ice and high intensity wind. Older tower design codes offered little if any information regarding ice and longitudinal strength requirements for transmission line system because the longitudinal tensile forces on conductors at the two sides of the transmission tower is nearly equal. The latter case is not always true because this balance can be easily broken in extreme conditions such as wind loading and if this takes place dynamic longitudinal loads will also affect the adjacent towers leading to a cascade failure. Therefore, the longitudinal loads should be taken into consideration during the design phase of the transmission lines especially when transmission lines are being located close to wind farms areas.

Problem Idealization

The tower used in the study is a lattice steel transmission tower. Details of the tower used in the study can be found in Table 1 and Figure 2. The

Cross Arms stiffness on the insulators at level 1	
Stiffness (X Direction) (N/ms)	2,009,640.648
Stiffness (Y Direction) (N/ms)	810,157.889
Stiffness (Z Direction) (N/ms)	7,189,801.410
Cross Arms stiffness on the insulators at level 2	
Stiffness (X Direction) (N/ms)	878,703.736
Stiffness (Y Direction) (N/ms)	184,076.421
Stiffness (Z Direction) (N/ms)	1,894,993.484
Cross Arms stiffness on the insulators at level 3	
Stiffness (X Direction) (N/ms)	235,109.349
Stiffness (Y Direction) (N/ms)	143,546.783
Stiffness (Z Direction) (N/ms)	1,689,902.831
Tower Material	
Yield Stress	249 MPa
Ultimate Stress	400 MPa
Conductor Type	Kiwi 72/7 ACSR
Span length	360 m
Insulator Length	2.438 m
Total Tower Length	54.7 m

Table 1: Transmission tower model.

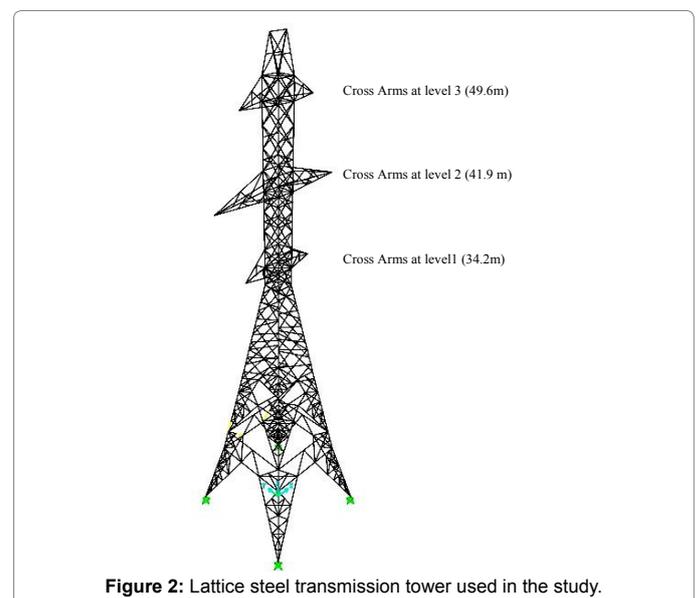


Figure 2: Lattice steel transmission tower used in the study.

towers cross arms stiffness's on the insulators were developed for each cross arm using SAP2000 software.

Wind Load Generation

Failure of transmission lines will lead to the interruption of electricity which has a catastrophic economical effect. Lateral loads should be well considered in designing the overhead transmission towers. The vibration and galloping of overhead transmission line may lead to a failure of the transmission tower which is the main supporting unit of the system. The failure in the transmission tower might cause the damage of adjacent towers leading to a catastrophic cascade failure of all towers which happened during Hurricane Katerina in 2005. In 1996 due to the failure of 19 transmission towers, Manitoba hydro company in Canada reported damage of about ten million US dollar [7]. According to Abdelnaby [1] a FORTRAN code was modified to calculate the drag forces in the along wind direction, and lift forces in the vertical direction for 12 incoherent points on the two middle spans of the cable for each cross arm model. Force time histories were simulated with 512 time steps each time step=0.2 seconds. Figure 3 shows the drag forces on 12 loading points on the cable carried by cross arm 1 force time history.

Transmission Line Modeling

A 3D transmission line model was created using finite element software (ADINA). A model was created for each cross arm due to the change in stiffness for each case as shown before. The line system studied consists of 6 equal 360 m spans, connected by five transmission towers (Figures 4-10). The towers were modeled as spring supports in X, Y, and Z direction with the previously calculated stiffness values for each cross arm model. The towers are connected to the Kiwi 72/7 ACSR conductors using insulators. Model assumptions are shown in Table 1 and Table 2. A static run was finished first for the transmission line system under gravity load only. After that, a dynamic analysis was conducted by applying the wind loads on the transmission line, to be able to study the effect of the vibration of the conductive cables due to wind loads on the stability of the transmission towers (Figures 11-14).

Transmission Tower Loading Due To Dynamic Wind Loads

The previously shown reactions were loaded on the cross arms as a time history on the transmission tower sap model in X, Y and Z directions as shown in Figure 15.

Analyses of Results

Failure of the transmission tower occurred by exceeding the yield stress value of the steel used in the study. The results showed failure of the lower members of the lattice steel tower and then followed by a failure of the whole transmission tower which might lead to a cascade failure for the whole line. Table 3 and Figure 16 show the lattice steel members where failure occurred.

Total Tower Length	54.7 m
Insulator Length	2.44 m
Conductor Weight	47.316 N/m
Conductor Diameter	44.07 mm
Conductor Modulus of Elasticity	
Conductor Density	

Table 2: Model Assumptions.

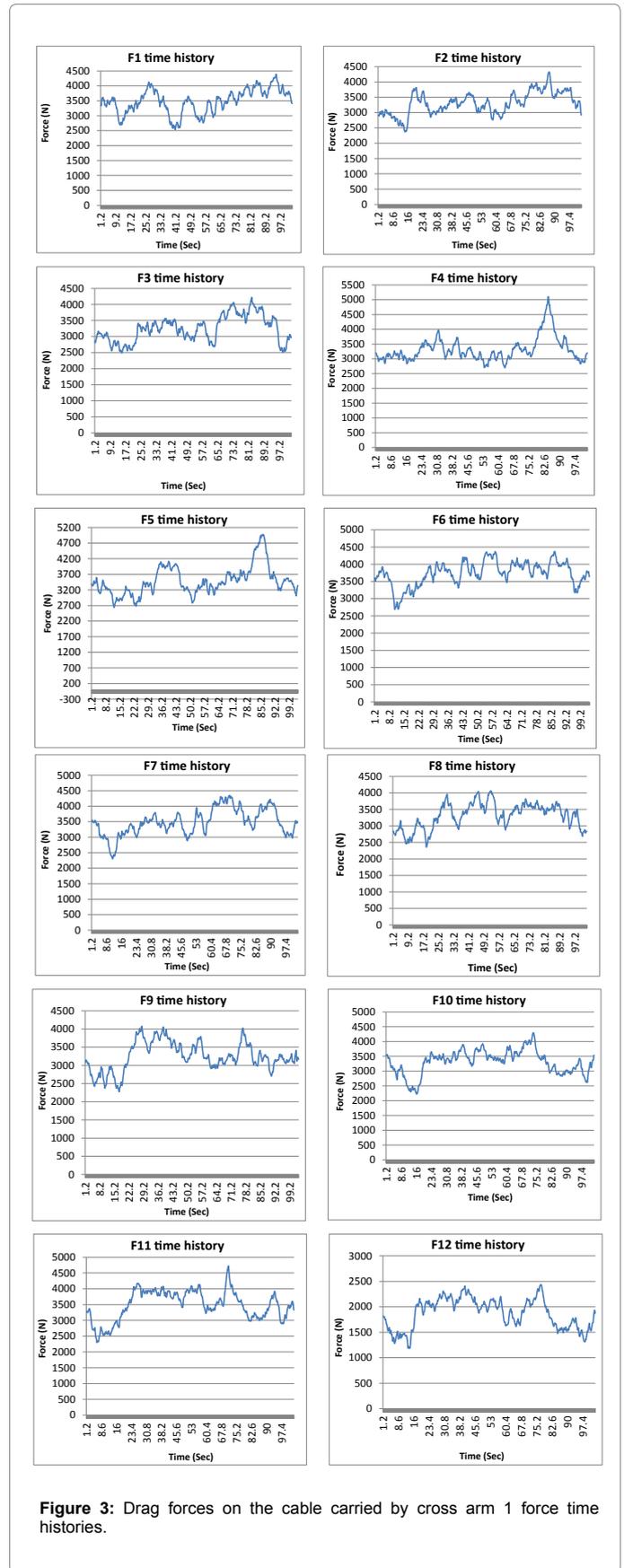
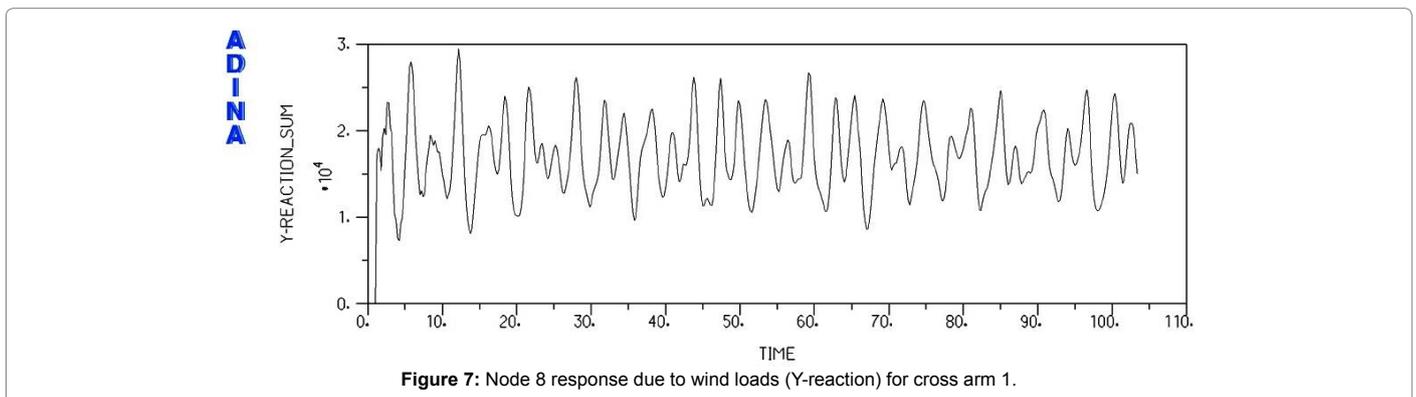
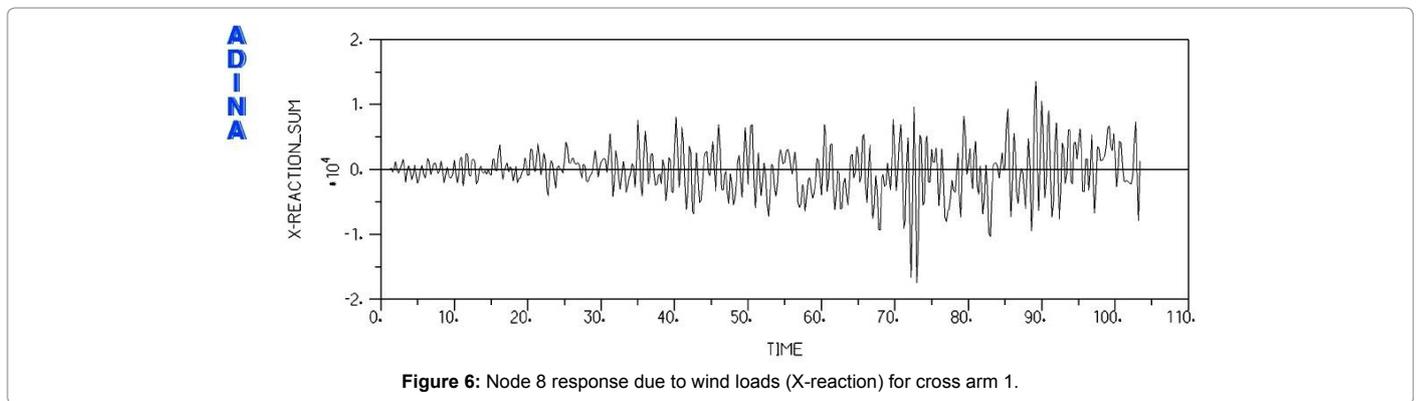
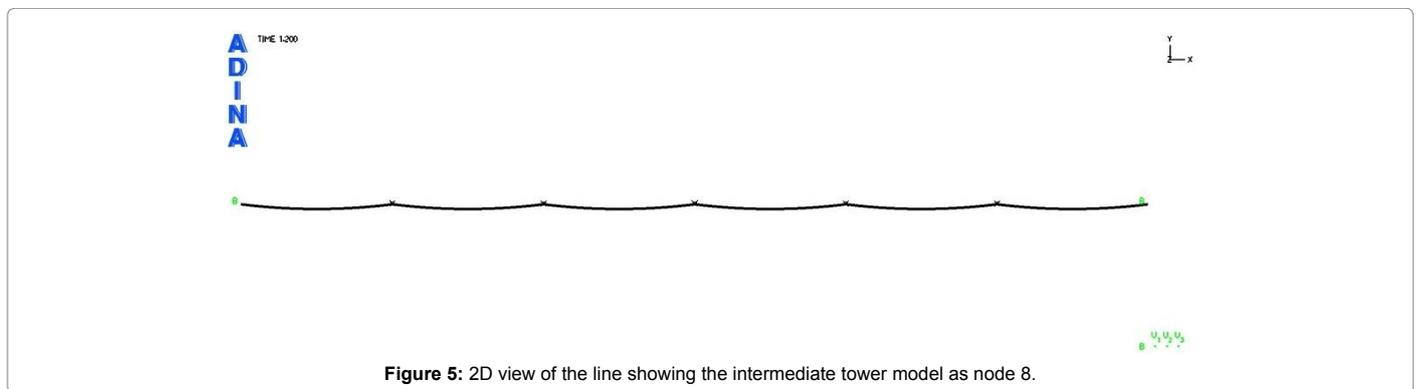
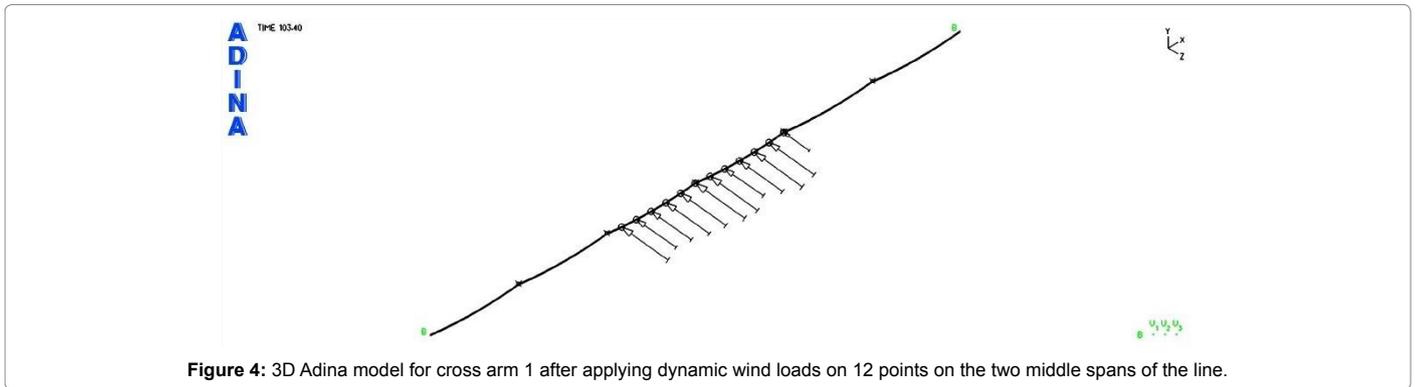


Figure 3: Drag forces on the cable carried by cross arm 1 force time histories.



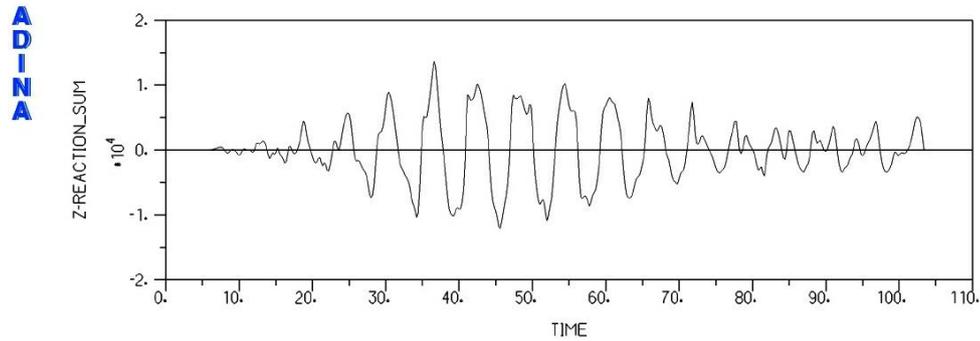


Figure 8: Node 8 response due to wind loads (Z-reaction) for cross arm 1.

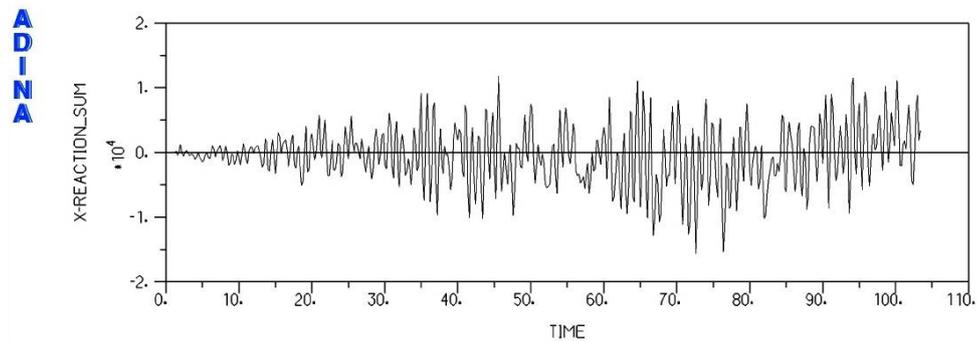


Figure 9: Node 3 response due to wind loads (X-reaction) for cross arm 2.

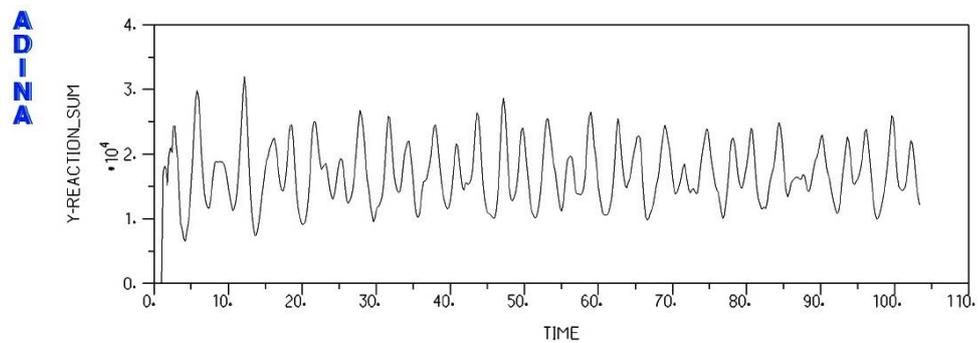


Figure 10: Node 3 response due to wind loads (Y-reaction) for cross arm 2.

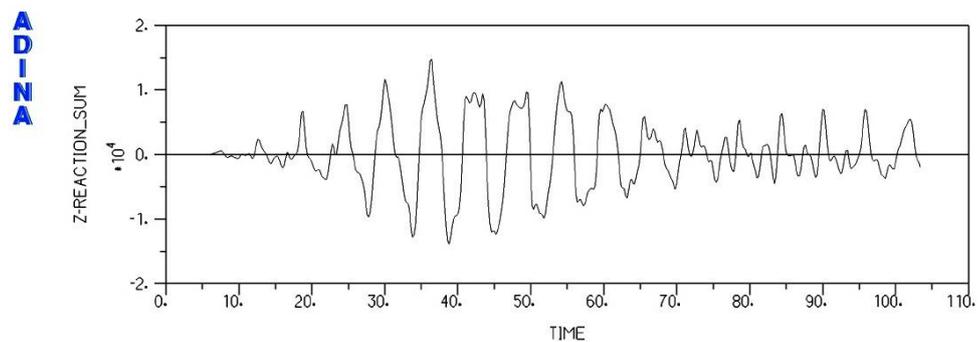


Figure 11: Node 3 response due to wind loads (Z-reaction) for cross arm 2.

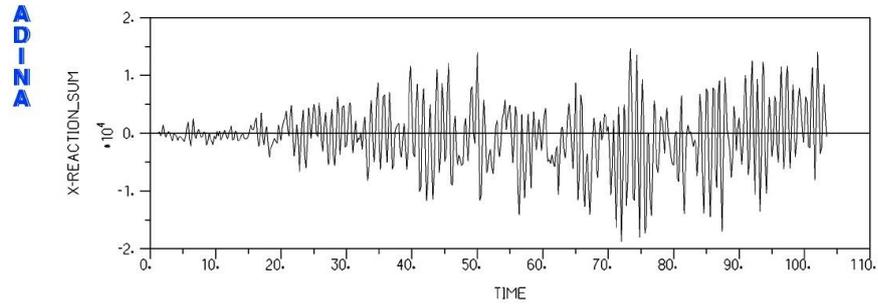


Figure 12: Node 3 response due to wind loads (X-reaction) for cross arm 3.

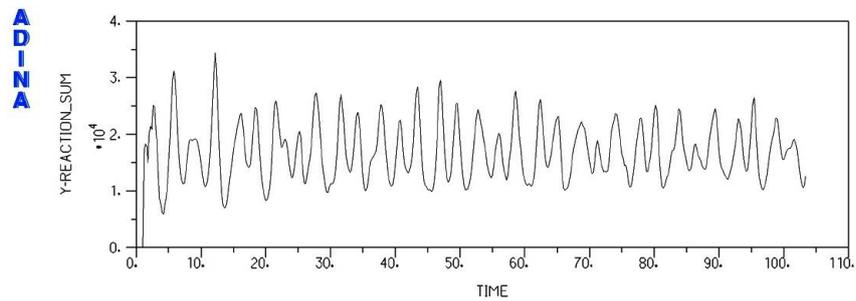


Figure 13: Node 3 response due to wind loads (Y-reaction) for cross arm 3.

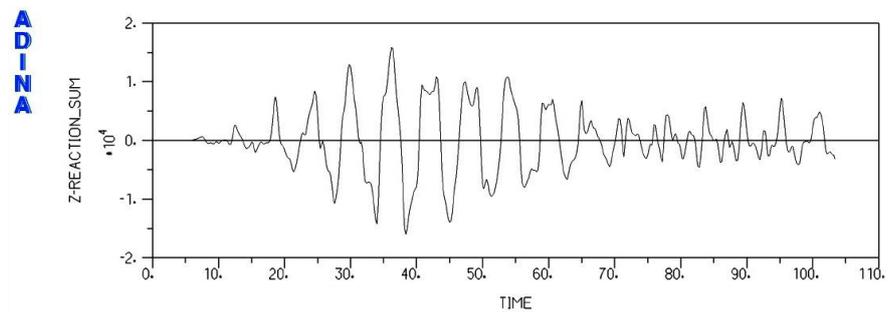


Figure 14: Node 3 response due to wind loads (Z-reaction) for cross arm 3.

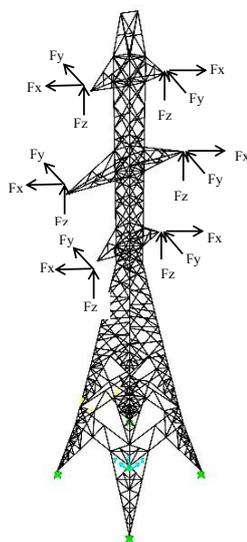


Figure 15: SAP 2000 transmission tower model loaded with the cable response in X Y and Z direction for each cross arm.

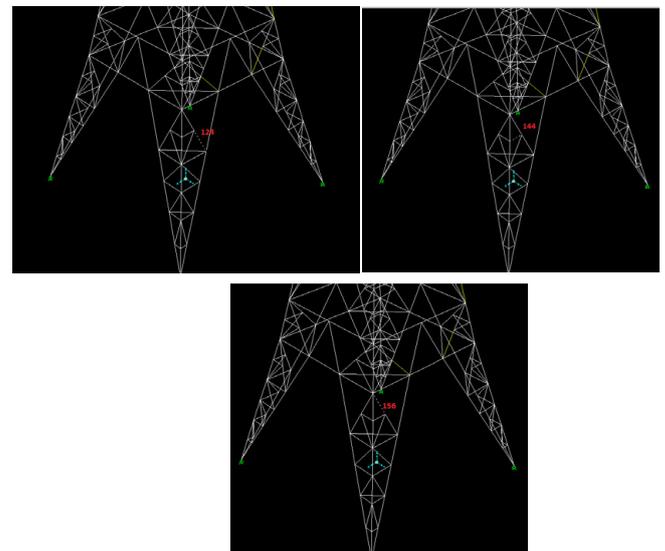


Figure 16: Failure of different lattice steel members.

Time Step	Frame	Stress
6	124	267.63
6	156	272.05
6.2	124	297.63
12.8	124	249.94
13.6	124	298.06
13.8	124	286.6
13.8	144	255.61
13.8	156	283.52
14	124	302.73

Table 3: Stresses at lattice steel members exceeding yield stress.

Conclusions

Repair of transmission lines is very costly, it can be in the billions of dollars, plus the cost of the disturbance of electricity and the impacts due to losing the economic activity. Overhead Transmission tower systems are critical structures, due to its sensitivity to any excitations, if failure happens in one tower, a cascade failure takes place in the remaining towers and this leads to a failure of the whole system. Overhead transmission tower systems should be designed to survive extreme meteorological conditions such as wind loading. A three dimensional finite element model using ADINA and SAP2000 was developed to be able to predict the response of the transmission tower. Due to the non-accuracy and the uncertainty of the equivalent static wind load calculations, the response due to dynamic wind loading was the case studied. Results showed failure in the lattice steel transmission tower. Failure happened by exceeding the yield stress value for steel used in the study. The results shows that designers should not count that longitudinal tensile force at the two sides of the tower are equal,

because this equality can be easily broken in some extreme conditions such as wind loading.

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