International Journal of Engineering Research and Reviews (IJERR)
Vol. 1, Issue 1, pp: (5-22), Month- October-December 2013, Available at: www.researchpublish.com

Models Assessment and Sensitivity Analysis of Steel Lattice Transmission Towers Subject To Conductor Lines Loading

Nazim Abdul Nariman

PhD candidate - Institute of Structural Mechanics
Bauhaus Universitat Weimar – Germany

Abstract: **Models of a transmission tower were generated in ABAQUS GUI for the static case considering the dead load of the transmission tower of a rod steel section with radius r=10.16 Cm, and cross section area A=0.0324 M² and mass m=254 Kg/m and modulus of elasticity E=21e10 Pa and poisons ratio =0.3 and density of D= 7842 Kg/M³ , snow load, conductor lines and ground lines which are made of steel cables with two different types due to their roles in the process of transferring the electricity power from place to another. The transmission tower models are all of dimension 24*24 M for the base and the height is 93 M from the ground. The distance between transmission towers is 450M, and from each side the total distance has been considered for the design span of the cables which is 900 M and it was done under the guidance of ASCE and NESC codes. The loads of the conductor lines were assigned to the transmission tower considering the two direction type of the transmission model of 180° on a straight line in each side as shown in the Figure(3). For model assessment of the transmission tower, Beam elements and Truss elements were considered in two different models. The boundary conditions of the supports were assigned pinned once in a model and fixed in another model. Mesh refinements were done 15 times for the model of a pinned support considering beam element type for a rod steel section. The designated outputs were the resultant of the reactions at the supports, the S.Mises of nodes at the supports and the displacement of nodes at the top of the transmission tower.**
Sensitivity analysis was adopted using a single angle steel section of size (20.32*20.32) Cm and thickness of 1.89 Cm and modulus of elasticity E=21e10 Pa, and poisons ratio =0.3, and density of D= 7842 Kg/M³ using variance based global sensitivity analysis (Sobol estimates) and the Box- Behnken response surface methodology was considered for sampling operation, linear and quadrilateral forms were used in the approximated model function. Three input variables were imposed as the influencing design factors on the static response of the transmission tower model which were the weight of the transmission tower, the conductor line load and the ground line load respectively, 15 runs were used to determine the designated real outputs.

Discussion and conclusion were figured supporting on the results in every comparison assessment between models outputs in every case of changing the element type, boundary condition of the models and the mesh refinement case.

First order sensitivity indices or main effects, interaction effects and total sensitivity indices for each variable for the three mentioned outputs were calculated using total variance law. The sensitivity indices showed the effect of each design input variable in the variance of the output.

Keywords: **Transmissiontower, Sensitivity indices, Sobolestimates, Box-Behnken Method and Mesh refinement.**

I. Introduction

A transmission tower is the main supporting unitof overhead transmission line to carry the heavy transmission conductor at a sufficient safe height from ground. In addition to that all towers have to sustain all kinds of natural calamities.So transmission tower designing is an important engineering job where all three basic engineering concepts, civil, mechanical and electrical engineering concepts are equally applicable. Figure (1) is showing the main parts of a transmission tower. There are three types of transmission towers due to their role to support transmission lines suspension transmission towers, station transmission towers and tension transmission tower. The tension towers are the most important type for research study because all the static and dynamic loads of conductor lines, ground lines, wind loads and seismic loads due to earthquakes have to be supported by this structure safely.

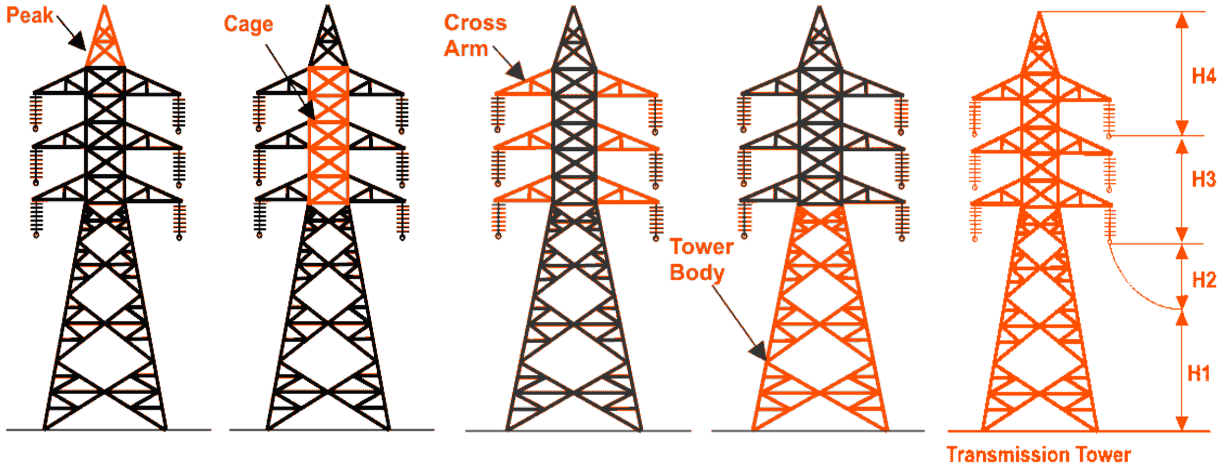
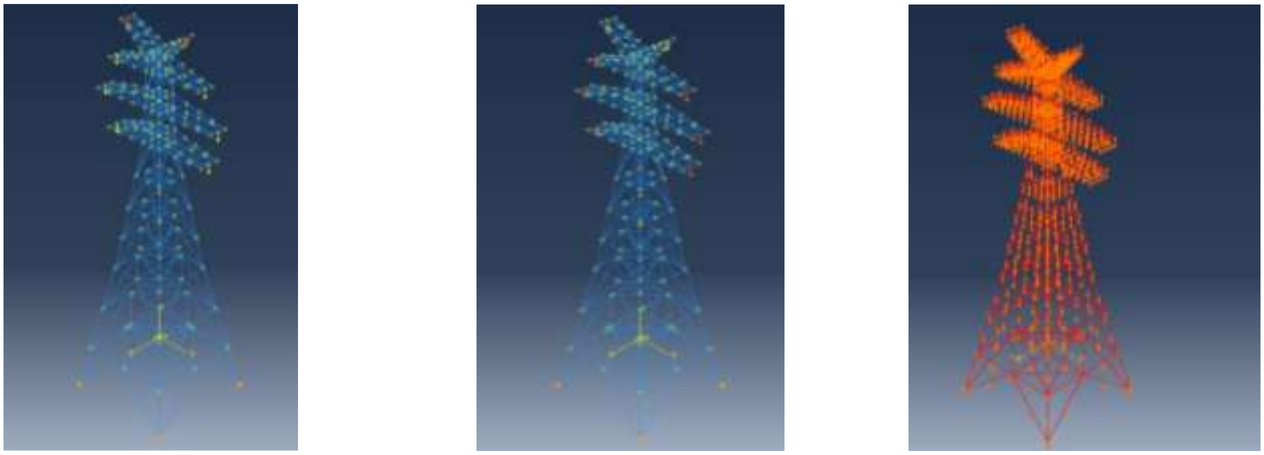


Figure (1) Transmission tower parts

Figure(2) is a tension transmission tower.

Figure (2) Tension transmission tower

Figure (3) shows the assignation of loads of the ground line, conductor line and the steel tower using Abaqus finite element program.



Ground line load

Conductor line load

Transmission tower load

Figure (3) Load assignation on the tower

II. Objective

The objective of this research is listed as follows:

1- Verification and assessment of transmission tower models with different support boundary conditions and their effects on the response, stiffness and safety of the transmission tower.
2- Assessment of transmission tower models designed using Beam elements and Truss elements and the effects of each design case on the behavior and response of the transmission tower.
3- Assessment of transmission tower models for mesh refinement by increasing the element numbers and determining the response of the transmission tower for each model.
4- Sensitivity analysis and evaluation of transmission tower models for design factors and their effects on the output uncertainty and response variance using global variance based sensitivity analysis.

Beam Elements and Truss Elements

Two transmission tower models of a rod steel section with radius r=10.16 Cm, and cross section area A=0.0324 M² and mass m=254 Kg/m and modulus of elasticity E=21e10 Pa and poisons ratio =0.3 and density of D= 7842 Kg/M³ were generated basing on a Beam Elements and Truss Elements. Astatic step was created for two models once as a Beam element and another as a Truss element, the static dead loads of transmission tower, the conductor andground lineswere assigned to the transmission tower models in addition to creating pinned boundary condition at the support, and two jobs were created and submitted to ABAQUS for analysis.

The output results for resultant reaction force at the supports, S.Mises at the support nodes and resultant displacement of three nodes at the top of the transmission tower were determined for each case, once for a Beam element and another for a Truss element. The tables (1),(2) and (3) andFigures(4),(5) and (6) are showing the results mentioned above.

Table (1) Resultant Reaction Forces at Supports

		Reaction Force N Loc1		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Beam Element	62395.2070	62755.8280	62755.9060	62395.2930
		Reaction Force N Loc1		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Truss Element	2062837.0000	2063447.1000	2063527.8000	2062772.9000

Table (2)S.Mises of Nodes at Supports

		S. MisesLoc 3 N/M2		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Beam Element	644442.0000	650674.8100	654490.5600	646683.8700
		S. MisesLoc 3 N/M2		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Truss Element	32538370.0000	28052528.0000	19014136.0000	25811914.0000

Table (3) Resultant Displacement at top Nodes

		Displacement M Loc1	
	Node 6	**Node 51**	**Node 187**
Beam Element	0.00096959	0.00074355	0.00082072
		Displacement M Loc1	
	Node 6	**Node 51**	**Node 187**
TrussElement	0.01749096	0.01598298	1.60E-02

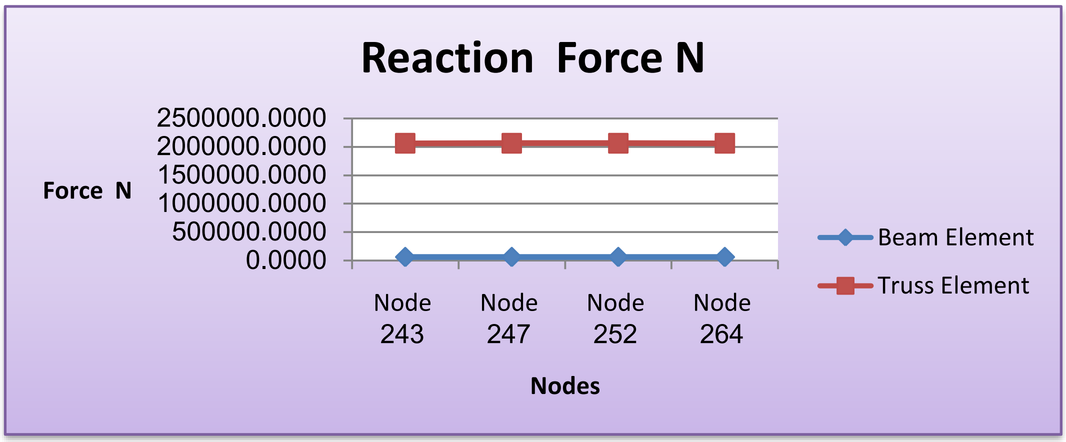


Figure (4) Resultant Reaction Forces at Supports

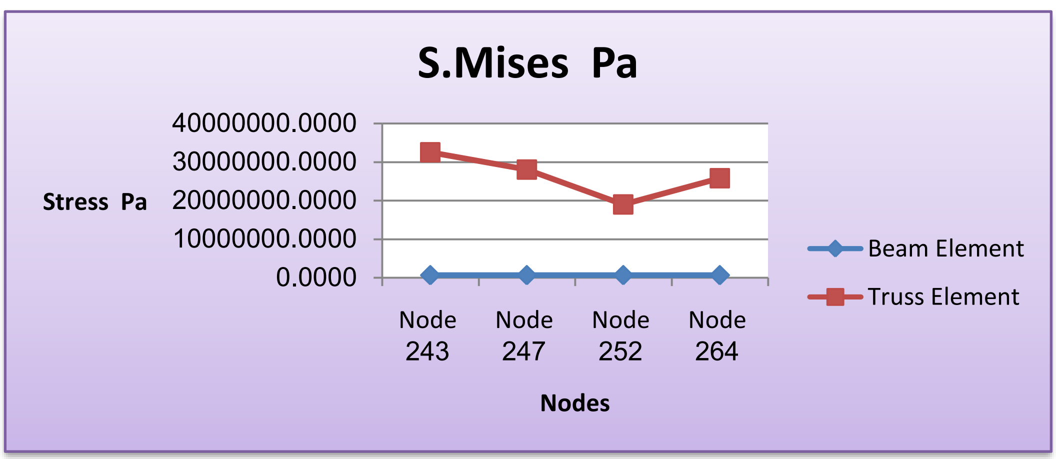


Figure (5)S.Mises of Nodes at Supports

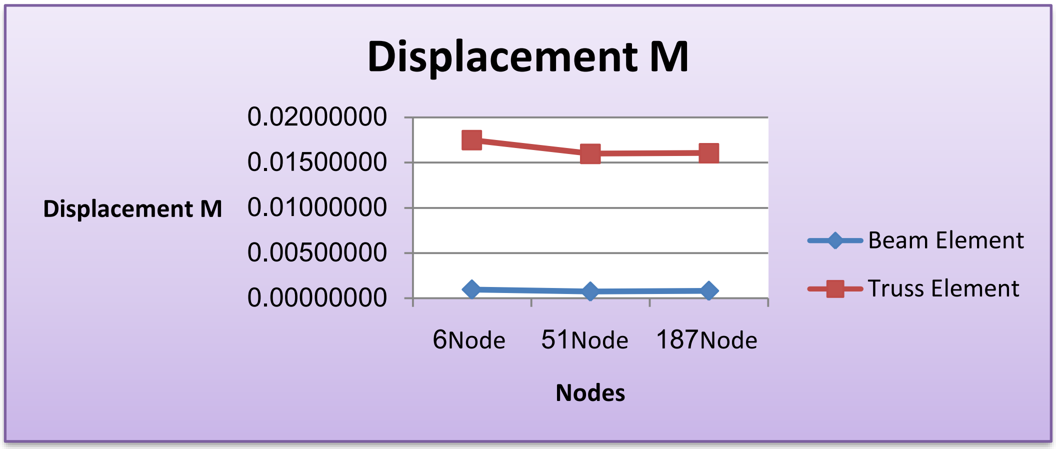


Figure (6) Resultant Displacement at top Nodes

Pinned and Fixed Supports:

Two transmission tower models of a rod steel section with radius r=10.16 CM, and cross section area A=0.0324 M^2 AND mass m=254 Kg/m and modulus of elasticity E=21e10 Pa and poisons ratio =0.3 and density of D= 7842 Kg/M^3 were generated basing on that the boundary condition at the supports once is pinned and another is fixed.

Astatic step was created for two models once the boundary condition at the supports is pinned and fixed in the other model, the static dead loads of transmission tower, the conductor and ground lines were assigned to the transmission tower models in each model, and two jobs were created and submitted to ABAQUS for analysis.

The output results for resultant reaction force at the supports, S.Mises at the support nodes and resultant displacement of three nodes at the top of the transmission tower were determined for each case. The tables (4),(5) and (6) and Figures(7),(8) and (9) are showing the results mentioned above.

Table (4) Resultant Reaction Forces at Supports

		Reaction Force N Loc1		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Pinned Support	**2062837.0000**	**2063447.1000**	**2063527.8000**	**2062772.9000**
		Reaction Force N Loc1		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Fixed Support	**2061283.7000**	**2061894.4000**	**2061971.1000**	**2061217.1000**

Table (5)S.Mises of Nodes at Supports

		S. MisesLoc 3 N/M2		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Pinned Support	**32538370.0000**	**28052528.0000**	**19014136.0000**	**25811914.0000**
		S. MisesLoc 3 N/M2		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Fixed Support	**32725528.0000**	**33049214.0000**	**35410536.0000**	**30826992.0000**

Table (6) Resultant Displacement at top Nodes

		Displacement M Loc1	
	Node 6	**Node 51**	**Node 187**
Pinned Support	**0.01749096**	**0.01598298**	**0.01603822**
		Displacement M Loc1	
	Node 6	**Node 51**	**Node 187**
Fixed Support	**0.01748863**	**0.01598064**	**1.60E-02**

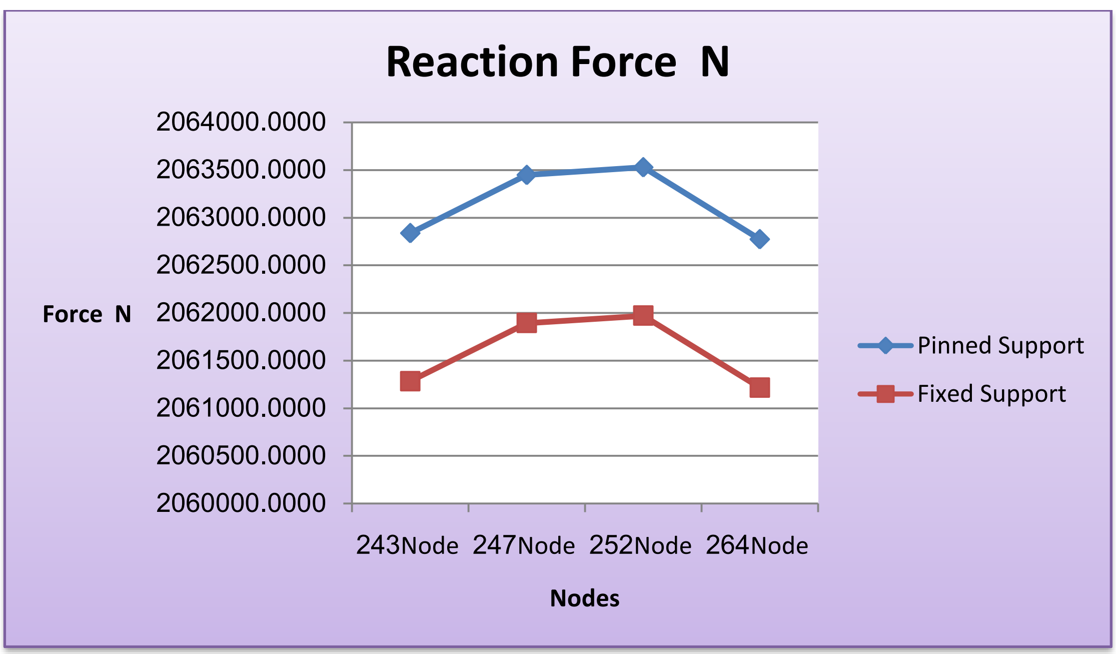


Figure (7) Resultant Reaction Forces at Supports

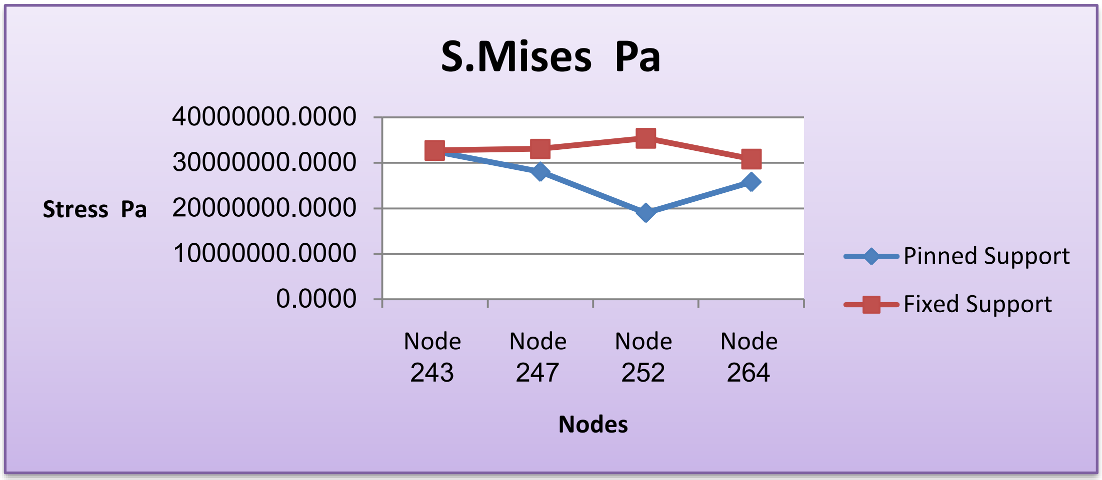


Figure (8)S.Mises of Nodes at Supports

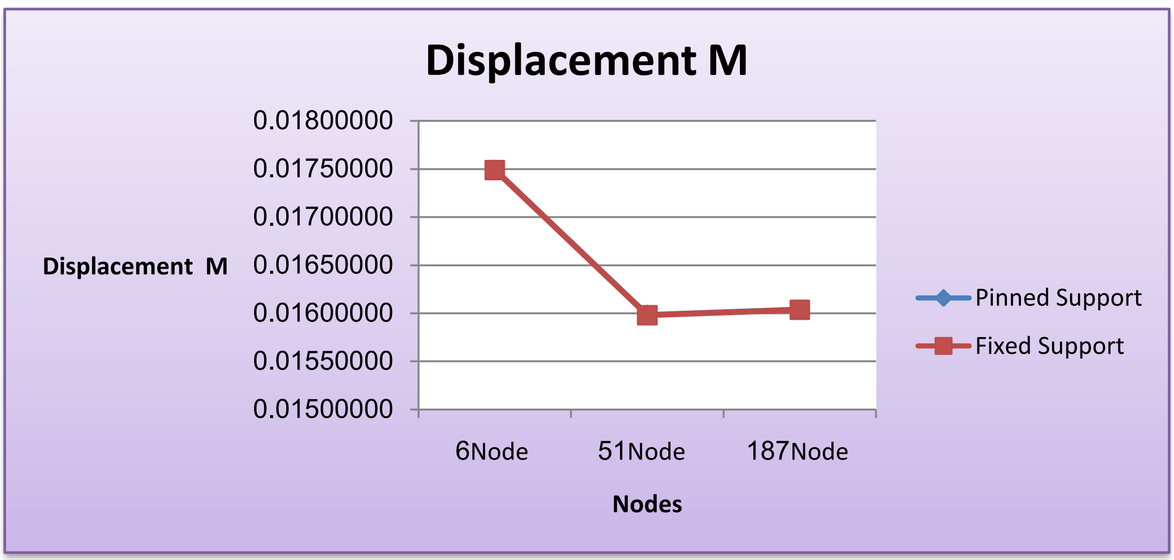


Figure (9) Resultant Displacement at top Nodes

Mesh Refinement:

For mesh refinement 15 Transmission towermodels of a rod steel section with radius r=10.16 Cm, and cross section area A=0.0324 M^2 AND mass m=254 Kg/m and modulus of elasticity E=21e10 Pa and poisons ratio =0.3 and density of D= 7842 Kg/M^3 were generated basing on refining the mesh for the Transmission tower models.Beam elements were used in the process. Astatic step was created for 15 models each model have a different node numbers increasing the global seed sizes by 0.1 each time, the static dead loads of transmission tower, the conductor and ground lines were assigned to the transmission tower models in each model in addition to creating pinned boundary condition at the support for all models, and 15 jobs were created and submitted to ABAQUS for analysis.

The output results for resultant reaction force at the supports, S.Mises at the support nodes and resultant displacement of three nodes at the top of the transmission tower were determined for each case. The tables (7),(8) and (9) and Figures(10),(11) and (12) are showing the results mentioned above.

Table (7) Resultant Reaction Forces at Supports

		Reaction Force N Loc1		
Mesh Refinement	**Node 243**	**Node 247**	**Node 252**	**Node 264**
517 Nodes	2062784.4000	2063394.6000	2063474.5000	2062719.5000
525 Nodes	2062784.5000	2063394.6000	2063474.5000	2062719.5000
553 Nodes	2062796.1000	2063406.4000	2063486.8000	2062732.0000
569 Nodes	2062815.6000	2063425.9000	2063506.3000	2062751.2000
596 Nodes	2062816.0000	2063426.4000	2063506.8000	2062751.9000
636 Nodes	2062803.0000	2063413.3000	2063493.6000	2062738.7000
663 Nodes	2062837.0000	2063447.1000	2063527.8000	2062772.9000
667 Nodes	2062837.0000	2063447.1000	2063527.8000	2062772.9000
698 Nodes	2062868.1000	2063478.5000	2063559.0000	2062804.0000
706 Nodes	2062868.1000	2063478.5000	2063558.9000	2062804.0000
744 Nodes	2062873.5000	2063483.6000	2063564.7000	2062809.9000
784 Nodes	2062892.4000	2063502.6000	2063583.7000	2062828.8000
804 Nodes	2062890.9000	2063501.0000	2063582.3000	2062827.2000
852 Nodes	2062897.9000	2063508.1000	2063589.3000	2062834.4000
925 Nodes	2062903.9000	2063514.0000	2063595.2000	2062840.1000

Table (8)S.Mises of Nodes at Supports

		S. Mises N/M2 Loc 3		
Mesh Refinement	**Node 243**	**Node 247**	**Node 252**	**Node 264**
517 Nodes	31546662.000000	27079580.000000	18474784.000000	24867252.000000
525 Nodes	31546662.000000	27079578.000000	18474786.000000	24867252.000000
553 Nodes	32001642.000000	26772108.000000	17989778.000000	24559296.000000
569 Nodes	32017180.000000	26767040.000000	17992956.000000	24553196.000000
596 Nodes	32017506.000000	26766934.000000	17993026.000000	24553070.000000
636 Nodes	32007188.000000	26770278.000000	17990872.000000	24557104.000000
663 Nodes	32538370.000000	28052528.000000	19014136.000000	25811914.000000
667 Nodes	32538370.000000	28052528.000000	19014136.000000	25811914.000000
698 Nodes	32594738.000000	28115778.000000	19068098.000000	25875004.000000
706 Nodes	32594706.000000	28115788.000000	19068080.000000	25875014.000000
744 Nodes	32838102.000000	27948954.000000	18795202.000000	25707818.000000
784 Nodes	33311032.000000	28901404.000000	19768558.000000	26643800.000000

804 Nodes	33309160.000000	28901948.000000	19767716.000000	26644428.000000
852 Nodes	33317656.000000	28899480.000000	19771536.000000	26641578.000000
925 Nodes	33732420.000000	29602924.000000	20619044.000000	27333920.000000

Table (9) Resultant Displacement at top Nodes

		Displacement M Loc1	
Mesh Refinement	Node 6	Node 51	Node 187
517 Nodes	0.0174916890	0.0159827230	0.0160374050
525 Nodes	0.0174913260	0.0159823580	0.0160370380
553 Nodes	0.0174911130	0.0159820820	0.0160367000
569 Nodes	0.0174905880	0.0159815510	0.0160361680
596 Nodes	0.0174909810	0.0159829720	0.0160381850
636 Nodes	0.0174911410	0.0159831550	0.0160383810
663 Nodes	0.0174908680	0.0159829800	0.0160382740
667 Nodes	0.0174909610	0.0159829760	0.0160382200
698 Nodes	0.0174906810	0.0159826480	0.0160379150
706 Nodes	0.0174905510	0.0159825180	0.0160377850
744 Nodes	0.0174929540	0.0159844350	0.0160393680
784 Nodes	0.0174931570	0.0159844480	0.0160394740
804 Nodes	0.0174932460	0.0159845170	0.0160395220
852 Nodes	0.0174933060	0.0159846040	0.0160396300
925 Nodes	0.0174936260	0.0159844590	0.0160392000

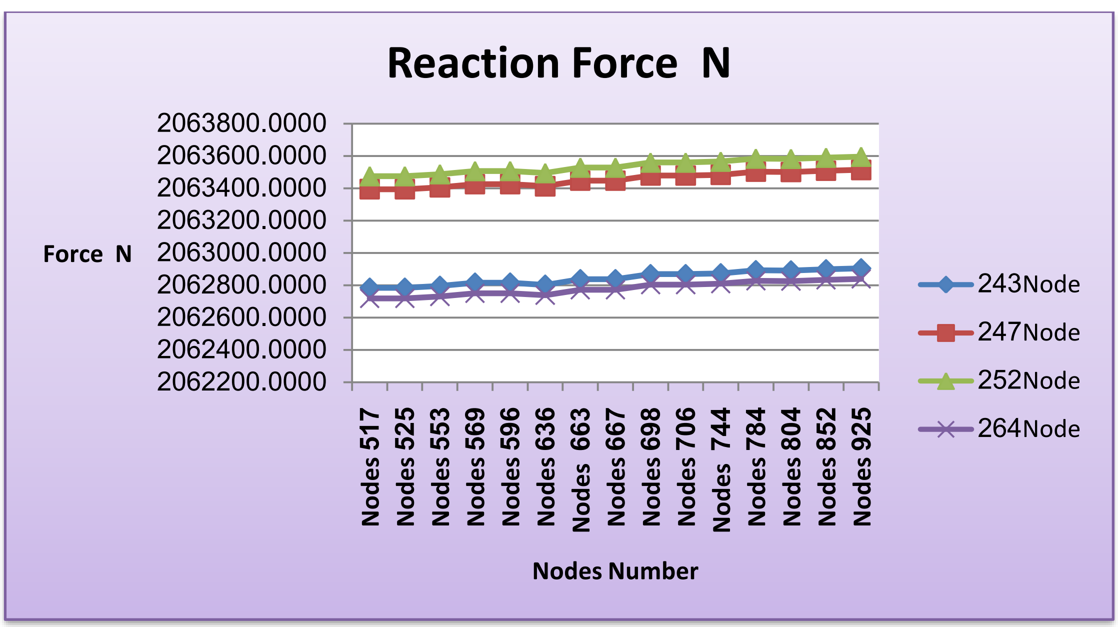


Figure (10) Resultant Reaction Forces at Supports

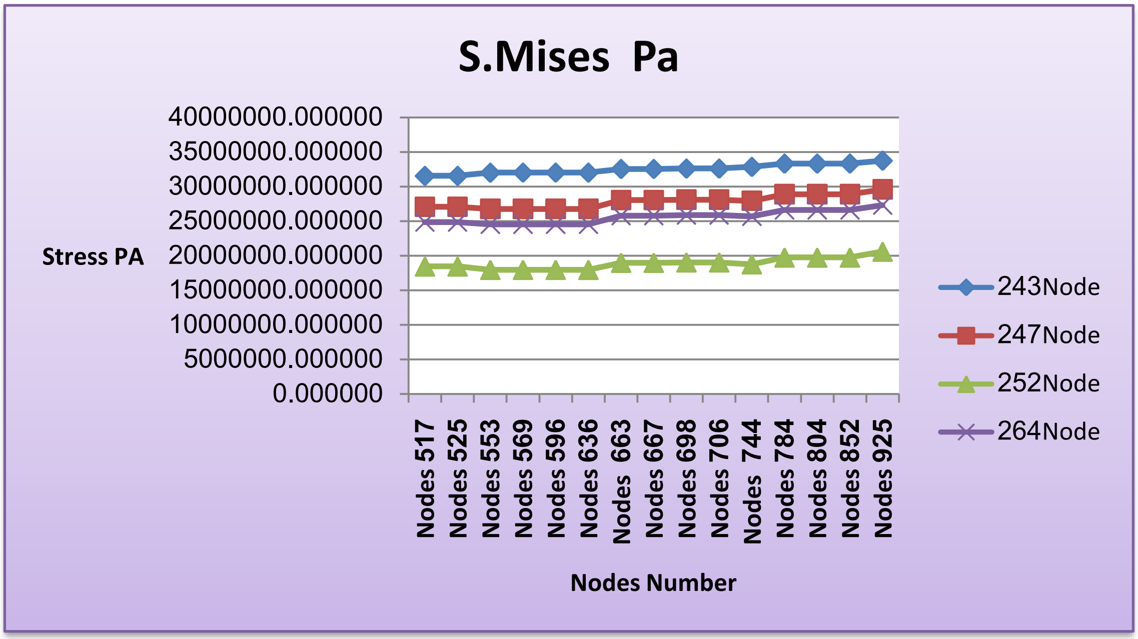


Figure (11)S.Mises of Nodes at Supports

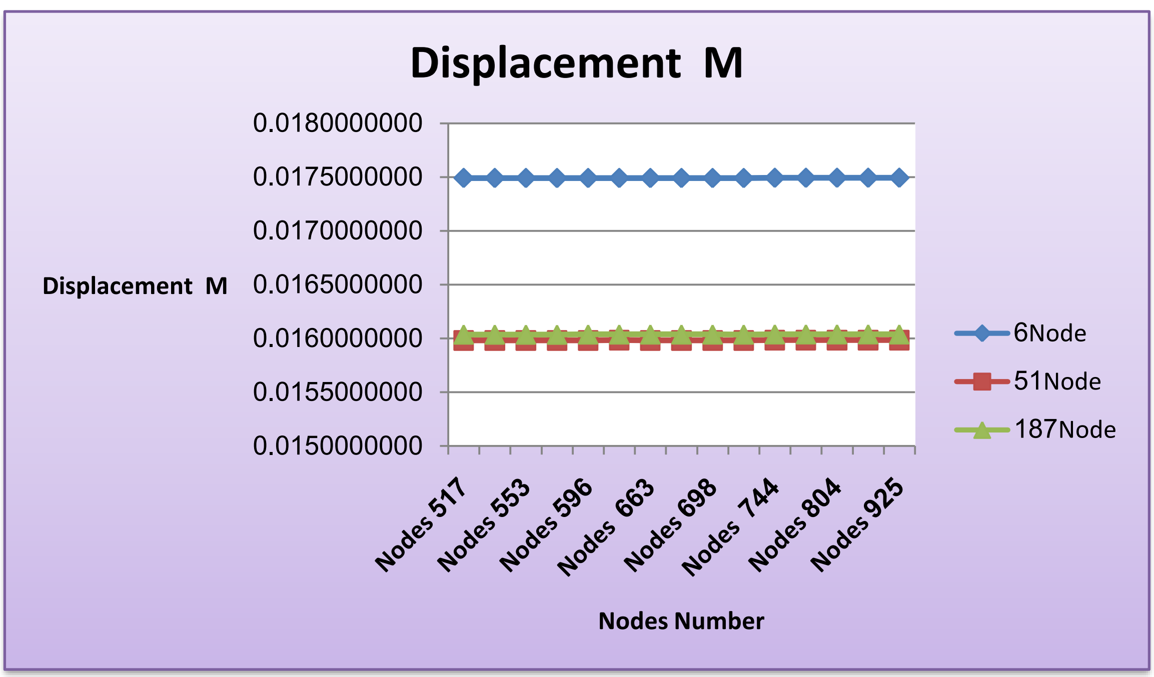


Figure (12) Resultant Displacement at top Nodes

The Figures (13) and (14) are showing the un-deformed shapes and deformed shapes with contour plots for Beam elements design and Truss elements design.

Figure (13) Beam element design

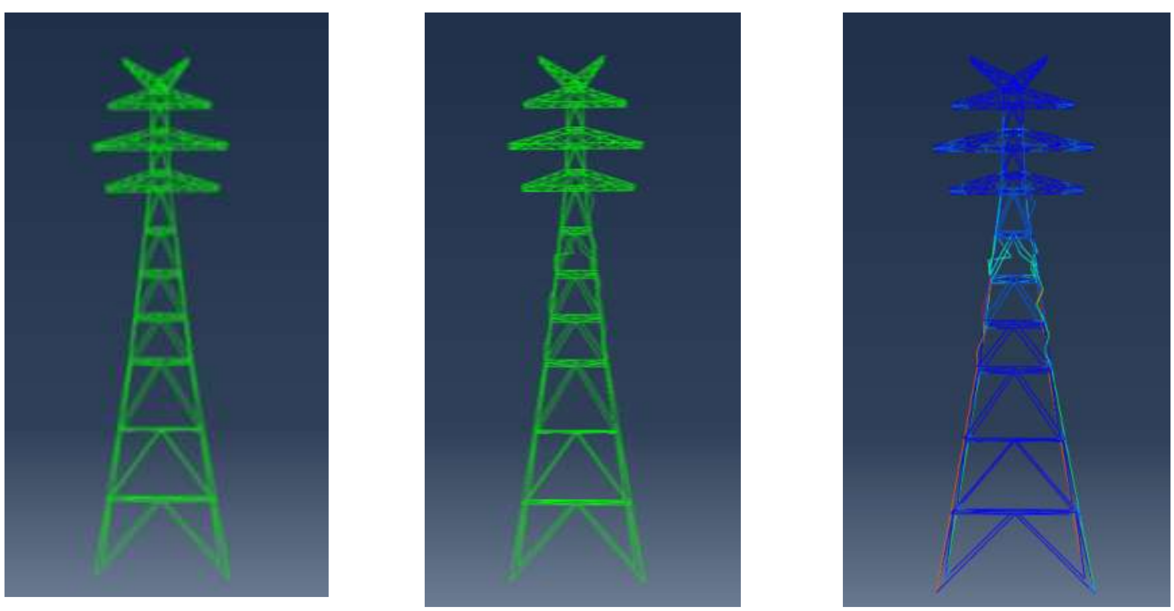


Figure (14) Truss element design

The Figures (15) and (16) are showing the un-deformed shapes and deformed shapes with contour plots for Beam elements design and Truss elements design.

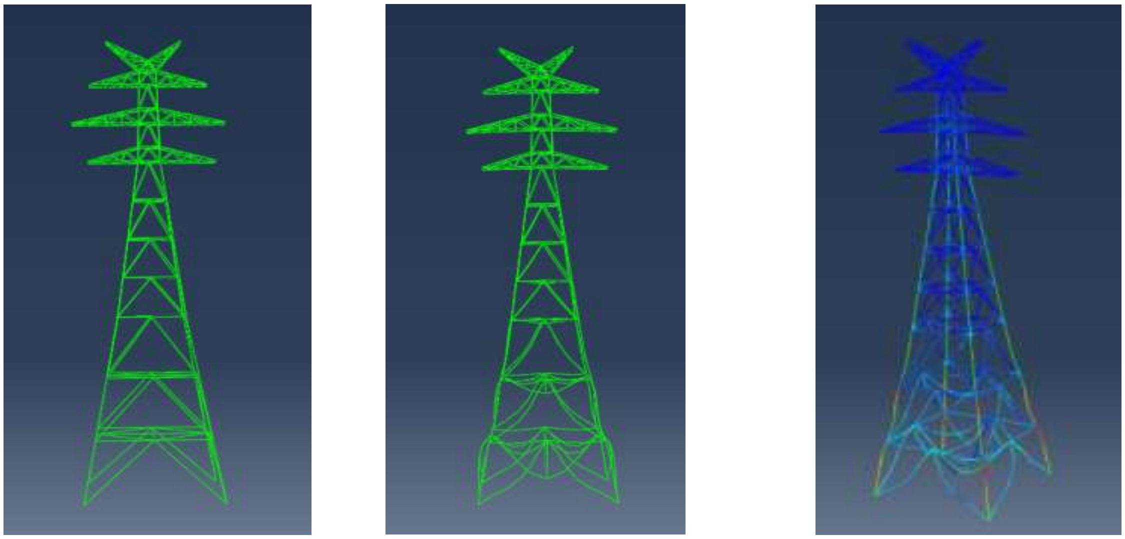


Figure (15) Fixed boundary condition of the supports

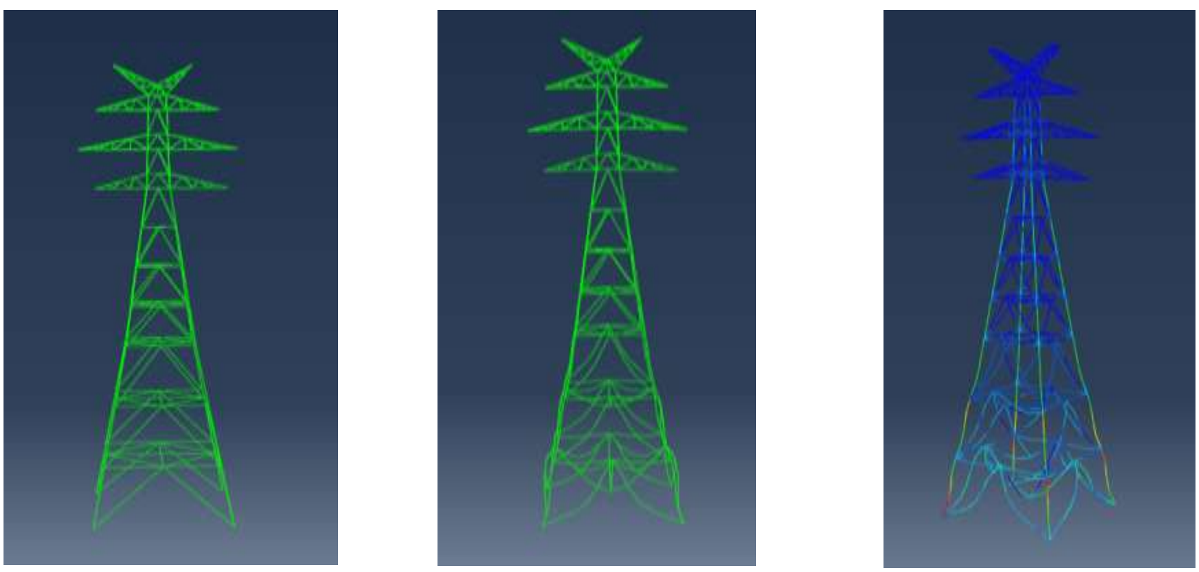


Figure (16) Pinned boundary condition of the supports

III. Sensitivity Analysis

Sensitivity analysis has been widely used in engineering design to gain moreknowledge of complex model behavior and help designers make informed decisionsregarding where to spend the engineering effort. In deterministic design, sensitivityanalysis is used to find the rate of change in the model output by varying input variables one at a time near a given central point, often called local sensitivity analysis. For designunder uncertainty, sensitivity analysis is performed with interaction effects of variables, but is seldomused to evaluate the nonlinear effect and the total effect (including linear, nonlinear main effects and interaction effects), informationthat is critical for ranking variable importance. Sensitivity analysis in general is the studyof how the output uncertainty of a model is apportioned to themodel input parameters uncertainties. It is assumed that a modelY is a function depending on a set of input parameters X, then Y =f (X1, X2, . . . ,Xn).

Sobol's method:

Sobol’s method is a global sensitivity analysis (SA) techniquewhich determines thecontribution of each input (or group ofinputs) to the variance of the output. The usual Sobol sensitivityindices include the main and total effects for each input, but themethod can also provide specific interaction terms.

Uncertainty Analysis with Variance Based Methods:

Variance-based methods for sensitivity analysis were first employed by chemists in the early 1970s (Cukier*et al.*, 1973). Cukier and colleagues not only proposed conditional variances for a sensitivity analysis based on first-order effects, but were already aware of the need to treat higher-order terms and of the underlying variance decomposition theorems (Cukier*et al.*,1978).

Conditional Variance:

Consider the generic modelY = f (X1,X2 …,Wk.) (5)Assume that each Xi has a nonull range of variation or uncertainty.
Determine now what happens to the uncertainty of Y if one factor Xi is kept fix at a particular value x_i.

Let VX_i (Y/Xi = x_i) be the resulting variance of Y taken over X_i (all factors except Xi). It is a conditional variance, as it is conditional on Xi being fixed to x_i.

Assigning Sensitivity Measure:

We may use
VX_i (Y/Xi = x_i) as a measure of relative importance of Xi, reasoning that thesmaller VX_i (Y/Xi = x_i), the greater the influence of Xi .

This however gives a measure which depends strongly on the choice of x_i. If we take instead the average of this measure over all possible points x_i, the dependence on x_i willdisappear so:

Exi (VX_i (Y/Xi)): This is the expected amount of variance that would be removedfrom the total output variance, if we were able to learn the true value of Xi.

First Order Sensitivity Index:

Si =Vxi (EX_i (Y/Xi))/V(Y) =V(E(Y/Xi))/V(Y) is defined as the first-order sensitivity index of Xi of Y.
Exi (VX_i (Y/Xi)) + Vxi (EX_i (Y/Xi)) = V(Y)

Higher Order Sensitivity Indices:

Given two generic factors Xi ,Xj the following result holds:

V(E(Y/Xi,Xj)) = Vi + Vj + Vij
with
Vi = V(E(Y/Xi))
Vj = V(E(Y/Xj))
Vij = V(E(Y/Xi,Xj)) -Vi-Vj The term Vij is the interaction term between the factors Xi and Xj.
It captures part of the response of Y to Xi and Xj that cannot be written as a superposition of effects separately due to Xi and Xj .

Total Sensitivity Index:

STi = E(V(Y/X_Xi))=V(Y)Also :

STi = 1 – V(E(Y/X_Xi))/V(Y)

For three input variables ST1 = S1 + S12 + S13 + S123

Properties of Sensitivity Indices:

Si is the measure of main effects, gives amount by which we can reduce output variance if Xi could be fixed by definition
STi> Si or equal in case that Xi is not involved in any interaction with other terms
STi– Si is a measure how much Xi is involved in interaction with other variables

$\sum$i Si ≈ 1 for additive models
$\sum$iSTi≥ 1.
If
$\sum$iSTi≈ 1 then the model is additive.

Experimental design (Box-Behnken Method):

The experiments were performedaccording to the Box-Behnken design which is a kind of response surface methodology. It is well known that response surface methodology, or RSM, is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective isto optimize this response. It is an empirical modeling technique devoted to the evaluation of the relationship of a set of controlled experimental factors and observed results.

Sensitivity Analysis of the Transmission Tower models in static case:

By considering Box-Behnken response surface methodology for sampling we will have three input variables X1,X2 and X3 representing the Transmission tower load, Ground line load and Conductor line loads. The goal is to optimize the response variable y. It is assumed that the independent variables are continuous and controllable by experiments with negligible errors. Itis required to find a suitable approximation for the true functional relationship between independent variables and the response surface. We consider linear and quadratic terms in the model function with linear interaction between input variables as follows:

$Y=B0+ B1X1+ B2X2+ B3X3+B4X1X2+B5X1X3+B6X2X3+B7X1^2+B8X2^2+B9X3^2$(1)

We determine the coefficients of regression (B0, B1, B2, B3,B4,B5,B6,B7,B8 and B9) in the equation (1) by the least square method:

$b=(X' X)^{-1} X'Y$ (2)

WhereX' is the transpose of the matrix X and =$(X' X)^{-1}$ is theinverse of the matrix X' X.
Matrix X is shown in the table (10)

we need to run 15 models as an arrangement coded variables supporting on three levels of each input variable , these three levels are maximum value denoted by 1 , medium value denoted by 0 and minimum value which is denoted by -1 due to the Box-Behnken methodology.

Table (10) X Matrix linear and quadratic terms

		X1	X2	X3	X1X2	X1X3	X2X3	X1^2	X2^2	X3^2
Run 1	1	-1	-1	0	1	0	0	1	1	0
Run 2	1	1	-1	0	-1	0	0	1	1	0
Run 3	1	-1	1	0	-1	0	0	1	1	0
Run 4	1	1	1	0	1	0	0	1	1	0
Run 5	1	-1	0	-1	0	1	0	1	0	1
Run 6	1	1	0	-1	0	-1	0	1	0	1
Run 7	1	-1	0	1	0	-1	0	1	0	1
Run 8	1	1	0	1	0	1	0	1	0	1
Run 9	1	0	-1	-1	0	0	1	0	1	1
Run 10	1	0	1	-1	0	0	-1	0	1	1
Run 11	1	0	-1	1	0	0	-1	0	1	1
Run 12	1	0	1	1	0	0	1	0	1	1
Run 13	1	0	0	0	0	0	0	0	0	0
Run 14	1	0	0	0	0	0	0	0	0	0
Run 15	1	0	0	0	0	0	0	0	0	0

The outputs of the 15 models run in ABAQUS are shown in Tables (11),(12) and (13) .

Table(11) Reaction force at the supports

		Reaction Force N Loc1		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Run 1	209782.8000	212847.8600	237681.7200	233533.6600
Run 2	591388.0000	599802.9400	667650.6200	655800.5600
Run 3	215945.0300	218259.0200	243842.3000	240440.7700
Run 4	597549.1900	605213.3100	673810.6200	662706.8700
Run 5	195905.0600	198098.9500	220760.9700	217479.3400
Run 6	577511.7500	585056.1900	650731.3700	639747.2500
Run 7	229824.0500	233009.7800	260764.3700	256495.8400
Run 8	611425.9400	619960.9400	690730.4400	678760.5000
Run 9	383627.6300	388872.1600	432665.9700	425160.0600
Run 10	389788.7200	394282.5000	438826.0000	432066.2200

Run 11	417542.8100	423778.2800	472666.0300	464173.9400
Run 12	423704.5900	429189.1600	478826.4400	471080.6900
Run 13	403665.4700	409029.9400	455745.6900	448119.9100
Run 14	403665.4700	409029.9400	455745.6900	448119.9100
Run 15	403665.4700	409029.9400	455745.6900	448119.9100

Table (12) S.Mises at the Nodes

		S. MisesLoc 3 N/M2		
	Node 243	**Node 247**	**Node 252**	**Node 264**
Run 1	9757072.0000	21648976.0000	14704623.0000	10525485.0000
Run 2	30759056.0000	62196008.0000	43231936.0000	28557784.0000
Run 3	9772078.0000	22107212.0000	14944354.0000	10922144.0000
Run 4	30774060.0000	62654240.0000	43471664.0000	28954440.0000
Run 5	9733159.0000	20381350.0000	14039970.0000	9612390.0000
Run 6	30735142.0000	60928380.0000	42567280.0000	27644688.0000
Run 7	9795991.0000	23374836.0000	15609008.0000	11835239.0000
Run 8	30797974.0000	63921868.0000	44136320.0000	29867536.0000
Run 9	20226648.0000	40425744.0000	28183760.0000	18430208.0000
Run 10	20241652.0000	40883984.0000	28423490.0000	18826868.0000
Run 11	20289480.0000	43419236.0000	29752800.0000	20653058.0000
Run 12	20304484.0000	43877472.0000	29992528.0000	21049718.0000
Run 13	20265566.0000	42151608.0000	29088144.0000	19739964.0000
Run 14	20265566.0000	42151608.0000	29088144.0000	19739964.0000
Run 15	20265566.0000	42151608.0000	29088144.0000	19739964.0000

Table (13) Displacement at the top Nodes

		Displacement M Loc1	
	Node 6	**Node 51**	**Node 187**
Run 1	0.00989823	0.00927759	0.00943499
Run 2	0.02648541	0.02475812	0.02492596
Run 3	0.01124009	0.00962783	0.00994596
Run 4	0.02782246	0.02511664	0.02544844
Run 5	0.00966115	0.00837697	0.00856751
Run 6	0.02624305	0.02386460	0.02407117
Run 7	0.01147326	0.01053494	0.01082404
Run 8	0.02806293	0.02601310	0.02630829
Run 9	0.01727186	0.01593769	0.01605562
Run 10	0.01864359	0.01630844	0.01658583
Run 11	0.01912222	0.01810250	0.01830873
Run 12	0.02042963	0.01844581	0.01881822
Run 13	0.01885066	0.01719143	0.01743586
Run 14	0.01885066	0.01719143	0.01743586
Run 15	0.01885066	0.01719143	0.01743586

Table (14) Sensitivity Indices for the three outputs

	Reaction Node 243	Stress Mises node 243	Displacement Node 51
unconditional V x1, x2, x3	**2.98705E+16**	**3.31834E+18**	**6.61E+01**
V x1	7.1406E+14	2.49793E+18	1.450464
Vx2	2.47323E+14	5.97792E+14	6.69E-27
Vx3	1.47454E+16	4.73309E+16	47.955966
Vx1 x2	8.02683E+14	7.45218E+16	-6.69E-27
Vx1 x3	5.22923E+15	6.8769E+17	16.680336
Vx2 x3	7.77936E+15	1.06384E+16	0.000000E+00
Vx1x2x3	3.52467E+14	-3.74681E+14	0.000000E+00
V(Y)	**2.98705E+16**	**3.31834E+18**	**6.61E+01**
Sx1	0.023905191	0.752766527	0.02194787
Sx2	0.008279839	0.0001801480	0.00000000
Sx3	0.493643206	0.014263429	0.72565158
Sx1 x2	0.026872104	0.02245756	0.00000000
Sx1 x3	0.175063485	0.207239299	0.25240055
Sx2 x3	0.260436348	0.003205949	0.00000000
S x1 x2 x3	0.011799827	-0.000112912	0.00000000
ST X1	0.237640607	0.982350474	0.27434842
ST X2	0.307388118	0.025730745	0.00000000
ST X3	0.940942865	0.224595764	0.97805213
TOTAL ST	**1.48597159**	**1.2326769836**	**1.25240055**

The results of the sensitivity Indices for the three outputs (Reaction force, S.Mises and Displacement) are shown in the Table (14).

IV. Discussion And Conclusion

The results of the models analysis in ABAQUS show that when the design elements are Beam elements, this will lead to deformation in the cross arms of the transmission tower as shown in Figure (13), and when the design elements changes to Truss elements this will increase the magnitudes of all the outputs (Reaction force, S.Mises and the Displacement) with a large quantity and large deformation with failure can be seen in the middle of the Transmission tower modelas shown in Figure (14) due to high stress concentration in that area and weak design.

When the boundary conditions of the supports of the Transmission tower is changed from pinned to fixed, this will decrease the magnitudes of the reaction force at the supports and increase the magnitude of the S.Mises of the nodes at the supports which can be seen as shown in Figure (15) and (16), but it will not change or it has a negligible effect on the magnitude of the Displacement at the top nodes of the Transmission tower.

Mesh refinement of the models will increase the magnitude of the outputs(Reaction force and S.Mises)by a reasonablevalue which is approximately linear in the action, but is obvious that it has a very small effect on the Displacement magnitude which is increasing by a very small value that can be neglected.
The results of the sensitivity indices shows that all the properties of the sensitivity are applied as shown below:

Total ST ≥ 1 which is the total sensitivity indices of all input variables and is equal or more than one unity, and the magnitude of the first order sensitivity indices of all variables don't exceed one unity. The third interaction sensitivity index S x1 x2 x3 is negative for S.Mises output, so it can be removed because it has no influence on the output variance.

Conclusions show that:

1- The variance of the input variable X3 (Conductor line load) is the most influencing factor in the variance of the Reaction force magnitudes at the supports and the variance of the Displacement magnitude at the top nodes of the transmission tower. This action can be confirmed because the load of the conductor line is too large in magnitude compared to the ground line load and the transmission tower load.
2- The variance of the input variable X1 (Transmission tower load) is the most influencing factor in the variance of the S.Mises magnitudes at the nodes near the supports of the Transmission tower.
3- The variance of the input variable X2 (Ground line load) has a small influence in the variation of the Reaction force magnitudes at the supports and has very small influence in the variation of the S.Mises magnitudes at the nodes near the supports but it has no influence(approaches zero) in the variance of the Displacement magnitudes at the top nodes of the transmission tower.

Recommendation for Future Works

1- I recommend researchers to make more transmission tower models with different topology in the truss arrangement to search the effect of multiple topologies on the sensitivity analysis of the transmission towers.
2- Modeling the conductor lines and the ground lines between two transmission towers to simulate the deformed shape of the cables beside the transmission towers and their contribution to the final result analysis.
3- Using other response surface methodologies such as Latin hypercube methodology in the sensitivity analysis step and compare the results to identify the most efficient method.

References

1- Andrea Saltelli, Marco Ratto, Terry Andres, Francesca Campolongo, Jessica Cariboni, Debora Gatelli, Michaela Saisana,Stefano Tarantola ,Global Sensitivity Analysis the primer,JohnWiey and sons limited, England, 2008.

2- Holger Keitel, GhadaKaraki , Tom Lahmera, Susanne Nikulla, VolkmarZabel , Evaluation of coupled partial models in structural engineering using graph theory and sensitivity analysis, Engineering Structures 33 (2011) 3726–3736, 2011.

3-Tom Lahmer, Thomas Most, Sensitivity Assessment for Coupled SimulationModels,Research Training Group "Model Validation" 1462, Bauhaus-Universit ¨ at Weimar,Germany, 2009.

4- Graham Glen, Kristin Isaacs, Estimating Sobol sensitivity indices using correlations, Environmental Modeling & Software 37-157-166, 2012.

5- Chen, W., Jin, R., and Sudjianto, A., Analytical Variance-Based Global Sensitivity Analysis in Simulation-Based Design under Uncertainty, ASME Journal of Mechanical Design. 127(5), 875-886, 2005.

6- OguzPerincek, MetinColak, Use of Experimental Box-Behnken Design for the Estimation of Interactions Between Harmonic Currents Produced by Single Phase Loads, International Journal of Engineering Research and Applications(IJERA),Vol.3,Issue2, March -April2013, pp.158-165.

7- Electrical Engineering(2013),http://www.electrical4u.com/electrical-transmission-tower-types-and-design/Accessed on 20th July 2013.