SDU International Technologic Science
Vol. 4, No 2, November 2012
pp. 115-123

OPTIMAL DESIGN OF TRANSMISSION TOWERS USING GENETIC ALGORITHM

Abdullah Fakhir MOHAMMED*, Mustafa ÖZAKÇA, Nildem TAYŞİ

Abstract

This study deals with the computational analyzes and weight optimization of transmission towers subjected to static loading. The finite element method is used to determine the stresses and displacements. An automated analysis and optimization procedure which integrate finite element analysis and numerical methods have been used for optimization. Also, a FORTRAN based genetic algorithm is implemented to search the optimum design. Three dimensional power transmission towers are dealt and size design variables are considered to demonstrate the efficiency of size optimization. Finally, the results that are obtained from this program by using different design variables are compared.

Keywords: Transmission towers, finite element method, optimization, genetic algorithms

1. Introduction

Transmission towers are the most important part of the systems for transferring the electrical power and its distribution. These structures are designed to support the conductors and ground wires of electrical power lines. A linear analysis is generally sufficient for the analysis of a transmission tower.

The structure cost usually accounts for 30 to 40 percent of the total cost of a transmission line. Therefore, selecting an optimum structure becomes a crucial part of a cost-effective transmission line design. A structural study usually is performed to determine the most suitable structure configuration and material based on cost, construction, and maintenance considerations and amount of electricity (Chen, 2001).

One of the numerous available analytical and numerical techniques, the Finite Element (FE) method has been the most popular method used in the analysis of transmission tower. Generally, the stiffness matrix method is employed in the model of the transmission tower. However, in spite of the rapid progress in high-speed computation, due to the large number of degrees of freedom needed for accurate modelling, detailed three-dimensional finite element analysis of transmission tower is still time consuming. Because it needs extensive data input and it produces massive output with solving enormous dimension matrices, which often shows the physical behavior of the transmission tower. Standard FE matrix displacement methods are used in this study for 3D static analysis, such as those mentioned in Textbooks in Engineering analysis. (Kasımali, 2012; Seyerlind, 1984; McGuire, 2000)

* Gaziantep Üniversitesi, İnşaat Mühendisliği Bölümü, 27310, Gaziantep. E-posta: green77park@yahoo.com.

Optimization is an automated design procedure in which the computers are utilized to obtain the best results. The numerical methods of structural optimization, with applications of computers automatically generate a near optimal design (converge to solve) in interactive manner. A program was modified and used to automate analysis and optimization of the structure written in FORTRAN language based FE analysis and Genetic Algorithm (GA) optimization technique (Tayşi, 2005).

2. Transmission Towers

Transmission towers are constructed to transport high voltage from the source to consumers. They reduce the number of locations from a maintenance point of view (longer span) to get proper ground clearance and to have strong support to be able to withstand wind load. The tower is a balanced structure with four legs covering the spans of 250 meters and above can be adopted for tower line.

As shown in Figure 1 transmission towers are consist of a pylon with crossarms connected by hanging insulator for supporting conductors and at the top earth wire with extra accessories like spacer and vibration dampers.

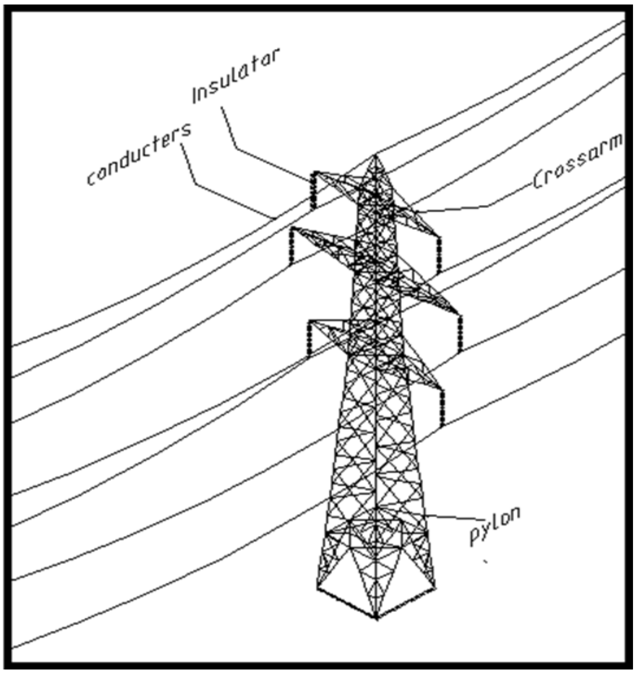

Figure 1. Transmission line tower

Generally transmission towers in line alignment classified to many standard types as mentioned below:

Tangent suspension towers: straight line and deviation angle up to about 2°. These towers are designed to withstand to the ice load, wind load and broken conductor loads. Hence 90 percent of the lines are of this type and the structural optimization tools become important to reduce the total weight of the structure under service condition.

Angle towers (semi-anchor towers): deviation angle greater than 2°. They must withstand the transverse load from the line tension and its components produced by this angle. Mainly for angle towers are classified into the types below (Grigsby, 2001);

- Light angle: from 2° to 15° angle of the line deviation.
- Medium angle: from 15° to 30° angle of the line deviation.
- Heavy angle and dead end: from 30° to 60° angle of the line deviation.

Transmission tower materials; Metals; galvanized steel and aluminum rods, bars and rolled shapes, fabricated plate and tubes. Concrete; spun with pre-tensioned or post-tensioned reinforcing cable, statically cast, nontensioned reinforcing steel and single or multiple piece. And other types of wood as grown and glued laminated, plastics, composites and variation of all the above.

Depending on their style and material contents, structures vary considerably in how they respond to loads. Some are rigid or flexible. Those structures that can safely deflect under loads and absorb energy while doing so, provide an ameliorating influence on progressive damage after the failure of the first element (Grigsby, 2001).

3. Loadings and Loading Cases on Transmission Tower

Transmission line design must consider loadings from many sources. These loads on a transmission line tower consist of three mutually perpendicular systems of loads acting vertically, normal and parallel to the direction of the line (Grigsby, 2001).

Transverse load, The loads were carried by the points of conductor and ground wire support with the direction perpendicular to the direction of the line as shown in Figure 2 including the wind load distributed over the transverse face of the structure of the tower.

Longitudinal load, This load acts in the direction parallel to the line on the tower structure and creates unequal conductor tension in the tower structure.

Vertical load, This type of load arises at the ends of the cross arms and on the peak point of ground wire downward and consist of the following vertical components:

- Weight of conductor itself and the weight of the ice if included in the covering weight span.
- Weight of insulators and accessories.
- Extra loads to be include for the weight of the man with maintenance tools.

Weight of the structure, The weight of the structure is unknown till the complete design of the structure is complete. First we put the initial weight of the structure by assuming reasonable cross section area and geometry of the tower and checking for design with the requirement of the codes and stress constraints.

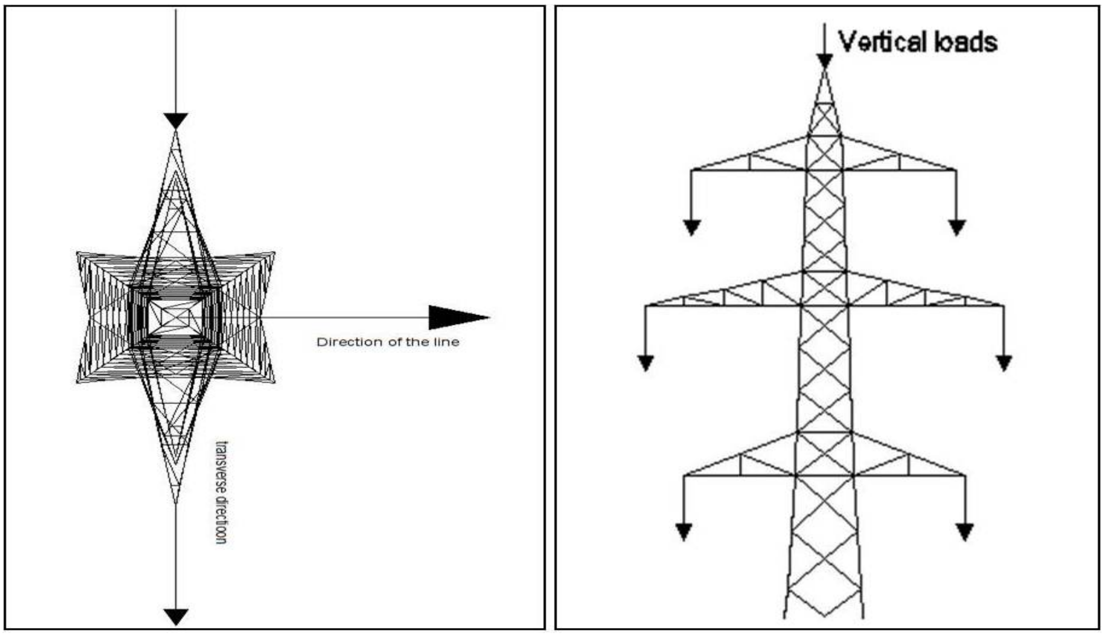

Figure 2. Direction of loading for transmission tower

4. Finite Element Matrix stiffness method

FE matrix stiffness method is a recent effective method of analysis in the engineering structures. Its effective and common application is supplementary with the availability of modern computers and effective computer programs. FE permits carrying out detailed analysis of any sophisticated 2D and 3D engineering structures and takes into account different features of a structure and loading. The method demands a set of new ideas. They are finite element, global and local coordinate systems, possible displacements of the ends, stiffness matrix of separate element and structure in whole, etc.

This method uses the idea of the displacement method and covers its further developments. Arbitrary structure should be presented as a set of finite elements and three aspects of any problem such as, statically, geometrically and physically should be presented in matrix form. FE matrix stiffness method does not require constructing of the bending moment diagram caused by unit primary unknowns in the primary system. Instead it is necessary to prepare few initial matrices according to strong algorithms and perform matrix procedures by computer using the standard programs (Karnovsky and Lebed, 2010).

5. Structural optimization

Structural optimization used in this study is one of search technique based on the GAs method have been used for many years with success in the design of structures and structural components. GAs, firstly examined by Holland at the University of Michigan as search procedures based on natural selection is the basic engine of Darwinian natural selection and survival of the fittest (Ghasemi et al., 1997)

The observations were made on the discrete optimal design because they note that almost all design variables in many of structural optimization problems were discrete in nature using the proposed GAs. This feature makes GAs a perfect choice for optimization problem, when the optimum solution produced will be feasible from both a calculation and practical point of view. S. Rajeev et. el. (Rajeev, S. and Krishnamoorthy, 1992) found that the number of function evaluations is greater, hence the number of analysis. Though the gradient computations was absent, GAs is slower compared to traditional optimization algorithms. This pitfall is not a great problem today to be a limitation in the computing environment, particularly considering the presence of robust computers with relatively low cost.

5.1 Fundamentals of simple genetic algorithm

The major elements of normal genetics are reproduction, crossover, and mutation they are utilized in the genetic search procedure. GAs varies from the traditional methods of optimization in the following points:

1. A population of points are used for starting the procedure instead of a single design point. Then a number of points are used as candidate results, GAs is fewer probable to catch confined in a local optimum.

2. The objective function value only is used by GAs. The mathematical forms are not used in the search procedure.

3. In GAs the design variables are characterized as strings of binary variables that relate to the chromosomes in normal genetics. Thus the search method is normally applicable for solving discrete and integer programming problems. For continuous design variables, the string length can be varied to get any preferred solution.

4. The objective function value relating to a design direction plays the role of fitness in normal genetics.

5. During every new generation, a new group of strings is created by using randomized parents choice and crossover from the old generation (old set of strings). Although randomized, GAs are not simply arbitrary search techniques. They efficiently explore the new arrangements with the available information to obtain a new generation with better fitness or objective function value (Rao, 2009).

6. Three dimensions (672) bars transmission tower example

The three dimensional transmission tower truss shown in Figure 3 with 672 elements and 306 nodes which is the considered configuration in present study. The following material properties are used: elastic modulus $E = 200 \times 10^9$ N/m^2, material density, $\rho = 7860$ kg/m^3 and Poisson's ratio=0.3. Nodes at the bottom of tower are fully constrained. Tower is loaded due to earth wire and conductor loading as shown in the Figure 3. Nodes A, B, C and D are loaded with different loads magnitudes as seen in Table 1.

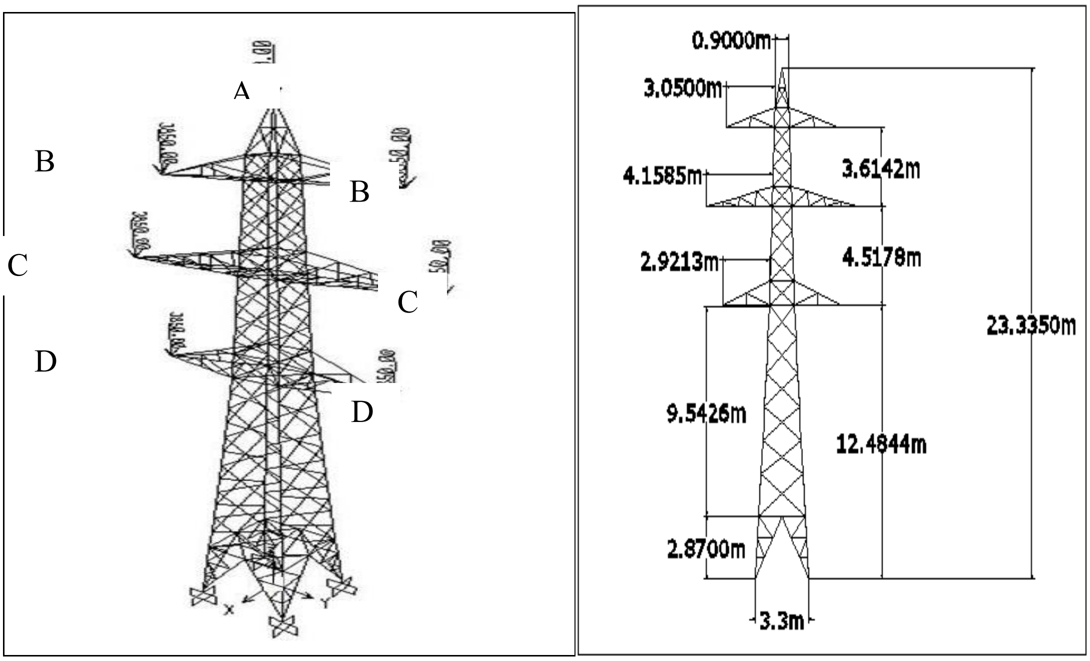

Figure 3. Transmission tower, dimensions (m) and applied loads (N)

Table 1. Loading of transmission tower

Node number	Load (N) (Z-direction)
B, C, D	-3850
A	-1900

Deflections at specific points shown in Figure 3 are given in Table 2 and compared with SAP 2000 results. As can be observed in Table 2 results of FORTRAN code are in good agreement with SAP2000 results.

Table 2. Comparisons of present method and SAP 2000

	Present	SAP2000
Nodes	deflections u_3(m)	
D	-1.59×10^{-4}	-1.58×10^{-4}
C	-3.29×10^{-4}	-3.29×10^{-4}
B	-2.08×10^{-4}	-2.08×10^{-4}
A	-1.23×10^{-4}	-1.23×10^{-4}
Weight(Kg)	48608	48606

Having confirmed the computational accuracy, the optimization procedure is employed to minimize the weight of transmission tower. The design constraints are maximum tensile stress of $\sigma_t = 400.0\times10^6$ N/m^2, maximum compressive stress of $\sigma_c = -400.0\times10^6$ N/m^2 and maximum displacement $0.1\,\text{m}$ for all nodes in all directions.

Initial design cross sectional areas of the members were 0.01 m^2, thickness and width of rectangular cross section of members are considered for the GA pseudo-continuous design variables. Minimum and maximum values of dimensions are 0.05 and 0.15 m respectively. The member groupings for design variable assignment are shown in Figure 4 and classified by;

- Rectangular cross section (with 12 thickness and 12 width, totaly 24 design variables)
- Square cross section (width and thickness are equal so totaly 12 design variables)
- Rectangular cross section (width of sections are constant and 12 thickness design variables)
- Rectangular cross section (thickness of sections are constant and 12 width design variables)

The GA parameters are specified to be; population size=100, number of generation 100, design variable binary string length $m = 8$.

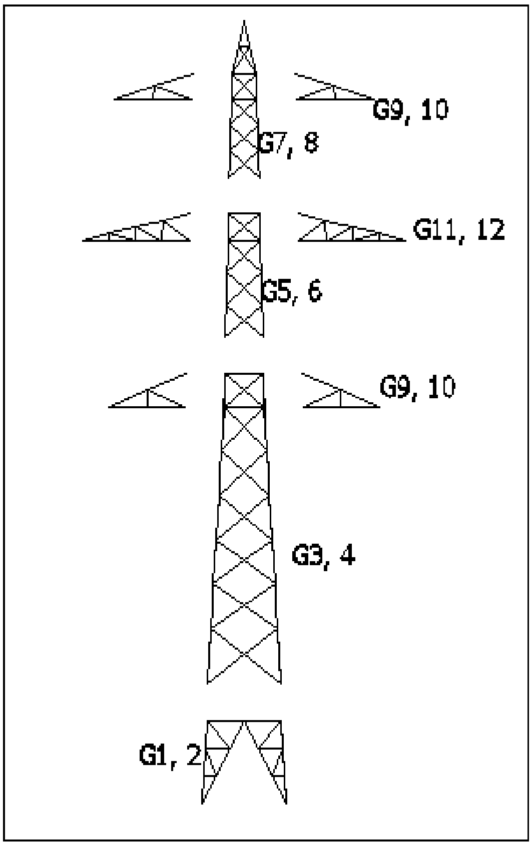

Figure 4. Transmission tower grouping of design variables

Discussion of Results: The resulting tower design of the GA for pseudo-continuous design variables are presented in Table 3. The optimum structure weight is obtained for various sections in square meters with the algorithm. For initial design cross sectional areas of the members were 0.01 m^2 and initial total weight is 48606 Kg. Percent improvements are shown in Table 3 and, size optimization results with 64.68 % reduction of total weight of the initial value. Figure 6 shows the objective function improvements with respect to iteration numbers of a typical optimization problem for rectangular section.

Table 3 Comparison of optimum transmission towers with various design variables

DV	Present GA (m^2)			
	Rectangular section DV=24	Square section DV=12	Width fixed section DV=12	Thickness fixed section DV=12
DV_1	0.00054	0.00453	0.0081	0.00751
DV_2	0.00873	0.0141	0.0119	0.00916
DV_3	0.0119	0.00924	0.00022	0.00721
DV_4	0.00131	0.00043	0.00697	0.0102
DV_5	0.00765	0.00022	0.0066	0.00539
DV_6	0.00683	0.011	0.00557	0.0116
DV_7	0.00053	0.00697	0.00295	0.00344
DV_8	0.00181	0.00873	0.0115	0.00152
DV_9	0.00132	0.0108	0.00533	0.00022
DV_{10}	0.00100	0.00645	0.00447	0.00405
DV_{11}	0.000669	0.00127	0.00405	0.00447
DV_{12}	0.00123	0.0135	0.0103	0.0115
Optimum weight (Kg)	17163.85	39729.30	33795.14	44085.71
Percent improvements	64.68	18.26	30.47	9.30

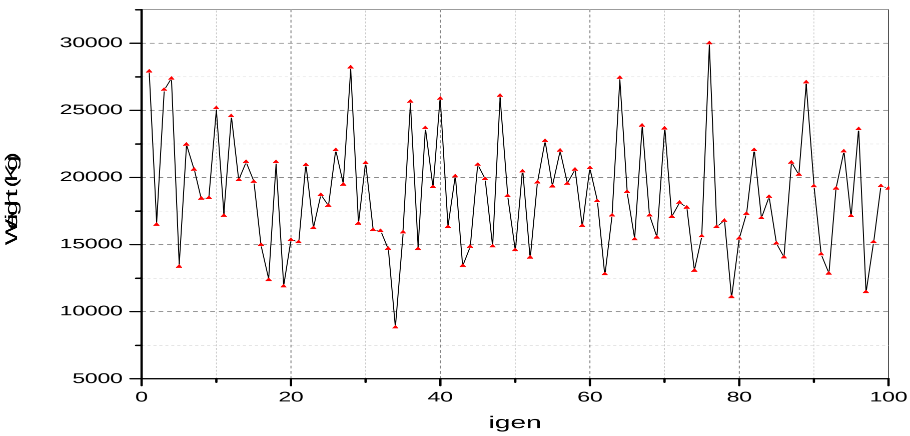

Figure 5. Weight improvements of an optimization problem.

7. Conclusions

The size optimization of transmission tower plays an important role in minimizing the amount of material used in the construction of the structure for economic point of view. If we reduce the amount of steel used for one tower the cost reduction on the total amount of steel material in the projects would be remarkable. Optimization algorithm starts following the implementation of the analysis of the structure. A FORTRAN program which uses the finite element methods based numerical analysis was modified to achieve size optimization based on genetic algorithm to perform the analysis and design of the space frame which is a complex structure in a three dimensional system.

The algorithm searches all the available solution under the constraints of allowable stress and displacement to converge solution or find the best solution. The best solution is selected among all available results satisfying the constraints by the algorithm. The design variables was cross sectional dimensions, while the solution is done for various types of sections. For all design variables significant decrease in weight of material with respect to the stress and displacement constraints were obtained. When comparing the result with the literature it's found that the optimum objective function is close to that presented in literature.

REFERENCES

Chen. W.F. (2001). Handbook of Structural Engineering. CRC Press LLC, Chapter 15 page 1035.

Ghasemi. M.R., Hinton E. and Wood. R.D. (1997). Optimization of trusses using genetic algorithms for discrete and continuous variables. *ADOPT Group*, EC16,3.University of Wales Swansea, UK.

Grigsby. L.L., (2001). The electric power engineering handbook. CRC Press LLC.

Karnovsky. I.A. and Lebed O. (2010). Advanced methods of structural Analysis. Springer, New York Dordrecht Heidelberg London

Kasimali. A. (2012). Matrix analysis of structures. 2nd edition, Southren illinois university-Carbondale.

McGuire. W., Gallagher. R.H., Ziemian R.D. (2000). Matrix Structural Analysis, 2nd edition, John Wiley & Sons, Inc.

Rajeev, S. and Krishnamoorthy, C.S. (1992). Discrete optimization of structures using genetic algorithms. Journal of Structural Engineering. 118(5), 1233-1250.

Rao. S.S. (2009). Engineering optimization Theory and practice. 4th edition, John Wiley & Sons, Inc.

Segerlind. L.J. (1984). Applied Finite element analysis. John wiley and Sons, Michigan state university.

Tayşi. N. (2005). Analysis and Optimum Design of Structures Under Static and Dynamic Loads. Gaziantep Üniversitesi Bilimleri Enstitüsü, Doktora tezi.