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Analysis and Optimum Design of Transmission Line Tower using Cuckoo Search Algorithm

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***Abstract*— Optimization techniques will enable the construction of efficient and light structures which is very much essential for the effective design of large structures. Optimization using the meta – heuristic search techniques is getting more importance due to its feasibility and applicability to structures with large number of design variables. These meta-heuristic search techniques are developed by mimicking the concepts of nature. Cuckoo search algorithm is one such meta-heuristic algorithm developed based on the breeding behavior of cuckoo species. This technique is applied to optimize the weight of the transmission line tower. Since transmission line tower is the large structure which comprises nearly 40 percent of the total cost of the transmission line, it is necessary to develop an optimum design to reduce the total cost. Initially the tower is analysed and optimized using STAAD pro and the results are compared with the optimization results obtained using Cuckoo Search (CS) algorithm. The results show that the CS algorithm gives better results.**

***Keywords*— Optimization; cuckoo search; heuristic algorithm.**

I. INTRODUCTION

Electric power consumption is increasing rapidly all over the world especially in the developing countries. This led to the increase in the power stations and transmission lines from the power stations to load centers. There is a significant increase in the transmission network in the last few years. The transmission towers costs nearly 40 percent of the total cost of the transmission line. Thus the reduction in the cost of the transmission line will enhance the economy of the country. This optimum design of the large structures with large number of design variables can be easily performed using the meta-heuristic search techniques.

The major purpose of the optimization techniques is to provide the best results from the available resources. First, the constraints are set out and then the objective function, which is either the weight or cost of the structure, should be minimized or maximized. Various mathematical methods have been developed to solve the engineering optimization problems. The scope of these mathematical techniques depends upon the type of the engineering problem to be solved. Due to the limited approachability and computational drawbacks of these mathematical techniques, meta-heuristic search techniques are developed and used in optimizing the engineering structures. Nature is the principal source of inspiration for these meta-heuristic search techniques. Several algorithms such as Genetic Algorithm, Particle Swarm Optimization algorithm, Cuckoo search algorithm, Firefly algorithm, Ant colony optimization, Glow warm optimization and Tabu search are developed. Out of these several algorithms Cuckoo Search algorithm is chosen for the optimization of the transmission line tower weight. This algorithm is developed based on the breeding behavior of cuckoo species combined with levy flight. The effectiveness of this algorithm to solve the optimization of transmission line tower is checked with two different configurations of transmission line towers.

II. ANALYSIS AND DESIGN OF TOWER

A high voltage transmission line structure is a complex structure in that its design is characterized by the special requirements to be met from both electrical and structural point of view. The electrical aspects decide the general shape of the tower with respect to its height and the length of its cross-arms that carry the electrical conductors. Thus the manoeuvrability in arriving at the optimum tower design is reduced by these electrical considerations. Though there is a scope for the weight minimization and optimum geometry shaping of a transmission line tower. The steps involved in the analysis and optimization are shown in the figure 1.

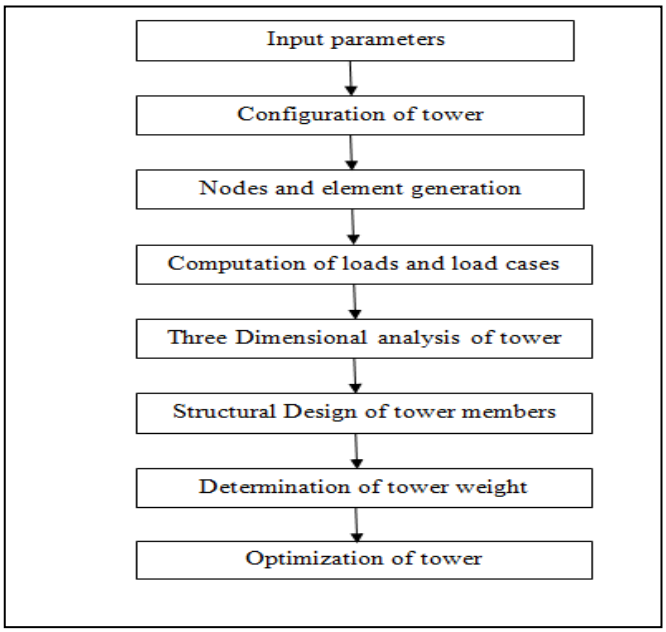

Fig. 1. Methodology Chart

The first stage is the configuration of the tower which depends upon the tower type, sag correction, wind pressure, temperature condition, possible ice loads, ground wire, conductors, insulators and terrain profile. Configuration of a transmission line tower basically requires a computation of conductor and ground wire sags and their permissible maximum working tensions under the critical wind pressure and temperature conditions. With regard to the panelling and nodes and element generation of the tower, it is normal practice to adopt a K or X type of bracing. The panel heights are obviously dependent on the choice of the bracing angle used in each of these panels.

In the static analysis of the tower, the primary loads that are considered are the wind and the dead weight loads with appropriate factors of safety. The additional load case of a broken conductor or ground wire loading condition also considered for the transmission tower. The extra load, normally termed as the longitudinal load, acts in a direction normal to the cross arm axis in each of the broken conductor and ground wire condition cases. The next stage is the structural design of the tower members in order to find out the weight of the tower. Then the optimization of the tower is done by considering design variables. Member sectional areas are usually treated as the design variables for weight optimization. The joint coordinates are included as design variables in the shape optimization. Finally, the optimization using the meta-heuristic algorithms is performed to find out the optimum cross sectional areas.

III. CUCKOO SEARCH ALGORITHM

Cuckoo Search Algorithm is a new meta-heuristic algorithm which is based on the obligate brood parasitic behavior of some cuckoo species in combination with the Levy flight behavior of some birds and fruit flies. Cuckoos are fascinating birds, not only because of the beautiful sounds they can make, but also because of their aggressive reproduction strategy. Cuckoo Search algorithm contains a population of nests or eggs. For simplicity, the following representations are used; where each egg in a nest represents a solution and a Cuckoo egg represents a new one. If the Cuckoo egg is very similar to the host's egg, then this Cuckoo's egg is less likely to be discovered, thus the fitness should be related to the difference in solutions. The aim is to employ new and potentially better solutions (Cuckoos) to replace a not-so-good solution in the nests. The pseudo code of optimum design algorithm is as follows:

- Initialize the Cuckoo Search algorithm parameters.
- Generate initial nests or eggs of host birds.
- Generate new Cuckoos by Levy flights.
- Alien eggs discovery.
- Termination Criterion.

IV. 244 BAR TRANSMISSION LINE TOWER

The 244 bar transmission tower is selected as a case study to show the efficiency, accuracy and reliability of the CS algorithm in terms of member grouping strategies. Parameters of the optimization process are taken accordingly. The isometric view of the tower is shown in the figure 2.

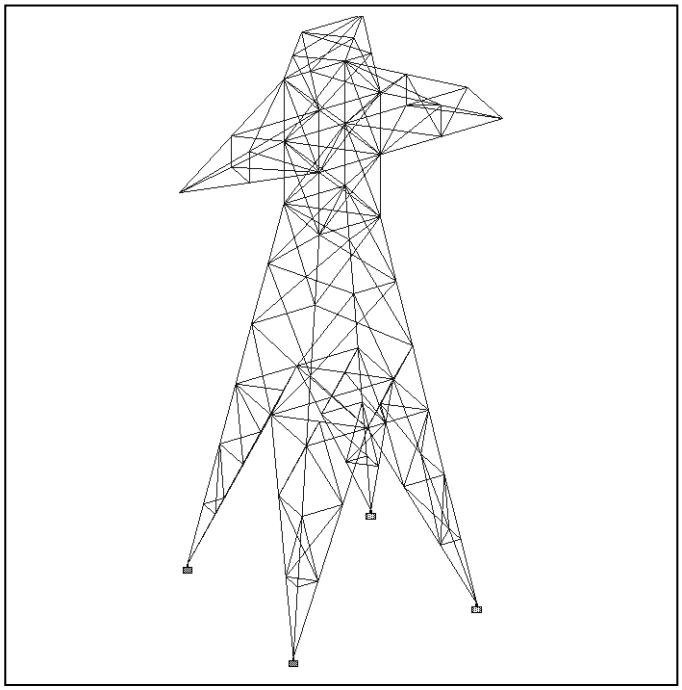

Fig. 2. Isometric view of 244 bar tower

The objective function is the weight of the tower and the constraints are the stress constraints and the deflection constraints. The tower has 77 nodes and 244 members. The members of the tower are grouped into 26 different groups and the design criteria obeying IS:802 is adopted. The loadings are applied at the end of the cross arms. Then it is analysed and optimized using STAAD pro and Cuckoo Search algorithm.

V. 472 BAR TRANSMISSION LINE TOWER

A 400 kV double circuit steel transmission line with a suspension towers (2^{o}angle deviation) is considered as a case study. The model of tower is square base, self-supporting type with angle sections. The isometric view of tower model in STAAD Pro software is given in figure 3. The tower has totally 148 nodes and 472 members. These members are grouped into 49 groups for the purpose of optimization. The grouping is made based on the symmetry of the members. The total number of Indian Standard angle sections considered is 72.

The three dimensional analysis of the tower considering all the members of the space truss as primary members has been performed using STAAD pro. The load and loading combinations criteria on the ground wire, conductor and the towers are found using IS:802. The loading calculations on tower due to conductor and ground wire were taken for normal condition as well as broken wire condition considering transverse as well as longitudinal direction wind. The tower loadings are determined on the basis of wind pressures, temperature variations and broken wire conditions. The factors of safety adopted in the designs have a great bearing on the cost of the structures and they have to be chosen so that the structures prove economical as well as safe and reliable. Rule 76(1) (a) of the Indian Electricity Rules, 1956 specifies the following factor of safety to be adopted in the design of the steel transmission line towers:

- Under Normal Conditions – 2.0
- Under Broken Wire Conditions – 1.5

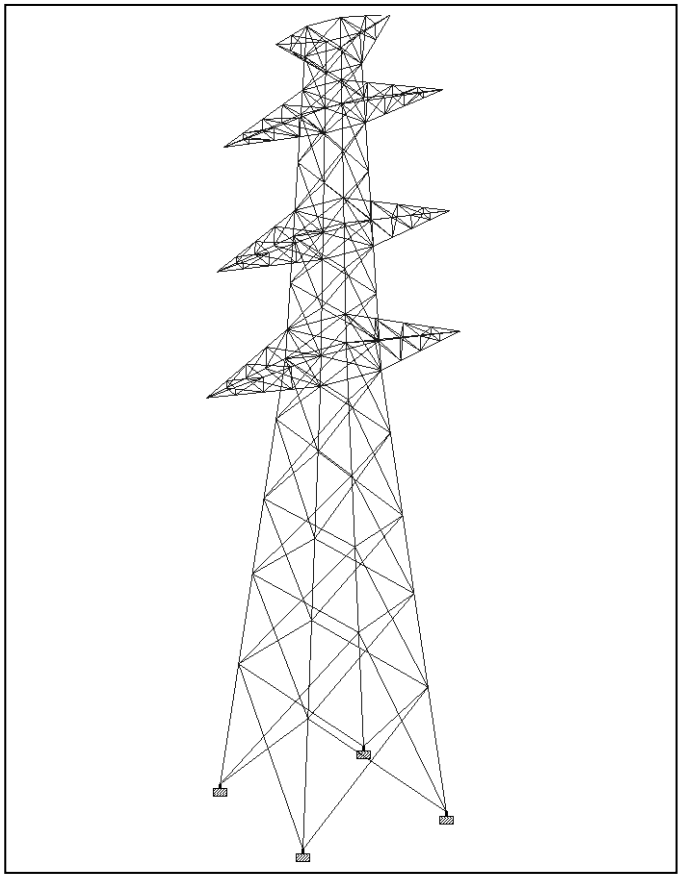

Fig. 3. Isometric view of 472 bar tower

VI. RESULTS AND DISCUSSIONS

The optimized weight of the transmission line tower obtained from STAAD pro and meta-heuristic algorithms according to IS:802 is listed in table 1. The optimum result obtained from Cuckoo Search is found to be the best result when compared to the results from STAAD pro.

TABLE I. OPTIMUM WEIGHT OF TOWERS

Tower	Weight of tower		
	Initial weight	***STAAD pro results (kN)***	***CS algorithm result (kN)***
244 bar	347.403	51.505	46.97
472 bar	932.598	384.166	346.268

The optimum weight of the 244 bar transmission line tower is found after 400 iterations and the optimum weight for 472 bar transmission line tower is found after 1000 iterations. The iterations history is shown in figure 3 and figure 4.

VII. CONCLUSION

The optimization results from CS algorithm shows that the weight of the 244 bar transmission line tower with 26 design variables can be reduced upto 8 percent and the weight of the 472 bar transmission line tower with 49 design variables can be reduced upto 10 percent. Thus the performance of the algorithm to optimize the weight of the tower depends upon the type of the tower and the number of design variables. However from the feasible results obtained, Cuckoo Search algorithm is found to be one of the best meta-heuristic algorithms to optimize the large steel transmission line towers.

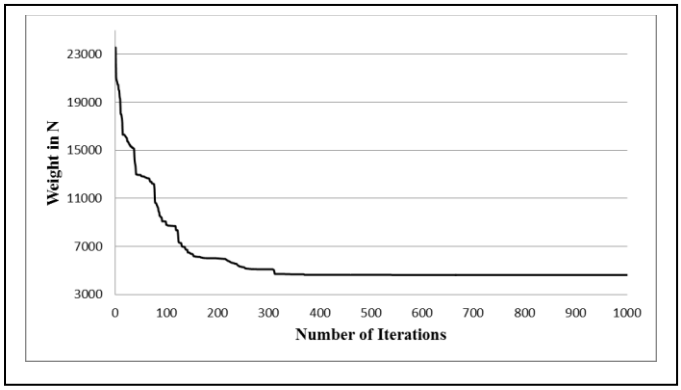

Fig. 4. Iteration History of 244 bar tower

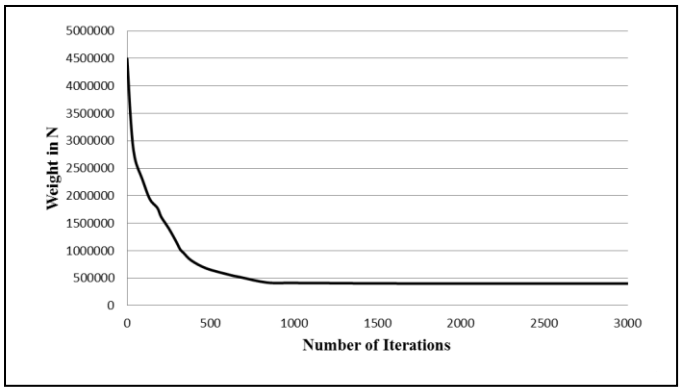

Fig.5. Iteration History of 472 bar tower

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