Weight Optimization of double circuit steel transmission line tower using PSO algorithm

R.Nagavinothini, C.Subramanian

Abstract— **Optimization techniques play an important role in the design of structures as it enables the construction of lighter, more efficient structures. Due to the limited approach and complexity of mathematical optimization methods for solving engineering problems, many new meta-heuristic algorithms, based on the evolution of nature have been developed. Among various meta-heuristic algorithms, Particle Swarm Optimization (PSO) Algorithm is found to be well suited to handle complex engineering problems. One such complex design problem is the weight minimization of transmission line tower because it involves large number of design variables. Since transmission line towers are the large structures that constitute the major part in the total transmission line cost, minimizing the weight and cost of these structures is an obvious need. In this paper, PSO algorithm is used for the weight optimization of 472 bar steel transmission line tower with 49 design variables and the results are compared with the optimization results performed using STAAD pro. The results shows that the weight of the tower can be optimized up to 7.4% from the optimized weight obtained from STAAD pro.**

***Index Terms*— Algorithm, Meta-heuristic, Swarm Transmission Line tower.**

I. Introduction

The increase in electric power consumption has led to the increase in the power stations and the interconnections between them to enhance economy. Thus the investment in these transmission facilities has increased considerably. Transmission line towers constitute about 40% of the total cost of the transmission line. Therefore, selecting an optimum structure becomes an integral part of cost effective transmission line design. The efficient design of the transmission line towers is based on both electrical and structural considerations. The general shape and height of the tower is based on the electrical aspects and so the optimization can be performed to reduce the weight and to arrive at the best geometry shaping [2].

Optimization is the process of finding the best solutions from which a designed can derive maximum benefit from available resources. It also enables the construction of efficient structures and also maintains safety and reliability. Over the past decades, large numbers of optimization techniques have been developed for solving complex optimization problems. Mathematical methods are not completely efficient for all types of optimization problems. Thus, meta-heuristic algorithms inspired from nature are developed. Among the popular bio-inspired algorithms, Particle Swarm Optimization (PSO) Algorithm has proven useful in various in various engineering design applications.

In this paper, the weight optimization of 472 bar transmission line tower is performed using PSO algorithm. The objective function is the weight of the structure. The constraints that enhance reliability are the stress parameters, height of the tower and the general shape of the tower. The concept and the steps involved in PSO are described first and then the design and optimization of transmission line tower taken from literature [14] is presented. The optimization using PSO method gives better results. The percentage of weight that can be optimized depends upon the type of the transmission tower and the number of design variables. It is found that the weight is reduced by the reduction in the size of the sections in the bracings that is subjected to very low stresses.

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II. Particle Swarm Optimization Algorithm

The PSO algorithm was first proposed by Kennedy and Eberhart in 1995. It is based on the sharing of information among the members of the special species. This algorithm has wide application in several engineering fields. This algorithm is robust and well suited to handle non-convex design spaces with discontinuities. With small number of function evaluations, PSO algorithm provides better or same quality of results [7].

A. Computational Algorithm

As with all numerical based optimization approaches the PSO process is iterative in nature, its basic algorithm is constructed as follows:

1) Initialize a set of particles positions and velocities randomly distributed throughout the design space bounded by specified limits.
2) Evaluate the objective function values using the design space positions. A total of *n* objective function evaluations will be performed at each iterations, where *n* is the total number of particles in the swarm.
3) Update the optimum particle position at current iteration *k* and global optimum particle position.
4) Update the position of each particle using its previous position and updated velocity vector.
5) Repeat steps 2-4 until a stopping criterion is met. For the basic implementation the typical stopping

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criteria is defined based on a number of iterations reached [7].

III. Transmission Line Tower

Transmission Line towers are the structures used for supporting extra high voltage electric transmission lines. These lines also carry heavy currents and this has necessitated the use of tall towers to support the transmission line which carries both extra high voltage and heavy currents. In spite of several classifications of towers, tangent suspension towers are used in large numbers in a transmission line. The tower line configuration depends upon the requirements of the transmission system ranging from single to double circuit vertical structures. The tower outline is determined by tower height, base width and top hamper width. The loads acting on the tower under normal condition and broken wire condition should be determined by considering the tower geometry and location of the tower. Then the analysis is carried out and finally the members of the tower have to be designed for both tension and compression. The axial stresses in tension and compression are considered as the constraints. The effective slenderness ratio with respect to different end conditions is also considered and the values are checked with the limiting slenderness ratio given in table 1. The computer aided design followed in this paper uses a fixed geometry and minimizes the weight of the tower. The geometry is described by the coordinates of the nodes [1].

Table 1. Limiting Values of Slenderness Ratios

Sl.No	Members	Slenderness Ratio
1	Leg members and main members in the cross-arm in compression	150
2	Members carrying computed stresses	200
3	Redundant members and those carrying nominal stresses	250
4	Tension members	355

IV. Tower Configuration

A 400 kV double circuit steel transmission line with a suspension towers (2^o angle deviation) is considered as a case study [15]. The model of tower is square base, self-supporting type with angle sections. The tower is analyzed using STAAD pro and the optimization is done for weight minimization. The isometric view of tower model in STAAD Pro software is given in figure 1.

The tower shown above has totally 148 nodes and 472 members. These members are grouped into 49 groups for the purpose of optimization. The grouping is performed on the basis of the position of the tower and symmetry. The total number of angle sections considered is 72. The total height of the tower is 50 m. The minimum ground clearance given for the tower is 8 m. All the other parameters are chosen accordingly. The load and loading combinations on the tower due to conductor and ground wire in normal condition as well as broken wire condition considering transverse and longitudinal direction wind are found using IS:802. 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 [1]:

1) Under Normal Conditions – 2.0
2) Under Broken Wire Conditions – 1.5

The analysis is performed using STAAD pro and the weight is optimized. The results obtained from STAAD pro is then compared the optimization result using PSO algorithm.

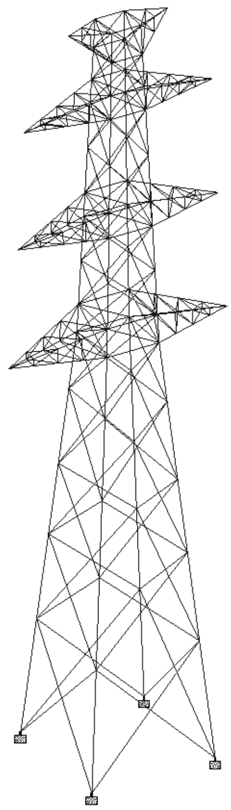

Fig 1. Isometric view of 472 bar Transmission Line Tower

V. Results and Discussion

The initial weight and the optimized weight of the 472 bar transmission line tower obtained from STAAD pro and PSO algorithm are given in table 2. Optimization using PSO algorithms is effective when compared to the optimization performed using STAAD pro. The optimum results found shows the effectiveness of the meta-heuristic algorithms for optimizing transmission line tower structures. The iteration history is shown in figure 2. The best weight is found after 1000 iterations.

Table 2. Optimum weight of 472 bar tower

Initial Weight of the Tower (kN)	Optimum Weight of 472 bar transmission line tower (kN)	
	STAAD pro	PSO
932.598	384.166	355.771

The optimum design variables obtained from PSO algorithm are given in table 3. These design variables are the

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angle sections assigned to the members that are grouped into 49 groups.

Table 3. Optimum Angle sections

Design variables	Optimum Angle Sections
1	ISA 20X20X6
2	ISA 25X25X3
3	ISA 90X90X10
4	ISA 30X30X4
5	ISA 25X25X3
6	ISA 80X80X10
7	ISA 35X35X6
8	ISA 20X20X3
9	ISA 35X35X3
10	ISA 40X40X4
11	ISA 130X130X15
12	ISA 200X200X18
13	ISA 25X25X3
14	ISA 20X20X3
15	ISA 25X25X3
16	ISA 60X60X10
17	ISA 200X200X12
18	ISA 65X65X10
19	ISA 150X150X18
20	ISA 55X55X6
21	ISA 150X150X15
22	ISA 55X55X6
23	ISA 150X150X12
24	ISA 45X45X4
25	ISA 45X45X4
26	ISA 130X130X15
27	ISA 40X40X5
28	ISA 25X25X5
29	ISA 130X130X12
30	ISA 40X40X5
31	ISA 110X110X10
32	ISA 20X20X3
33	ISA 25X25X5
34	ISA 20X20X3
35	ISA 25X25X3
36	ISA 45X45X4
37	ISA 20X20X3
38	ISA 25X25X3
39	ISA 20X20X3
40	ISA 20X20X3
41	ISA 20X20X3
42	ISA 25X25X3
43	ISA 20X20X3
44	ISA 30X30X3
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48	ISA 20X20X3
49	ISA 20X20X3

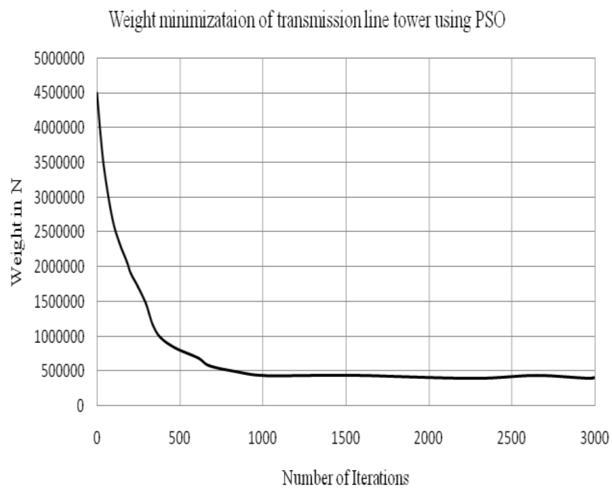

Fig 2. Iteration History

VI. CONCLUSION

Particle Swarm Optimization algorithm is found to be more efficient for optimizing the weight of transmission line tower with the small number of function evaluations. From the feasible results obtained from the optimization of the 472 bar double circuit transmission line tower, it is possible to say that the PSO algorithm is the effective optimization method. The weight of the 472 bar double circuit transmission line tower is reduced up to 7.4%. This weight reduction depends upon the type of the tower under study. The study can be further extended to compare the optimization of different meta-heuristic algorithms for the optimization of tower.

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