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A procedure for the size, shape and topology optimization of transmission line tower structures

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ABSTRACT

This paper presents a methodology for topology optimization of transmission line towers. In this approach, the structure is divided in main modules, which can assume different pre-established topologies (templates). A general rule for the templates creation is also presented, which is based in terms of the design practice and feasibility of prototype testing. Thus, these allow that the optimal solution has an important characteristic of direct industrial application. Furthermore, during the optimization process the size and shape of the structure are optimized simultaneously to the topology choice. For numerical examples, two structures were assessed. The first one is a transmission line tower studied in CIGRÉ (2009). Eight different load cases were considered. The second one is a single circuit, self-supported 115 kV transmission line tower. The structure was subjected to a cable conductor rupture scenario and a wind load hypothesis. In both examples the constraints from the ASCE 10-97 (2000) were applied. Due to the non-convex nature of the problem and to the presence of discrete variables in the procedure, the optimization was conducted through the Firefly Algorithm (FA) and the Backtracking Search Algorithm (BSA), which are two modern heuristic algorithms. The results for the size, size and shape, and size, shape and topology optimization are presented and discussed, as well as an analysis of the performance of the algorithms. It is shown that the proposed scheme is able to reduce up to 6.4% of the structural weight, when compared to a classical size optimization procedure on original structures.

1. Introduction

The structural optimization of trusses has been widely studied [3–23]. In contrast to some structures that are generally unique (e.g. bridges and buildings), the same design of a given transmission line tower is frequently built several times, up to hundreds of times in a single transmission line. Thus, cost savings and performance improvements obtained by structural optimization procedures can have a large impact in the entire transmission line.

Some studies, focusing on academic research, have already been performed in the context of optimization of truss towers, for instance, Rao [24], Natarajan and Santhakumar [25], Taniwaki and Ohkubo [26], Sivakumar et al. [27], Mathakari and Gardoni [28], Kaveh [29], and Noilublao and Bureerat [30]. Although they presented several advances, some important additional aspects must be taken into account for a direct industrial application concerning the optimal design of transmission line tower structures. One of the main issues not addressed in the previously mentioned works is related to constructive feasibility of the design and its performance in prototype testing.

On the other hand, some works addressing direct industrial applications, which take into account such aspects to some degree, can also be found in literature. Shea and Smith [31] addressed optimization of a full-scale transmission line tower. The structure is subjected to multiple load cases and code constraints. However, the optimal structural designs obtained do not agree with regular configurations normally acceptable for a construction and prototype testing. Besides, the procedure imposes the design to be symmetric in its four faces, which is not always used in transmission towers. París et al. [32] studied the shape optimization of a transmission line tower, subjected to multiple load cases and code constraints. Because the procedure is based on continuous design

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Fig. 1. Transmission line towers with staggered bracing: suspension (left) and angle (right) towers.

variables, then it is not able to ensure that the final design is composed by commercially available profiles. Guo and Li [33] performed the size, shape and topology optimization of a large-scale transmission line tower. The structure is subjected to one wind load case and code constraints. The topology optimization is performed in the inclined part of the tower body (below its waist) using two different methods. In both cases the optimal design is necessarily symmetric in the four faces of the tower. París et al. [34] performed the size and shape optimization of a transmission line tower subjected to multiple load cases considering discrete values of cross-sectional areas and code constraints. The optimization was performed by dividing the structure into blocks. Since the geometry of the blocks is changed independently, the final design presents differences between the slopes of the legs in each block. This makes the final design unfeasible from the constructive and prototype testing point of views. Additionally, the optimization procedure also imposes symmetry in the four faces of the design. Chen et al. [35] presented an approach where the tower body shape is selected first and then the components' types are optimized. The procedure considers discrete values of cross-sectional areas. In the process of tower body shape modification, the number of tower sections, the height of each section, and the type of diaphragm used are changed, considering stress and stability constraints. As in previous studies, symmetry on all faces is imposed.

The previous mentioned work basically adopts localized modifications strategies to update the structural topology. Note that the term *localized* is employed here to refer that the allowable changes are in the level of nodes and elements, which can be created or removed, and moved within certain intervals (i.e., small parts of the structure are modified). However, carrying out modifications to nodes and elements directly can lead to some other important drawbacks. The final design may not be significantly improved in comparison to size and shape optimization [31], it can be unfeasible from the constructive point of view [31], and only some part of the structure may be effectively optimized [33,35]. Furthermore, it becomes difficult to correctly evaluate effective buckling lengths when bars are removed from the structure [23].

Another important observation is that all the previously mentioned studies imposed symmetry according to all faces of the structure. However, this approach is not always adopted in the design of full-scale transmission line towers. Staggered bracing,

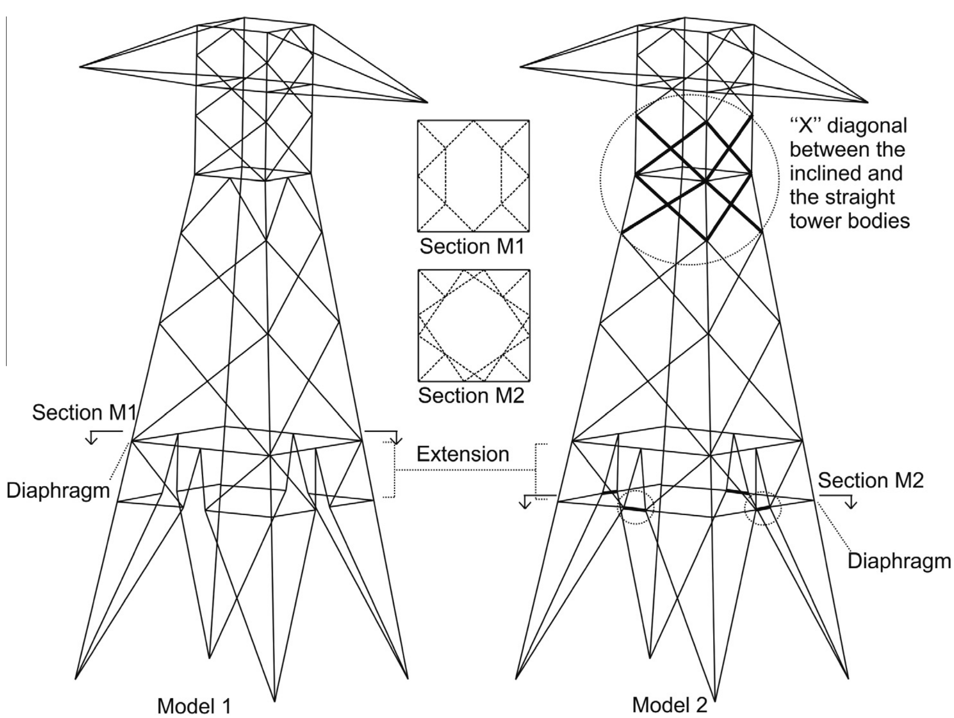

Fig. 2. Difference on the topology of transmission line towers.