Optimization Design of Transmission Tower Based on Intelligent Selection

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Abstract. In this work, the optimal design method for self-supporting transmission tower is put forward, whose procedure is that the tower body form is selected intelligently firstly and then the members types of tower are chosen. The case base of towers is established with application of object-oriented technology. Then, the knowledge of tower body is mined out with case based reasoning and data mining technology. At the same time, the structural regulations of tower in the standard are merged into the knowledge base. So, the intelligent selection system of tower structural scheme based on case reasoning and data mining is explored. A 500kV self-supporting tower is optimized according to above method and a real model test is conducted. Comparison between optimal tower and original tower indicates that weight of optimal tower is decreased by 3% and its ultimate bearing capacity is increased by 19%. Statistical analysis results of 20 optimal towers indicates that the weight is average reduced by 4.7%, the components of the optimal tower are stressed more uniformly and bearing capacity of the tower is enhanced 12% at least.

1. Introduction

The supports of EHV transmission lines are normally steel lattice towers. The cost of towers constitutes about 28 to 42 percent of the cost of transmission line and hence optimum tower design will bring in substantial savings [1]. Safety and economy are major issues in the design of civil engineering structures. The goal of structural optimization design is to achieve the best coordination of the units within the structure. At the same time, the performance of the material is most reasonable and meets the relevant requirements of the specification [2, 3].

At present, the transmission tower design procedure in China is usually type selection-analytical and calculation-full stress material selection-redesign. It is generally done in a few repetitive designs accounting to the designer's experience. In fact, it is still in the category of structural analysis, rather than the optimal design according to the active search optimal scheme.

2. Transmission line tower and design variables

One typical transmission tower is illustrated in figure 1. The tower is divided into three parts: the tower head, the tower body and the tower legs. In this work, the optimal design method for self-supporting transmission tower is put forward, whose procedure is that the tower body form is selected intelligently firstly and then components’ types of tower are chosen.

Structural layout optimization is the intelligent selection of inter-section layout, including structural shape, section type, tower slope, upper and lower opening dimensions, and section height dimensions. There are many restrictions on the size of the tower head, including clearance, height limit of each cross arm, cross arm spacing limit, etc. The optimization effect of the tower head structure is not
obvious for many reasons. Therefore, in this paper, the optimization design is mainly for the tower body.

Figure 1. One typical transmission line tower.

The optimization of the tower body includes four aspects: the shape of the tower structure, the type of section layout, the type and size of the member section, and the material of the component. Optimization of the tower body includes optimization of tower structure layout (tower structure shape, section layout type) and component (section type, specification, material). The tower head and tower legs are only optimized for components.

3. Intelligent selection of transmission tower
The optimal methods of tower are mostly designed for the tower whose shape is finalized. Only the angle bar section or section arrangement type is optimized, but not for the whole structure optimization. In this paper, the tower body type is selected intelligently first. The structure of the tower body is adjusted through intelligent selection. The arrangement of the towers is more reasonable, and the stress condition of the tower is improved. Then the angle bars types are designed optimally including the member type and cross section.

Conceptual design, preliminary design and detailed design are the three stages of the engineering structure design process, and the most critical step is conceptual design. Conceptual design plays a decisive role in the function and quality of the entire project, which is directly related to the success of the project and the design. Structural selection is the most important part of the conceptual design stage, and it is also one of the important decision-making tasks in the early stage of building structure design. The intelligent selection of tower structure mainly includes three parts: knowledge acquisition, knowledge determination and scheme generation [4, 5].

3.1. Knowledge acquisition
Knowledge acquisition of tower structure is an analysis and design process used to model tacit knowledge to be incorporated into the tower structure intelligent selection system. It includes static and dynamic knowledge acquisition process.

In the initial stages of knowledge acquisition, access to the target level of knowledge is the main task. The target level of knowledge here refers to the program and its corresponding set of attributes. Programs set and attribute set are primarily established by domain experts, the literature knowledge, norms rules knowledge, design examples knowledge etc.

Dynamic knowledge acquisition process of tower structure is shown in figure 2. First, the initial knowledge base of the tower structure is generated by way of an interactive session. Then, a tower structure type program is generated by the tower selection program and submitted to the structure program evaluation module. At last, optimal solution is obtained by decision module of tower structure program if it runs successfully. The learning system model illustrated in figure 3 is used in knowledge acquisition which is defined by H. Simon [6, 7].
3.2. Knowledge identification

Knowledge identification here is to determine the source of knowledge of the various types of tower structures. There are various classifications to tower structure, such as materials, structural systems and other partition. Figure 4 lists three kinds of section arrangement types and figure 5 lists three kinds of diaphragm arrangement types [8].

3.3. Scheme generation

The scheme generation system of tower structure intelligent selection consists of three parts: conventional database module, structure type intelligent generation module, relations finding module.

The tower structural information can be increased, deleted, modified and inquired in conventional database module. The structure type intelligent generation module contains intelligent segmentation to tower, intelligent selection of internodes and diaphragm surfaces, tower legs modeling function. Association rule mining is used to relations finding module [9].

4. Optimization of tower body components

The design variables of transmission tower body components are discrete variables because the components are used angle bar whose specifications such as width, thickness, etc. are discrete [10]. The following function can be used to express the mathematical model of the discrete variable optimization design:

\[
\begin{align*}
\min & \quad f(X) \\
\text{s.t.} & \quad g_j(X) \leq 0, \quad j = 1, 2, \cdots, m \\
& \quad x_i \in S_j, \quad S_j \subseteq S, \quad i = 1, 2, \cdots, n
\end{align*}
\]  

(1)
where \( f(X) \) is the objective function and \( X=(x_1, x_2, \ldots, x_n)^T \) is the vector of design variables. \( g_j(X) \) is the constraint function. The constraints of transmission tower optimization mainly include strength constraints, compression stability constraints, and slenderness ratio constraints.

The stress constraint is

\[
\sigma_j = \frac{N_j}{A_j} \leq f
\]

where \( \sigma_j, N_j, A_j, f \) are stress, axial force, section area, design value of tensile (compression) strength of member \( j \).

The stability constraint is

\[
\sigma_{cr} = \frac{N_j}{\varphi_j A_j} \leq f
\]

where \( \sigma_{cr} \) and \( \varphi_j \) are equivalent stability stress and axial compression buckling coefficient of member \( j \).

The slenderness ratio constraint is

\[
\lambda_j \leq \lambda
\]

where \( \lambda_j \) is the slenderness ratio of member \( j \). And \( \lambda \) is the allowable slenderness ratio of member \( j \).

5. Optimal design and true type test of a 500kV self-supporting tower

ZB12 tower which is designed by Hunan Electric Power Design Institute is re-optimized design according to the above optimization method. Un-optimized and optimized structural scheme of tower is shown in figure 6.

The weight of the former tower was optimized to 10.193 tons, and the weight of the optimized tower was reduced to 9.862 tons, which was reduced by 3.25% before and after optimization.

TTA which is programmed by Northeast Electric Power Design Institute is used to calculate the carrying capacity of tower. Then true type test of ZB12 tower is implemented in Beijing Electric Power Research Station. Figure 7 illustrate the true type test of ZB12 tower.

Among the measuring points of the tower body, only one section main member inner force increased by 5.33%, and the internal forces of the other main members and the oblique members were reduced, especially the internal force of the cross oblique members were significantly reduced. It
shows that this method can better optimize the section arrangement layout and reduce the internal force, thus reducing the bar specifications and reducing the tower weight.

After optimization, the internal force of only 7 of the 37 tested members increased, and the internal forces of the other members decreased, which qualitatively showed that the internal forces of the rods were reduced.

After structural optimization, the tower failure test showed that the failure load of the tower was 155% of the normal working load. However, the failure load of the tower which was not optimized is 130% of the normal working load. The carrying capacity of tower is greatly enhanced under extreme conditions and its safety reliability is improved.

Figure 7. True type test of an optimal design 500kV self-supporting tower.

In order to further verify the optimization effect of the method, 20 towers were selected from the major power design institutes across the country for optimization design, which further confirmed that the method can reduce the tower weight by 3%-5%, and at the same time, the ultimate loads carrying capacity of the towers were at least increased by 12%.

6. Conclusions
Optimum design of transmission line towers has been discussed in this paper. It has been shown that the intelligent selection can be applied successfully to the tower structural design. The tower body form is selected intelligently firstly and then components types of tower are chosen. According to this method, the tower carrying capacity can be improved while its weight is reduced.

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