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Research on Wind-induced Vibration Control of High-rise Steel Structures Based on Machine Learning Algorithm

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Abstract: In recent years, the research on vibration control of high-rise steel structures has developed vigorously, and many research results have been applied to practical projects. The main purpose of wind-induced vibration control of high-rise steel structures is to reduce the discomfort of occupants and the damage of precision equipment and non-structural components. This kind of high-rise steel tower structure is highly flexible, and under the action of strong wind load, the dynamic response of the structure is also great, which has a very adverse impact on the safety of the structure itself, the technological requirements of the building and the comfort level, etc. Therefore, it is increasingly important to effectively control the wind-induced vibration response of the structure. Machine learning algorithm is the research hotspot of gust prediction, and its advantage lies in that this kind of method can establish the nonlinear relationship between gust related variables and gust without depending on some specific parameters. Due to the uncertainty of the control system including structural system and control, the complexity of mathematical model and difficult to grasp dynamic characteristics, the wind-induced vibration control effect of high-rise buildings needs to be further improved. In this paper, the wind-induced vibration control of high-rise steel structures is described in detail by using machine learning algorithm.

1. Introduction

In recent years, the research on vibration control of high-rise steel has developed vigorously, and many research results have been applied to practical engineering. High rise steel structure buildings have light weight, small damping ratio, relatively flexible, more sensitive to wind load and concentrated wind vibration energy. Therefore, it is easier to realize wind vibration control [1]. The main purpose of wind vibration control of high-rise steel structure is to reduce the discomfort of residents and the damage of precision equipment and non structural components [2]. This kind of high-rise steel tower structure has strong flexibility. Under strong wind load, the structural dynamic response is also great, which has a very adverse impact on the safety of the structure itself, the process requirements of the building and comfort. Therefore, it is increasingly important to effectively control the wind-induced vibration response of the structure [3]. Steel structure TV Tower is a typical high

flexibility structure, and it has become a consensus to control it, especially this kind of structure with comfort requirements, although there are examples applied to practical engineering [4]. As a high-rise structure, TV tower is highly flexible and sensitive to earthquake and wind load. Because of the large displacement of the tower top, it is difficult to meet its normal use requirements. Therefore, the main goal of wind-induced vibration control of high-rise steel structure buildings is to reduce the acceleration response of the structure, not to reduce the story displacement of the structure [5]. The structure of control is divided into active control, passive control and hybrid control. The application of active control in practical engineering is limited due to the need of external input energy and the "time lag" in calculation method [6].

Machine learning method is the research hotspot of gust prediction. Its advantage is that this kind of method can establish the nonlinear relationship between gusts related variables and gust without relying on some specific parameters [7]. Due to the uncertain properties of the control system including structural system and control, such as nonlinearity, complexity of mathematical model and difficult to grasp dynamic characteristics, the wind-induced vibration control effect of high-rise buildings needs to be further improved [8]. This paper discusses the application of gust early warning in wind turbines by using the method based on machine learning and combined with the characteristics and actual needs of wind turbines [9]. Fuzzy control is a rule-based control method, and the induction of fuzzy rules and the establishment of rule base are the central links in the transition from actual control experience to fuzzy controller. Because people have limited knowledge of the controlled objects and the selection of control rules is too simple, the design of fuzzy controller is somewhat rough in some cases, which affects the control effect [10]. Applying machine learning algorithm to optimize the fuzzy rule base can improve the design of fuzzy controller and improve the control effect.

2. Effect of wind on high-rise structures

2.1 Natural wind characteristics

TV Tower is a major part of high-rise structure. Due to the large height of high-rise structure and relatively flexible bending stiffness, it is easy to produce large vibration and deformation under transverse load. Gust warning does not directly warn the unit related problems such as over speed, fault and temperature rise, but selects gust as the prediction object. Natural wind is the flow of air. Air flows from places with high pressure to places with low pressure to form wind. The wind speed observation time history records show that the downwind instantaneous wind speed includes long-period and short-period components [. Therefore, we divide the wind into mean wind and fluctuating wind. When the wind speed is relatively stable, the task of the unit is to operate stably and maximize the power generation benefit. At this time, it is required to reduce the sensitivity of the control parameters so that it can remain stable when the wind speed fluctuates slightly. If these parameters specially set to deal with gust remain fixed in all time periods, it will lead to the existence of potential safety hazards and the reduction of power generation efficiency. Considering the field level optimization and adding the influence of other units in the whole wind farm, the probability of future gust is predicted, which provides a reference for the differential setting parameters of units and alleviates the contradiction between benefit and safety. Using the real historical operation data of the unit and referring to various information such as wind speed, wind direction and air temperature, the machine learning algorithm is used to model a single unit. The original data form indicates whether there is gust in the current period, and gust warning is the prediction of gust occurrence probability in the future period. Therefore, the labeling results should be shifted in time series to facilitate model training. Wind speed curve of a gust identified in historical operation data. The time of occurrence is 7: 24: 20 on January 24th, 2020, and the gust duration process is shown as 15th to 20th seconds in

the figure. As shown in Figure 1.

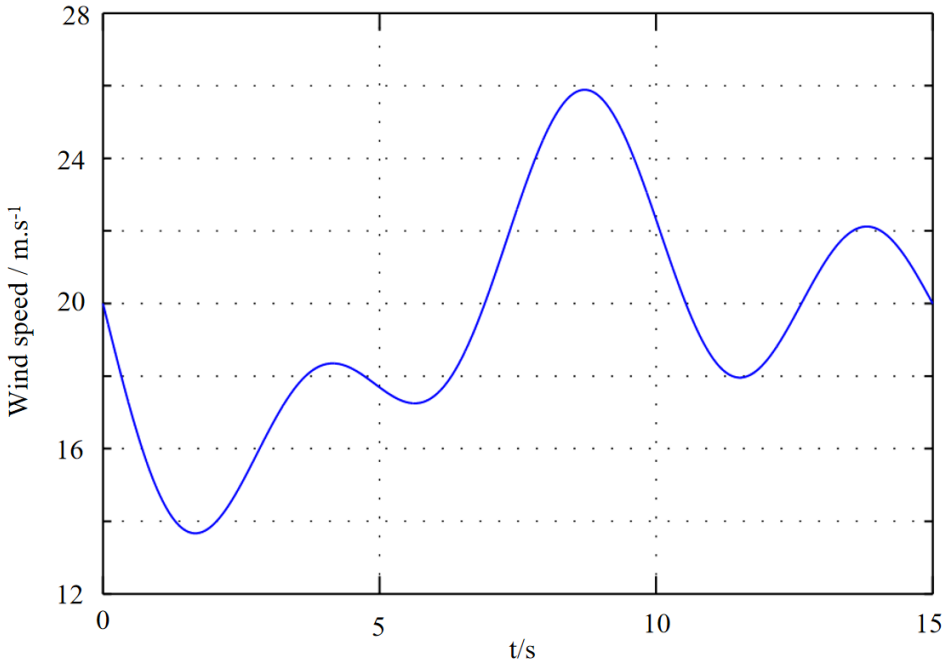

Figure 1: Wind speed under gust

The average wind speed or pressure determined according to the specified landform, height, return period and average time interval is called basic wind speed or basic wind pressure. The gust pattern refers to the form of EOG (wind speed decreases, then rises abruptly, then drops abruptly, and then rises to the initial value).

2.2 Wind-induced vibration of high-rise structures

Under the action of wind load, high-rise structures usually produce wind-induced vibration responses in downwind, cross wind and torsional directions. Therefore, the wind load is generally divided into three directions. In most cases, the wind-induced vibration response along the wind direction accounts for the main part, which is also the most concerned problem in engineering. When the wind speed fluctuates greatly, the primary goal of the unit is to deal with gusts and ensure safety, and try to avoid overrun shutdown and overload caused by the sudden rise of wind speed. At this time, the control parameters are required to be more sensitive to quickly deal with the suddenly changing external environment and ensure the safety of the unit. The calculation methods of wind-induced vibration response can be divided into time-domain method and frequency-domain method. The time-domain method is directly based on the dynamic equation of the structure, inputs the measured or numerically simulated wind load time history, and then uses the direct integration method and central difference method to solve the differential equation. When there is gust, the rotating speed of the unit is in normal distribution within 1700~2000m/min; When there is no gust, the rotating speed of the unit is within 1000~1900m/min. It can be seen that the gust mode and parameter setting can well distinguish the speed distribution of the unit with or without gust. As shown in Figure 2.

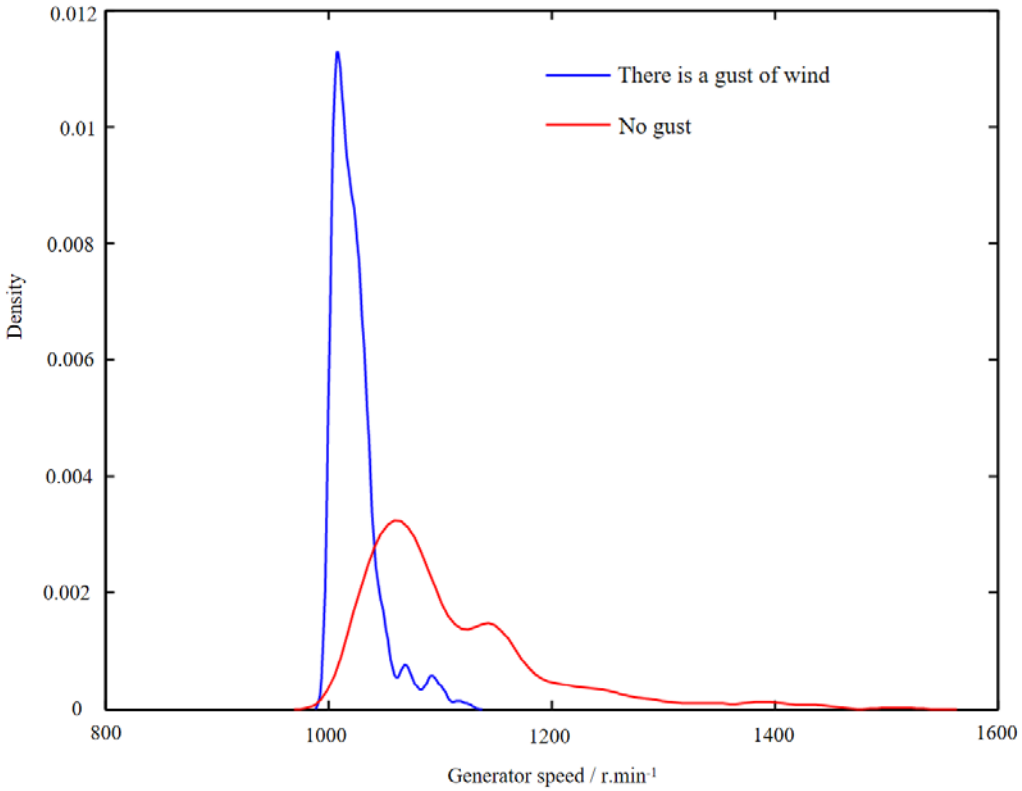

Figure 2: Distribution curves of generator speed and density with and without gust

As far as wind resistance research of high-rise buildings and tall structures is concerned, the computational wind engineering can not provide practical results. At present, the research on wind effects of high-rise buildings and tall structures mainly relies on theoretical analysis methods and boundary layer wind tunnel experiments. This paper refers to the definition of EOG gust in IEC specification and makes some changes according to the actual situation. Gust patterns and parameters can also be summarized from field experience, which can be either sudden increase of wind speed or sudden drop of wind speed; It can be the change of wind speed or wind direction.

3. Principle and application of machine learning algorithm

3.1 Algorithm Introduction

According to the similarity of function and form of algorithms, algorithms can be classified. Common algorithms include regression algorithm, regularization method, case-based algorithm, decision tree algorithm, Bayesian method, kernel based algorithm, support vector machine algorithm, clustering algorithm, association rule learning, artificial neural network, etc. In small heterogeneous data sets with high variability, it is challenging to find the best decision boundary, which depends on whether there are abnormal conditions in the process of training or testing, and judge the performance too high or too low. The machine learning algorithm performs well on the data set, and the randomness is attractive, so it is not easy to fall into over fitting. In many current data sets, compared with other algorithms, it has great advantages and randomness, which makes it have good anti noise ability. In order to obtain objective evaluation, cross-validation method is used to combine different training set and test set data and output the average performance. It can process high-dimensional data without feature selection, and has strong adaptability to data sets: it can process both discrete

data and continuous data, because most learning schemes of data sets can use the same instance twice, and if it exists twice in the training set, it will affect the learning results.

3.2 Machine learning

The program development of machine learning includes the following steps: data acquisition, data inspection, data cleaning, modeling, evaluation and deployment.

① Data acquisition. The collected data comes from different data sources, including log files, database records, CSV files, etc.

② Data inspection and cleaning: Check the validity of the obtained data and remove abnormal data, such as abnormal data obviously exceeding the normal value range.

③ Modeling: In this stage, select the appropriate algorithm and train a model on the data.

Boosting is a machine learning integration method, which is mainly used to reduce the variance and deviation of algorithms, and transform weak learning algorithms into strong learning algorithms to improve the performance of algorithms. Boosting gets the final result by combining multiple classifiers and voting according to the output results of all classifiers. Machine learning can realize the prediction of energy consumption through a large amount of data learning, with simple method and fast calculation speed, so as to make full use of the advantages of existing hardware and software of dustpan counting machine and reduce the dependence on manual experience. The data prediction model based on machine learning can only learn some statistical laws or experiences from past data, not strict laws or theorems. The unit is artificially controlled, and its parameters and state are likely to change in the future.

In the project, because it is used for correlation analysis and prediction of feature quantities, machine learning algorithm is selected to analyze the correlation of feature quantities and predict them. Each new model is affected by the performance of the previous model, and the weight is determined according to the confidence of the model. The effectiveness of data also has an impact on learning. The system design should keep the data correct as much as possible to provide a basis for future data analysis.

4. Conclusions

In the wind-induced vibration response of TV tower structure, the frequency distribution of displacement response and acceleration response is quite different. The first-order vibration mode still accounts for most of the displacement response, while the acceleration response has a great contribution, especially the first-order vibration mode. The higher the wind speed, the larger the proportion of higher-order vibration modes in the total acceleration response. Quantitative machine learning has a great influence. The more data, the higher the prediction accuracy of machine learning. According to the characteristics that higher-order vibration modes contribute a lot to acceleration response, a mass distribution index is proposed, which distributes the control mass according to the acceleration response of each order vibration mode. By controlling the second or more vibration modes, the acceleration control effect is greatly enhanced compared with only controlling the first order vibration mode. Machine learning algorithm has great potential in the application of wind-induced vibration control of high-rise steel structures. Due to the high requirements for the verifiability and universality of data fusion, its development needs a lot of experimental verification. Their development requires a lot of experimental efforts. If the theory is transformed into products, machine learning algorithm will help to promote the automation of NDT system. And significantly improve the reliability, robustness and integrity of data evaluation results.

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