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DATA DRIVEN MODEL FOR THE PREDICTION OF THE EXPECTED LIFETIME OF TRANSFORMERS

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ABSTRACT

Power transformer is one of the most expensive equipments in the electrical power grid. Transformer outages may lead to substantial economical losses. One of the most important parameters governing a transformer's life expectancy and reliability is transformer aging condition and loading condition. At the same time, it is found that electric consumption is highly correlated with weather condition, therefore, in this study, we present a solution that firstly, predict the probability that a transformer Accelerated Aging Event (AAE) happens under the given weather condition; secondly, to predict the severity of the AAE, i.e., the scale of the accelerated aging factor for the event. Finally, we computed the expected life expectancy of the transformer under possible weather conditions trajectories during transformer's remaining life span using Monte Carlo simulation.

1 INTRODUCTION

It is known that logarithm of insulation life accelerating factor is a function of the reciprocal of absolute temperature of the mineral oil. when the mineral oil temperature exceeds a certain threshold value, the transformer will experience an accelerated aging event (AAE). Here AAE is defined as events when the accelerating factor is larger than 1. The temperature of the mineral oil is determined by the transformer loading condition. Then the task of predicting the AAE becomes finding the indicating factors for higher loading conditions. First, it is well known that electrical energy load is highly correlated with weather conditions. For example, consecutive number of days with high temperature in summer days will result in increase in electric consumption used for the cooling of buildings. Second, occurrence of some special events, like the night of the super bowl will induce temporally higher power demand. Therefore, it is believed that there is a high causal relationship between weather conditions and special calendar events with over-loading induced transformer AAE. The other possible condition when a transformer may experience an AAE, is during some maintenance event. For example, when maintenance is being conducted on one transformer in a substation, usually the operating transformer in the same substation may take excess load, and result in an AAE.

Therefore in this study, we used NOAA weather condition data to, firstly, predict the probability that a transformer Accelerated Aging Event (AAE) happens under the given weather condition; secondly, to predict the severity of the AAE, i.e., the scale of the accelerated aging factor for the event. Finally, we computed the expected life expectancy of the transformer under possible weather conditions during transformer's life cycle using Monte Carlo simulation.

2 DATA PROCESSING

The relationship between the HST and transformer life consumption is governed by the Arrhenius reaction rate theory. In this study, we define the transformer accelerated aging event (AAE) as event when the accelearted aging factor α is larger than 1.

Weather data was obtained from NOAA weather dataset. The missing values in the raw data was filled with linear interpolation. Simple statistics, i.e., average, max, min values, of each measurement type are computed at daily and hourly resolution for the service area.

3 MODEL SET UP

To generalize, the model framework includes 3 steps. We first build the Gradient Boosting Machine Model to predict the probability that a transformer Accelerated Aging Event (AAE) happens under the given weather condition; secondly, a model to predict the severity of the AAE, i.e., the scale of the accelerated aging factor for the event. Finally, we computed the expected life expectancy of the transformer under possible weather conditions during transformer's life cycle using Monte Carlo simulation.

The Gradient Boost Machine algorithm is an ensemble method, where the method takes an "additive" expansion of the regression tree. The model sequentially fits a new tree on the residual from the previous tree. In this study, the model to predict the probability that an AAE happens under the given weather condition takes the logistic regression tree as basic learner; The model to predict the severity of the AAE, uses the linear regression tree with least square loss function.

The weather condition measurements demonstrate strong seasonality characteristics. Thus a linear model is first used to model the seasonality in the weather measurement data. Then a multivariate Monte Carlo method is used to simulate the residuals from the linear seasonality model. After the seasonality is modeled by the linear model, the residual from the linear model can be simulated with Monte Carlo method. The multivariate Monte Carlo method allows marginal distributions to be non-normal, like distribution with fat tails and asymmetry, which is usually observed from real data set. The method uses copula theory, which allows the definition of the joint distribution through the marginal distributions and the dependence between the variables.

4 CONCLUSION

The AAE event prediction model yielded good and consistent performance for both in-sample and out-of-sample dataset, with out-of-sample AUC (area under curve) measured at more than 96%. The model for prediction of the severity of the AAE event also yielded good performance with in-sample cvRMSE is 0.85% and out-of-sample cvRMSE is 0.9%. Monte Carlo method allows simulation of transformer life cycle. Also note that the method presented here is also applicable for the prediction of behavior of smaller distribution transformers where only smart meter loading data and temperature are known. The predictive model for transformer aging will help predict transformer failure and customer impact.