A Prediction Method of Wind Power In-Place Consumption Capacity

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Abstract. In Heilongjiang Province, China, the generated wind power is mainly consumed in-place, the uncertainty of wind power variability and electric load lead the difficulty in wind power in-place consumption capacity prediction. In this paper a wind power in-place consumption capacity prediction model based on scenario-markov chain simulation (SMCS) is proposed. The wind velocity and wind power output could be accurately predicted for the calculation of wind power in-place consumption capacity by the presented prediction model. The case study results of a real region power system verify effectiveness of the proposed model.

1. Introduction

As the rapid growth of energy, especially clean energy, demand in China, the installed capacity of renewable energy has exploding since the beginning of this decade. The wind power resource is plentiful in Three-North areas of China where also have been selected as the main renewable energy generation base, hence, Heilongjiang Province, the northernmost and easternmost province of China holds abundant wind resource, has installed over 5.6GW wind power by the end of 2017 and the wind power penetration rate of Heilongjiang already exceeds 20%. Reason from the limit of power transmit capacity between regions, the generated wind power is mainly consumed in place. While, the seasonal variation of climate and the unbalance of electric load among regions lead the difficulty of in place wind power consumption, therefore, the worsening wind curtailment hurts the development of wind power in health [1,2].

The accuracy of wind velocity and electric load prediction is very important for wind power in-place consumption capacity prediction [3-5]. In the literature [6], the key factors that influence wind power consumption are concluded and the physical interpretation of short-circuit capacity ratio of wind farm and wind power penetration limit are discussed. Literature [7] studies the wind power consuming situation of hign wind power penetration regions, also the literatute analyzes and compares the difference between independent running power system and interconnected power system. Fan P.F. and Zhang L.Z from NCEPU construct a wind power penetration limit calculation model which takes generater power output range, electric power balance, spinning reserve requirment and transmission power limit of tie line as the constraint conditions and the minimum total running cost as the optimizing object [10]. Starting from optimal power flow, literature [11] presents the non-linear power flow model...
for calculating wind power consumption capacity, and interior point method is utilized to solve the simulation model. Considering the key limit of grid real-time dispatching, Kang and Jia transfer the security constraints for whole grid to power output limit for each node which takes both real-time dispatching of whole grid and power flow security of each node into account, also the wind power consumption capacity for each node is analyzed [12]. Literature [13] proposes an approach that could enhance the wind power consumption capacity by utilizing the power adjustment capacity of DC tie line and optimizing the operation mode of the tie lines.

This paper introduces a wind power consumption capacity prediction approach which bases on scenario-markov chain simulation (SMCS). In this work, the concept and content of SMCS are proposed, firstly. Then, the application of SMCS on wind power consuming prediction is presented. In the end, a case study is undertaken to verify the effectiveness of this approach.

2. Scenario-Markov Chain Simulation

2.1. Scenario analysis

The scenario analysis is a prediction method which makes a prediction about the possible situations or consequences for the predicted object base on the premise of the situations or consequences will last till the future.

The characteristics of scenarios analysis:

1) The scenarios analysis believes the development tendency is multifarious, thus the predicting outcomes should be varied.
2) The scenarios analysis pays attention on the inner environment, critical factors and congruence of the system.
3) The scenarios analysis claims a higher subjective imagination, the subject view of the decision maker plays important role in further analysis.
4) The scenarios analysis combines quantitative analysis and qualitative analysis, a lot of qualitative analysis are integrated in quantitative analysis during the analysis procedure.

1) The analysis procedure of scenarios analysis:
2) The confirmation of analyzing theme.
3) The selection of key influence factors.
4) The description and filtration of the scheme: combine specific descriptions of influence factors and form a number of schemes that describe the further scenarios.

Simulation exercise.
5) The establishment of analyzing strategy.
6) The formation of early warning system.

2.2. The Markov Chain prediction model

Markov Chain is a stochastic process that meets the requirement of Markovian effect which include:

1) The probability distribution of the system state at moment t+1 is only related to the system state at moment t and has no concern with the system state before moment t.
2) The state transition from moment t to t+1 has no concern with the value of t.

\[
P(X_{n+1} = x | X_1 = x_1, X_2 = x_2, ..., X_n = x_n) = P(X_{n+1} = x | X_n = x_n)\]  \hspace{1cm} (1)

The equation above could describe the Markovian effect, where, \(X_1\), \(X_2\), \(X_3\) ... are the state sequence, \(x\) is a state during the process.

A transition probability from a state to another could be obtained from the Markov transition probability matrix, thus, a prediction analysis could be undertook by this property. Assuming the state space is \(\{x_1, x_2, ..., x_n\}\), its transition probability could be presented as follow.
\[ P\{ X(t+1) = j \mid X(t) = i \} = p_{i} \quad i \in n \]  

(2)

For the system, it could have \( n \times n \) states and its Markov transition probability matrix could be described as bellow.

\[
P = \begin{bmatrix}
p_{11} & p_{12} & \cdots & p_{1n} \\
p_{21} & p_{22} & \cdots & p_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
p_{n1} & p_{n2} & \cdots & p_{nn}
\end{bmatrix}
\]

(3)

3. The wind power consumption capacity prediction based on SMCS

3.1. The prediction model of wind power output based on SMCS

According to scenario analysis method, season and weather are chosen as the key factors to partition scenarios. As shown in figure 1, there are 9 scenarios built by season difference and weather difference.

![Figure 1. The scenarios of wind velocity](image)

Collecting the historical data of wind velocity and classify them in to the scenicarios according to the season and weather condition when the data obtained. Summing up the wind velocity distribution in every scenario and obtain the transition probability matrix Utilizing Markov simulation model.

\[ P\{ v(t+1) = j \mid v(t) = i \} = p_{ij} \quad i, j \in \Phi_{k} \]  

(4)

\[
P_{wind} = \begin{bmatrix}
p_{11} & p_{12} & \cdots & p_{1n} \\
p_{21} & p_{22} & \cdots & p_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
p_{n1} & p_{n2} & \cdots & p_{nn}
\end{bmatrix}
\]

(5)

Where, \( v(t) \) is the wind velocity at moment \( t \), \( v(t+1) \) is the wind velocity at moment \( t+1 \), \( \Phi_{k} \) is the sample space of wind velocity, \( p_{ij} \) is the transition probability of wind velocity, \( P_{wind} \) is the transition probability matrix of wind velocity.
According to the present wind velocity to proceed short-term prediction utilizing Markov simulation model and predict the wind power output by wind velocity-wind power model.

\[
v_{\text{wind}, t+1}^{\text{pred}} = v(\max P(v_t, v_k))
\]  

\[
P_{\text{wind}, t+1, l}^{\text{pred}} = \begin{cases} 
0, & 0 \leq v_{\text{wind}, t+1}^{\text{pred}} \leq v_{ci} \\
(A + B v_{\text{wind}, t+1}^{\text{pred}} + C v_{\text{wind}, t+1}^{\text{pred}}^2) P_{\text{rated}}, & v_{ci} \leq v_{\text{wind}, t+1}^{\text{pred}} \leq v_r \\
0, & v_r \leq v_{\text{wind}, t+1}^{\text{pred}} \leq v_{co} \\
v_{co} \leq v_{\text{wind}, t+1}^{\text{pred}}, & \end{cases}
\]  

\[
P_{\text{wind}}^{\text{pred}} = \alpha \sum_{l=1}^{N} \beta P_{\text{wind}, t+1, l}
\]  

Where, \( v_{\text{wind}, t+1}^{\text{pred}} \) is the predicted wind velocity at moment \( t+1 \), \( P_{\text{wind}, t+1, l}^{\text{pred}} \) is the predicted power output of wind turbine \( l \), \( P_{\text{wind}}^{\text{pred}} \) is the predicted power output of the wind farm, \( A, B \) and \( C \) are the power output constants of wind turbines, \( \beta \) is the wind turbine working state coefficient that values 1 when it is working or 0 when it is overhauling, \( \alpha \) is the coefficient of association of wind turbines within the wind farm which could be set as 0.9.

3.2. The prediction model of electric load based on SMCS

Similarly with wind power prediction, there are also 9 scenarios set up in terms of season and load intensity, and the collected historical electric load data are also classified into the scenarios according to their external environment, as presented in figure 2.

![Figure 2. The scenarios of electric load](image-url)

Summing up the electric load distribution in every scenario and obtain the transition probability matrix Utilizing Markov simulation model.
\[ P \left\{ L(t + 1) = m \mid L(t) = n \right\} = p_{mn} \quad m, n \in \Phi_z \]  

\[ P_{load} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1z} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{z1} & p_{z2} & \cdots & p_{zz} \end{bmatrix} \]  

Where, \( L(t) \) is the electric load at moment \( t \), \( \Phi_z \) is the sample space of electric load, \( p_o \) is the transition probability of electric load, \( P_{load} \) is the transition probability matrix of electric load. The short-term electric load could be predicted by utilizing Markov simulation model as follow.

\[ L_{t+1}^{pred} = L(\max P(L_t \mid L_z)) \]  

3.3. The prediction model of wind power consumption capacity

The power generated by traditional power sources and the power delivered through cross-section should be taken into consideration when calculate the wind power consumption capacity. The traditional power sources include combine heat and power unit (CHP), thermal power plant and hydro-power plant.

\[ P_{tri} = \sum P_{CHP} + \sum P_{thermal} + \sum P_{hydro} \]  

Where, \( P_{tri} \) is the power generated by traditional power source, \( P_{CHP} \) is the power generated by CHP unit, \( P_{thermal} \) is the power generated by thermal power plant, \( P_{hydro} \) is the power generated by hydro-power plant.

The wind power consumption capacity and wind power consuming rate could be calculated by taking advantage of the predicting outcomes of wind power and electric load prediction models.

\[ P_{wind,acc}^{pred} = L^{pred} + \max(P_{out}^{pred}) - \min(P_{in}^{pred}) - \min(P_{tri}^{pred}) \]  

\[ \eta_{wind}^{pred} = \frac{P_{wind,acc}^{pred}}{P_{wind}^{pred}} \times 100\% \]  

Where, \( \eta_{wind}^{pred} \) is the wind power consumption rate, \( P_{wind}^{pred} \), \( P_{wind,acc}^{pred} \) and \( L^{pred} \) are the predicted wind power output, predicted wind power consumption capacity and electric load, respectively. \( P_{out} \) and \( P_{in} \) the power output and input through the cross-section, respectively.

4. Case study

The study takes Binxi District, Heilongjiang Province, China as the simulation case. There are 110MW power source within the region, all of the traditional power source are CHP units with the installed capacity of 60MW, and the installed capacity of wind power is 50MW. The maximum power output through the cross-section is 80MW and the region is pure power output area that means the power input through the cross-section could be ignored.
All of the wind turbines are located in Ruichi Wind Farm which include 25 w2000c-99-80 wind turbines. The rated power for each turbine is 2MW, and the cut-in, rated and cut-out wind velocity are 3m/s, 14m/s and 25m/s, respectively.

The historical hourly wind velocity data and electric load data are collected for 10 years. Sum up the historical data and predict the short-term wind velocity and electric load by SMCS. The simulation results are shown in figure 3 and figure 4, it clearly presents that with the prediction method that proposed in this work the correlation coefficients between predicted value and measured value of wind velocity and electric load are 0.982 and 0.967, respectively. The high correlation between predicted value and measured value proves the effectivity of SMCS.

![Figure 3. The predicted and measured value of wind velocity](image_url)

![Figure 4. The predicted and measured value of electric load](image_url)

According to wind velocity-wind power output model, the short-term wind power output could be predicted as illustrated in figure 5. Though calculation, the correlation coefficient between predicted value and measured value is 0.934, it could be believed that the non-linear relationship between wind velocity and wind power output enlarges the prediction error of wind power output. Comparing with the prediction accuracy of wind power, the prediction of wind power output is a bit weak, but it still shows high prediction accuracy.
Figure 5. The predicted and measured value of wind power output

The predictions of wind power in-place consumption capacity and consumption rate are presented in figure 6 and figure 7. The correlation coefficients between predicted value and measured value of the two factors are 0.964 and 0.952, respectively.

Figure 6. The predicted and measured value wind power consumption capacity

Figure 7. The predicted and measured value wind power consumption rate
5. Conclusion
This work proposes a prediction model for wind power in-place consumption which based on scenario-markov chain simulation. The proposed model takes season, weather and electric load intensity into consider to enhance the accuracy of the prediction model. From the results of the case study, the veracity of predicted wind velocity and electric load is satisfactory to analyze wind power consumption. This prediction model could provide strong support for grid dispatching department in power dispatching within high wind power integration areas.

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