INTRODUCTION

The electricity industry is changing from the traditional monopoly control to the competitive supervision. Deregulation and introduction of competition have become a general development trend of the world’s electricity industry. Many developed countries in Europe and America have happened or are preparing for a series of reforms \cite{1-4}. The market-oriented reform of the electricity industry has brought huge economic benefits, which is reflected in many aspects, such as reducing the cost of power generation, improving the level of power supply to the users, implementing fair dispatch, and attracting investment from various parties \cite{5-7}. The electricity market is a large and complex non-linear system. Energy policy, environmental regulations, national economic development trend, electricity market rules, competition of market participants and physical characteristics of the transmission network will affect the actual operation of the electricity market. How to directly analyze the characteristics of electric spot and futures market according to the sampling data of actual electricity market is an important research subject. It can complement the imperfections brought by the simplification of the theoretical model and further analyze the characteristics of the electricity market that coexists in spot and futures transactions.

REVIEW OF RELATED RESEARCHES

The electricity market consists of two parts: the electric spot market and the financial market for electricity \cite{8}. For the electricity price and load on the spot market (especially for the system clearing electricity price and the locational marginal price on the day-ahead market), some scholars researched the statistical law of electricity price, chaotic features, and established their forecasting model accordingly by the use of the probability and statistics theory, chaos theory, fuzzy theory and artificial intelligence technology \cite{9-13}. For the electricity futures price on the financial market for electricity, some scholars established its forecasting model.
model by the use of gray theory \cite{14}. However, these researches ignore the relationship between the spot market and the futures market on the electricity market.

Cointegration theory integrates the features determined by the long-term equilibrium relationship in the strength and quantitative economics that is set up by the time series method for the short-term dynamic of the model, and becomes a powerful modeling theory \cite{15}. Many domestic and foreign scholars researched the dynamic relationship between the futures price and spot price of the general commodity by the use of cointegration theory \cite{16}. The results show that there is a cointegration, long-term and stable equilibrium relationship between the futures price and spot price of the most commodities (crude oil, soybeans, wheat) \cite{17-19}. However, in the research of the relationship between the electric spot and futures market, the research results based on the cointegration theory are very rare. On this basis, considering the non-stationarity of the electricity futures and spot electricity price, this paper uses the cointegration theory to discuss the relationship between the electric spot and the futures market.

3 CONSTRUCTION OF COINTEGRATION BETWEEN THE SPOT PRICE AND THE FUTURES ELECTRICITY PRICE AND ERROR CORRECTION MODEL

3.1 Cointegration theory

3.1.1 Concept of cointegration

Cointegration relationship describes an equilibrium relationship between two (or more) non-stationary time series. The moments (mean, variance, covariance and so on) of each time series change with time, but the moments of some linear combination (equilibrium relationship) in these series are characterized by time invariance.

Definition (linear cointegration) \cite{20}, for m-dimensional vector time series \( \{ Y_t \} \), its component sequence is called as (d, b) order linear cointegration, denoted as \( Y_t \sim Cl(d,b) \). If

1. Component sequence of \( \{ Y_t \} \) is I(d) sequence; 2. There is a vector \( a \neq 0 \), so that \( Z_t = a Y_t - I(d-b) \), b>0, in which \( a \) is called as cointegration vector.

When \( m = 2 \), the cointegration vector \( a \) is unique; when \( m > 2 \), there is a multiple cointegration relationship between the vector time series \( \{ Y_t \} \). Assuming that there are \( r \) linearly independent cointegration vectors, to arrange these linearly independent cointegration vectors and form a mxr-dimensional matrix \( A \) (cointegration matrix), the rank of matrix \( A \) is called as the cointegration rank.

3.1.2 Unit root test

(1) Stationary time series

The stationarity of time series refers to the characteristics of the statistical law of time series that does not change with time. The time series that mathematically meets the following conditions is stationary time series \( \{ y_t \} (t=1,2,...) \):

1. Mean \( E(y_t) = \mu \) is a constant that is independent of time \( t \);
2. Variance \( \text{Var}(y_t) = \sigma^2 \) is a constant that is independent of time \( t \);
3. Covariance \( \text{Cov}(y_t, y_{t+k}) = Y_k \) is a constant that is independent of time \( t \), but only related with time interval \( k \).

For stationary time series, its mean and variance do not change with the passage of time. There is an oscillation, but the oscillation is temporary, and it ultimately will return to the long-term mean level. The unit root test is a more commonly used test method in the time series non-stationarity test methods. The most widely used methods are DF (Dicker-Fuller) and ADF (Advanced Dicker-Fuller) test methods \cite{21}.

(2) DF test method

Regression calculation is used for the time series \( \{ y_t \} \):

\[
\Delta y_t = \alpha + \beta t + (\rho - 1)y_{t-1} + \epsilon_t \tag{1}
\]

Where: \( \Delta \) is the first order difference; \( \Delta y_t = y_t - y_{t-1} \); \( \{ \epsilon_t \} \) is a random error term, which is a white noise process that follows the independent distribution; \( \alpha, \beta \) and \( \rho \) respectively represent a constant trend term and a linear trend term; whether \( \alpha, \beta \) and \( \rho \) are non-zero according to the regression parameters; the Equation (1) contains three basic regression models: excludes the trend term, but only includes the constant term and includes the constant trend term and linear trend term; \( \rho \) is the test statistics. Generally, the null hypothesis \( H_0 \) is that the time series \( \{ y_t \} \) has a unit root, indicating its stationarity.

To calculate DF statistics \( \tau_{DF} \) according to the estimation result of Equation (1), and compare with the critical value \( \tau_{DF0} \), if \( \tau_{DF} > \tau_{DF0} \), \( H_0 \) is rejected and the series is non-stationary, or otherwise the series is stationary.

(3) ADF test method

In DF test, \( \{ \epsilon_t \} \) in the regression model (1) is not guaranteed to be white noise, nor the unbiasedness of \( \rho \), so ADF test method is proposed. It solves the relevant issues of high order of the error term \( \{ \epsilon_t \} \) through introducing the lag difference term. That is, the test equation is:

\[
\Delta y_t = \alpha + \beta t + (\rho - 1)y_{t-1} + \sum_{j=1}^{n} \delta_j \Delta y_{t-j} + \epsilon_t \tag{2}
\]

Where: the meaning of parameters \( \lambda, \alpha, \beta, \rho \) and \( \{ \epsilon_t \} \) is the same as that of Equation (1); \( \Delta y_{t-j} \) is a lag term; \( \delta_j \) is a corresponding coefficient; \( n \) is the order of the lag
term, which can be determined according to AIC (Akaike Information Criterion).

Similar to the Equation (1), ADF test also contains tests in three cases: the regression includes constant, constant and linear trend, both of which are not included. Generally, the null hypothesis $H_0$ is $\rho = 1$. To calculate ADF statistics $\tau_{ADF}$ according to the estimation result of Equation (2), and compare with the critical value $\tau_{ADF}$, whether the series is stationary can be determined.

When $n=0$, the Equation (2) turns into Equation (1) then ADF test is DF test. No matter DF or ADF test, it is necessary to determine the series trend term in advance. Currently, the problem of determining the trend item is not solved theoretically, but the trend item can be determined according to the series diagram.

3.1.3 Cointegration test

For many cointegration test methods, EG two-step method and maximum likelihood method are the most commonly used methods.\cite{20}

(1) EG two-step method

This method is commonly used to test the cointegration relationship of a single equation model in the vector time series. The test procedures are simple and clear. The first step of this method is to use the least square method OLS for static regression (Equation (3)) of the two variables, thus obtaining an estimate value of $(1, -\beta)$, and $\epsilon_t$.

$$y_t = \alpha + \beta x_t + \epsilon_t$$

(3)

The second step is to use ADF test for stationary test of the residual $\epsilon_t$. If $\epsilon_t$ is a stationary series, the series $\{x_t, y_t\}$ cointegrate, $(1, -\beta)$ is the cointegration vector.

The practice proves that EG two-step method is simple and effective, but it can only be applied to the cointegration system with a unique cointegration relationship. When the cointegration rank (namely, the number of cointegration vectors) increases, EG two-step method does not work.

(2) Johansen cointegration test

For the system equation model of vector time series, the main work is to test the existence of cointegration relationship and the number of cointegration vectors. For this reason, a series of test methods based on model coefficients are proposed. A more representative method is likelihood ratio test method proposed by Johanson.\cite{22, 23}. It tests the existence of cointegration relationship by the rank that affects the matrix in the error correction model. The test method can not only test whether there is a cointegration relationship between variables, but also accurately determine the number of cointegration vectors, which has a stronger test capability than EG two-step method.

In Johansen method, the vector autoregressive (VAR) model is the simplification of the vector autoregressive moving average (VARMA) model, with the general mathematical expression:

$$\Delta Y_t = D + \Pi Y_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta Y_{t-i} + \epsilon_t$$

(4)

Where: $Y_t$ is n×1 dimensional vector of the cointegration relationship to be tested; $D$ is a definite term, which can take different forms according to the nature of data to be tested, such as zero vector or nonzero constant vector; the selection of $k$ should ensure that the mean value of $\epsilon_t$ is 0, multivariate normal white noise process of finite covariance matrix; $\Pi$ and $\Gamma$ are coefficient matrices.

The number of cointegration vectors is equal to the order of $\Pi$, so the cointegration relationship between variables can be tested by the order of the coefficient matrix $\Pi$. 0 order ($\Pi = 0$) indicates that there is no cointegration relationship. In the case of bivariate, there is a cointegration relationship between the two variables only when $\Pi = 1$.\cite{23}

Johansen proposed that the test of trajectory statistics and the maximum characteristic root statistics exists null hypothesis of at most r cointegration vectors. That is, $\Pi$ order is at most $r(r = 0, 1, ..., n-1)$. The mathematical form of the two statistics is respectively:

$$\lambda_{\text{trace}} = -T \sum_{i=r+1}^{n} \ln(1-\lambda_i)$$

(5)

$$\lambda_{\text{max}} = -T \ln(1-\lambda_{r+1})$$

(6)

Where: $\lambda_1, ..., \lambda_n$ is r maximum square correlation coefficients between residuals obtained by regression of $\Delta Y_{1-t}, \Delta Y_{t-2}, ..., \Delta Y_{t-k}$ and 1 by $\Delta Y_t$ and $Y_{t-1}$. The critical value is taken from Osterwald-Lenum.\cite{24}.

3.2 Cointegration between spot price and futures electricity price and error correction model

3.2.1 Selection of data

Data are from Nordpool power operation mechanism of the Nordic countries (http://www.nordpool.com), the futures electricity price per day for the first half of 2006 (select the closing price of the weekly contract futures per day as the futures electricity price) and the spot electricity price (select the average price of the weekly contract futures per day as the spot electricity price). The spot electricity price is the average price of the system clearing price in 24 hours a day as the spot electricity price. In certain holidays, the futures market does not carry out transaction. There are a total of 118 sample data for electricity price, and the unit of data is EUR/MWh.

Figure 1 and Figure 2 are respectively the timing diagram and differential diagram for the spot and futures electricity price (FPR: futures electricity price; SPR: spot electricity price). As can be seen from the timing diagram, the spot and futures electricity price are non-stationary, with a common trend of change,
but their first-order difference sequence diagram shows stationarity and a very similar change cycle, which is a typical feature of the cointegration relationship.

Figure 1. Timing diagram of futures and spot electricity price.

Figure 2. First-order difference sequence diagram of futures and spot electricity prices.

3.2.2 Non-stationarity test
Before discussing the cointegration between spot and futures electricity price, the unit root test is first carried out for the futures and spot electricity price series, in order to analyze their non-stationary characteristics. This section uses ADF test method to carry out the unit root test for the variables. The test results are shown in Table 1.

### Table 1. ADF unit root test results.

<table>
<thead>
<tr>
<th>Time series</th>
<th>Futures electricity price</th>
<th>Spot electricity price</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF statistics</td>
<td>-2.45 ☭</td>
<td>-6.25 **</td>
</tr>
<tr>
<td>5% critical value</td>
<td>-2.91</td>
<td>-3.50</td>
</tr>
<tr>
<td>1% critical value</td>
<td>-3.50</td>
<td>-3.50</td>
</tr>
</tbody>
</table>

Note: The constant term trend is selected from the test model of \{fpr\}, \{spr\}, the order of the lag term is 1 order, which is determined by AIC criterion and SC criterion. **indicates that rejection of time series at the significance level of 1% is a null hypothesis of non-stationarity.

As can be seen from Table 1, for the spot and futures electricity price series, ADF statistic is greater than the critical value of the test, and the null hypothesis of non-stationarity is rejected, indicating that the spot and futures electricity price series are non-stationary series. For the first order difference sequence of spot and futures electricity price, ADF statistic is less than the critical value of the test, and the null hypothesis is accepted, that is, the first order difference of the futures and spot electricity price series is stationary. Thus, the test results show that the futures electricity price series \{fpr\} and the spot electricity price series \{spr\} are first-order integrated series.

3.2.3 Cointegration equation
There are many methods to test and estimate the cointegration relationship. This paper uses Engle-Granger two-step method to determine the cointegration relationship between spot and futures electricity price.

In EG two-step test, the following cointegration equation can be established by OLS regression with \(spr\) as an independent variable and \(fpr\) as a dependent variable.

\[
spr_t = -17.80 + 1.45fpr_t
\]  

To carry out stationarity test of the residual series of the above model \(\varepsilon_t = spr_t + 17.80 - 1.45fpr_t\), the ADF test results are shown in Table 2. Table 2 shows that ADF statistic is less than the critical value of the test at the significance level of 1%, the residual series is a stationary series. Thus, there is a cointegration relationship between the spot electricity price and the futures electricity price.

### Table 2. ADF test results of residual series.

<table>
<thead>
<tr>
<th>Time series</th>
<th>(\varepsilon_t = spr_t + 17.80 - 1.45fpr_t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF statistics</td>
<td>-3.95</td>
</tr>
<tr>
<td>5% critical value</td>
<td>-2.91</td>
</tr>
<tr>
<td>1% critical value</td>
<td>-3.50</td>
</tr>
</tbody>
</table>

Note: The constant term trend is selected from the test model of \(\varepsilon_t\), the order of the lag term is 4 order, which is determined by AIC criterion and SC criterion.

3.2.4 Error correction model
According to the cointegration theory, if there is a cointegration relationship between variables, the error correction model can be used to directly describe the short-term fluctuation and long-term equilibrium. Based on the cointegration relationship between futures and spot electricity price, the following error correction model can be established:

\[
\Delta fpr_t = \theta_0 + \theta_1 Z_{-1} + \sum_{i=1}^{k} \lambda_{1i} \Delta spr_{-i} + \sum_{i=1}^{k} \gamma_{1i} \Delta fpr_{-i} + \varepsilon_{1t}
\]  

\[
\Delta spr_t = \theta_2 + \theta_3 Z_{-1} + \sum_{i=1}^{k} \lambda_{2i} \Delta spr_{-i} + \sum_{i=1}^{k} \gamma_{2i} \Delta fpr_{-i} + \varepsilon_{2t}
\]

Where: \(\lambda_{1i}, \lambda_{2i}, \gamma_{1i}, \gamma_{2i}\) are short-term adjustment coefficients; \(Z_{-1} = fpr_{-1} - 0.53spr_{-1} - 19.28\) is an error correction term in the cointegration relationship between futures and spot electricity price; \(\theta_0, \theta_3\) are the coefficients of error correction term; \(k\) is the order of lag term. The model not only considers the long-term
cointegration relationship between non-stationary variables, but also considers the short-term fluctuation of stationary variables, thus realizing the effective combination of long-term relationship and short-term dynamic in the time series of electricity price. Table 3 gives the parameter estimates for the error correction models (8) and (9).

Table 3. Parameter estimates for error correction model.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Explained variables</th>
<th>Aspr (model 8)</th>
<th>Aspr (model 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>T statistical value</td>
<td>Coefficient</td>
</tr>
<tr>
<td>C</td>
<td>0.02</td>
<td>0.23</td>
<td>0.08</td>
</tr>
<tr>
<td>Z_{t-1}</td>
<td>-0.05</td>
<td>1.24</td>
<td>0.48</td>
</tr>
<tr>
<td>Aspr_{t-1}</td>
<td>-0.01</td>
<td>-0.29</td>
<td>0.009</td>
</tr>
<tr>
<td>Aspr_{t-2}</td>
<td>-0.01</td>
<td>-0.73</td>
<td>-0.02</td>
</tr>
<tr>
<td>Aspr_{t-3}</td>
<td>-0.03</td>
<td>-1.32</td>
<td>-0.07</td>
</tr>
<tr>
<td>Aspr_{t-4}</td>
<td>0.0012</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Aspr_{t-5}</td>
<td>0.47</td>
<td>4.68</td>
<td>0.18</td>
</tr>
<tr>
<td>Aspr_{t-6}</td>
<td>-0.05</td>
<td>-0.51</td>
<td>-0.11</td>
</tr>
<tr>
<td>Aspr_{t-7}</td>
<td>0.05</td>
<td>0.43</td>
<td>0.26</td>
</tr>
<tr>
<td>Aspr_{t-8}</td>
<td>0.07</td>
<td>0.56</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Note: The cointegration relationship in the error correction model $Z_{t-1} = fpr_{t-1} - 0.53 spr_{t-1} - 19.28$

The difference terms in the error correction model reflect the influence of short-term fluctuation in spot and futures electricity price, while the coefficients of error correction term reflect the adjustment strength in deviation from the long-term equilibrium. Viewing from the estimate value of the coefficients, the adjustment strength for the spot electricity price is relatively large, while the adjustment strength for the future electricity price is relatively small.

4. **GRANGER CAUSALITY ANALYSIS OF SPOT AND FUTURES ELECTRICITY PRICE**

Granger causality has been universally favored by its simplicity. The error correction model established based on the cointegration relationship opens up an effective way to research the causal relationship between non-stationary variables. This paper uses the causality test method based on the error correction model to analyze the causal relationship between the spot market and the futures market.

4.1 **Granger causality test based on error correction model**

In 1987, Engle and Granger pointed out that, if there is a cointegration relationship between variables, in the error correction model constructed, the causal relationship can be generated through two channels: 1. short-term impact of change in the lag term of regressor; 2. long-term impact of error correction term.

When two economic variables are the first-order integrated variables and both of them are cointegrated, an error correction model can be established. It is illustrated by taking the error correction models (8) and (9) of futures and spot electricity price as an example.

If $\lambda_{1i} (i=1,2,\ldots,k)$ is significantly different from 0 in general, $spr_i$ is the short-term Granger cause of $fpr_i$; if $\theta_i$ is not significantly 0, $spr_i$ is the long-term Granger cause of $fpr_i$. On the contrary, if $\lambda_{1i} (i=1,2,\ldots,k)$ is significantly equal to 0 in general, $spr_i$ is not the short-term Granger cause of $fpr_i$; if $\theta_i$ is significantly 0, $spr_i$ is not the long-term Granger cause of $fpr_i$. Similarly, whether $fpr_i$ is the long-term or short-term Granger cause of $spr_i$ can be tested.

4.2 **Granger causality test of spot and futures electricity price**

The previous analysis shows that there is a cointegration relationship between the spot electricity price and the futures electricity price, so their causal relationship can be tested by the error correction model (8) and (9). The causality test results are shown in Table 4.

Table 4. Granger causality test results.

<table>
<thead>
<tr>
<th>Lag order</th>
<th>Sample number</th>
<th>Null hypothesis</th>
<th>F statistics</th>
<th>Granger causality test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>114</td>
<td>$\gamma_1 = 0$ (i=1,2,3,4)</td>
<td>0.27827</td>
<td>0.89324</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\gamma_2 = 0$ (i=1,2,3,4)</td>
<td>3.69235</td>
<td>0.00756</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\theta_1 = 0$</td>
<td>0.21741</td>
<td>0.87884</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\theta_2 = 0$</td>
<td>4.40432</td>
<td>0.00213</td>
</tr>
</tbody>
</table>

According to the results in Table 3, for the error correction model (8), at the significance level of 5%, when $\lambda_{1i} (i=1,2,\ldots,k)$ is significantly different from 0 in general, $spr_i$ is not the short-term Granger cause of $fpr_i$; moreover, when $\theta_i$ is significantly 0, $spr_i$ is also not the long-term Granger cause of $fpr_i$. For the error correction model (9), at the significance level of 5%, when $\gamma_2 (i=1,2,\ldots,k)$ is significantly different from 0 in general, $fpr_i$ is the short-term Granger cause of $spr_i$; moreover, when $\theta_2$ is not significantly 0, $fpr_i$ is the long-term Granger cause of $spr_i$. Therefore, there is only a unidirectional Granger causal relationship between the spot market and the futures market from the futures electricity price to the spot electricity price.

4.3 **Pulse response analysis of spot and futures electricity price**

The impulse response function can analyze how a variable perturbation affects other variables through the model, and ultimately gives feedback to the variable itself [29]. The impulse response analysis method can be used to research the interaction between the changes in the futures electricity price and spot electricity price. Here, Cholesky method of adjusting the degree of freedom is used to regularize the residuals of the endogenous variables. Figure 3 and Figure 4 respectively show the impact of a standard error impulse of the residual term $e_i$ in the error correction model (8) and (9) on the changes in the futures electricity price and spot electricity price.
As can be seen from Figure 3, the futures electricity price has a strong response to the standard error impulse. The fluctuation of electricity price is increased by 0.85, and reaches a maximum value of 1.29 on the third trading day, and then the degree of impact gradually decreases, and finally it tends to be 1.05. The impact of a standard deviation impulse of futures electricity prices on the spot electricity price is very significant, and presents a rising trend. It reaches 0.52 on the 20th trading day. Thus, viewing from a short term or a long term, the futures electricity price is significantly affected by its own impact, with a stable positive response, and tends to be 1.05 for a long term from strong to weak.

As can be seen from Figure 4, the spot electricity price has a stronger response to the standard error impulse. The electricity price is increased by 2.85, and then gradually decreases, and finally tends to be 1.01. The impact of spot electricity price impulse on the futures electricity price is significant in a short term. The electricity price is increased by 0.26 in the first trading day, and then continues to rise, and finally tends to be 2.01, which is more than the impact on the spot electricity price. Therefore, there is a significant impact on the spot electricity price in a short term, but there is a greater impact on the futures electricity price in a long term.

According to the above analysis, there is a positive impact on the spot electricity price and futures electricity price. The change of electricity price on one market (spot market or futures market) will have a direct positive impact on the change of electricity price on another market (futures market or spot market).

4.4 Forecasting of futures electricity price

The forecasting model of futures electricity price is established based on the error correction model (8). To estimate parameters of the model by using 112 sample data from January 1, 2006 to June 12, 2006, the forecasting model of the futures electricity price can be obtained:

$$
\Delta p_{f,t} = 0.022209 + 0.054849 \Delta p_{f,t-1} - 0.535142 \Delta p_{f,t-3} - 0.007506 \Delta p_{s,t-1} - 0.022435 \Delta p_{s,t-3} - 18.850335 
+ 0.483704 \Delta p_{f,t-1} - 0.053304 \Delta p_{f,t-2} + 0.028883 \Delta p_{f,t-3} + 0.062309 \Delta p_{f,t-4} - 0.0007506 \Delta p_{s,t-1} - 0.022435 \Delta p_{s,t-3} 
- 0.038072 \Delta p_{s,t-1} + 0.0041155 \Delta p_{s,t-4} 
$$

(10)

Based on the forecasting model of futures electricity price, the futures electricity price in June 2006 can be forecasted. The forecasting results and forecasting errors are shown in Table 5, where:

$$\text{Relative error} = \frac{P_i - \bar{P}_i}{P_i} \times 100\%$$

(11)

$$\text{Average relative error} = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{P_i - \bar{P}_i}{P_i} \times 100\% \right|$$

(12)

Where: $P_i$: actual value of futures electricity prices; $\bar{P}_i$: forecast value of futures electricity price; $N$: total forecasting electricity price.

Table 5. Forecasting results of futures electricity price.

<table>
<thead>
<tr>
<th>Date</th>
<th>Actual value of futures electricity prices</th>
<th>Forecast value of futures electricity price</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0613</td>
<td>44.47</td>
<td>44.48512</td>
<td>0.034</td>
</tr>
<tr>
<td>0614</td>
<td>44.60</td>
<td>44.43064</td>
<td>0.38</td>
</tr>
<tr>
<td>0615</td>
<td>44.40</td>
<td>44.34698</td>
<td>0.119</td>
</tr>
<tr>
<td>0616</td>
<td>44.30</td>
<td>44.31021</td>
<td>0.0002</td>
</tr>
<tr>
<td>0619</td>
<td>44.90</td>
<td>44.31997</td>
<td>1.513</td>
</tr>
<tr>
<td>0621</td>
<td>44.60</td>
<td>44.38768</td>
<td>0.476</td>
</tr>
<tr>
<td>Average</td>
<td>44.56</td>
<td>44.37993</td>
<td>0.404</td>
</tr>
</tbody>
</table>

As can be seen from Table 5, the maximum forecast error is 1.513% and the average forecast error is 0.404%, which indicates that the forecasting model of futures electricity price based on the error correction model and combined with the long-term equilibrium relationship of electricity price series and the short-term dynamic have high forecast accuracy.

5 RESEARCH CONCLUSION

By taking the Nordic electricity market as an example, this paper carries out systematical empirical research on the dynamic relationship between the spot market and the futures market. The research results show that,
the spot electricity price and the futures electricity price in the Nordic electricity market are non-stationary variables, with a single integrated order of 1, and there is a cointegration relationship between them; there is only a unidirectional long-term and short-term Granger causal relationship between the spot market and the futures market from the futures electricity price to the spot electricity price; the forecast model of the futures electricity price not only considers the long-term cointegration relationship between non-stationary variables, but also considers the short-term fluctuation of stationary variables, thus realizing the combination of long-term relationship and short-term dynamic in the time series of electricity price, and obtaining a higher forecast accuracy.

REFERENCES