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Analysis of Power Fluctuation Characteristics of Tidal Current Energy Generation and Selection of Sampling Interval

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Abstract. With the continuous maturity of tidal current power generation technology, the scientific requirements for testing and evaluation are also increasing. In the process of analyzing the measured power data of tidal current power generation, the selection of sampling interval has a significant impact on the accuracy of power fluctuation analysis. Choosing an appropriate sampling interval can reduce data processing and improve calculation speed while ensuring the accuracy of test data. Based on the measured power data of tidal current power generation in a certain sea area of China during rising and falling tides, this paper calculated and analyzed the power fluctuation of multiple sampling intervals through discrete index analysis and first-order difference component analysis. And based on the entropy weight method, obtained the regularity of power fluctuation with sampling interval, calculated the comprehensive fluctuation coefficient to determine the maximum sampling interval, and proposed a recommended sampling interval of 60 seconds. This has important practical significance for scientifically testing tidal current power generation.

Keywords. Tidal current, power, fluctuation, sampling interval

1. Introduction

Marine renewable energy is a strategic emerging industry formed by the intersection of energy, high-end equipment manufacturing, and marine engineering. It has important strategic significance for the rational development of marine resources, accelerating the transformation of energy structure, and responding to global climate change [1]. In recent years, the development and utilization of marine renewable energy technology have received high global attention, and China has also made significant progress in this field. China has successively developed over 30 tidal current power generations and over 40 wave power generations, among which the tidal current power generation technology has developed rapidly, and some devices have been in the product finalization stage. With the rapid development of tidal current power generation technology, large-scale utilization has become the future development trend, and the need for field testing and

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evaluation is becoming increasingly urgent.

The tidal current energy is a kind of energy that changes with time and space, which determines that the power has unpredictable fluctuation. With large-scale power current power generation connected to the grid, the negative impact of power fluctuation on the grid operation becomes more apparent [2]. Therefore, mining the essential attributes of tidal current power fluctuation can minimize the risks on grid operation.

In the process of power fluctuation analysis, the sampling interval can affect the accuracy of the test results. The smaller the sampling interval, the higher the accuracy of the analysis, but there will be redundancy in the power generation information. The larger the sampling interval, the possible loss of key information, and inaccurate analysis results. In different sampling intervals, it is expected to find a maximum sampling interval, which can not only reduce information redundancy but also reflect the authenticity of the power [3]. Therefore, selecting a reasonable sampling interval has important practical significance for scientific testing of tidal current power generation.

2. The Status of Field Testing of Tidal Current Power Generation

2.1. International Status

The global tidal current power generation technology has developed rapidly, and a large number of tidal current power generations have been demonstrated and operated in different sea areas around the world. European and American marine power generation research institutions have long carried out research on testing methods and field testing. In 2009, the "Assessment of power performance of tidal energy conversion systems" was developed by the European Marine Energy Center (EMEC). In 2012, the International Electrotechnical Commission (IEC) issued the "Marine Energy—Wave, Tidal and Other Water Current Converters-Part 200: Electrical Production Tidal Energy Converters - Power Performance" (IEC/TS 62600-200:2013). In 2004, EMEC began field testing tidal current power generation. By 2022, 15 tidal current power generations had been tested at EMEC, mainly including power characteristics and power quality characteristics. Different types of tidal current power generations had been tested at the National Renewable Energy Laboratory (NREL) of the United States [4].

2.2. China Status

Focusing on the demand for field testing and evaluation of tidal current power generation, and considering the distribution of tidal current energy resources in China and the characteristics of complex marine environments, since 2011, the National Ocean Technology Center (NOTC)has successively researched field testing and evaluation methods, construction of testing systems, testing verification, and other work. In 2022, NOTC issued the "Field Testing Method for Power Characteristics of Tidal Current Power Generation" (GB/T 41342-2022). By utilizing the self-developed field testing system, NOTC has continuously, real-time, and long-term measured the marine environmental factors and power factors, and has successively analyzed and evaluated the power characteristics and power quality characteristics of nine tidal current power generations. It will provide scientific data support for technological innovation, improve equipment research and development levels, and optimize equipment performance [5].

2.3. Analysis of Power Fluctuation Research Status

Currently, there is no analysis of the power fluctuation of tidal current power generation in China and foreign references, and this paper mainly refers to the power fluctuation analysis of wind power generation. References [6-8] analyzed the wind power fluctuation by using mathematical statistics based on the measured data, and determined the optimal sampling interval. References [9-11] analyzed and predicted wind power fluctuation based on the time series method, which can predict ultra-short-term wind power and has certain practical value. References [12-14] analyzed the power characteristics and power quality characteristics of tidal current power generation through measured data, visually reflecting the power generation capacity and quality, there is no essential explanation for power fluctuation.

3. Field Testing

In order to study the relationship between the power fluctuation of tidal current power generation and the sampling interval. Based on the measured data of tidal current power generation distributed in the Zhoushan sea area of Zhejiang Province, China. This paper selects the power at a rising and falling tide as a data sample, with a sampling interval of 1s, to quantitatively analyze the power fluctuation. It can be seen from Figure 1 that the real-time power of rising and falling tide. This paper only considers the impact of flow velocity on power fluctuation, so the data sample does not include data during flat tide without power generation and negative power data during grid connection and disconnection.

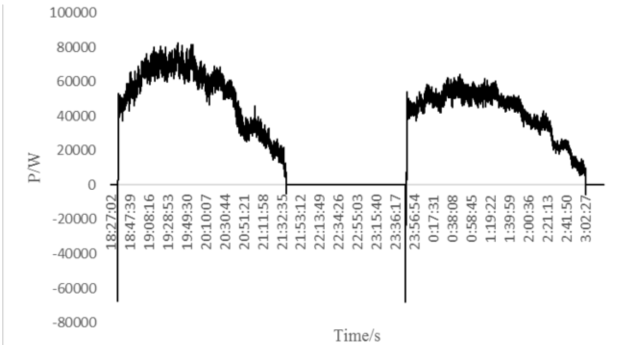


Figure 1. Real-time power of rising and falling tide.

4. Discrete Index Analysis

4.1. Discrete Index

The discrete index reflects the degree of numerical difference, and can be used to determine the balance and stability in power fluctuation analysis. In this paper, average value, range value, quartile difference, and coefficient of variation are selected as analysis indicators [13].

4.1.1. Average Value

The average value can reflect the overall level of power within a certain period of time.

$$P_{AVG} = \frac{1}{N}\sum_{i=1}^{N} P_i \tag{1}$$

In the equation, P_{AVG} is the average power, P_i is the power at a certain time, and N is the number of data samples.

4.1.2. Range Value

The range value can reflect the difference between the maximum and minimum power within a certain period of time.

$$R = P_{\max} - P_{\min} \tag{2}$$

In the equation, R is the range value, $P_{\max}$ is the maximum power in the measured data, and $P_{\min}$ is the minimum power in the measured data.

4.1.3. Quartile Difference

The quartile difference is the difference between the upper quartile and the lower quartile. A larger value means greater variability in the data.

$$Q = Q_3 - Q_1 \tag{3}$$

In the equation, Q is the quartile difference, Q_3 is the power value of the upper quartile, which is located at 75%, and Q_1 is the power value of the lower quartile, which is located at 25%.

4.1.4. Coefficient of Variation

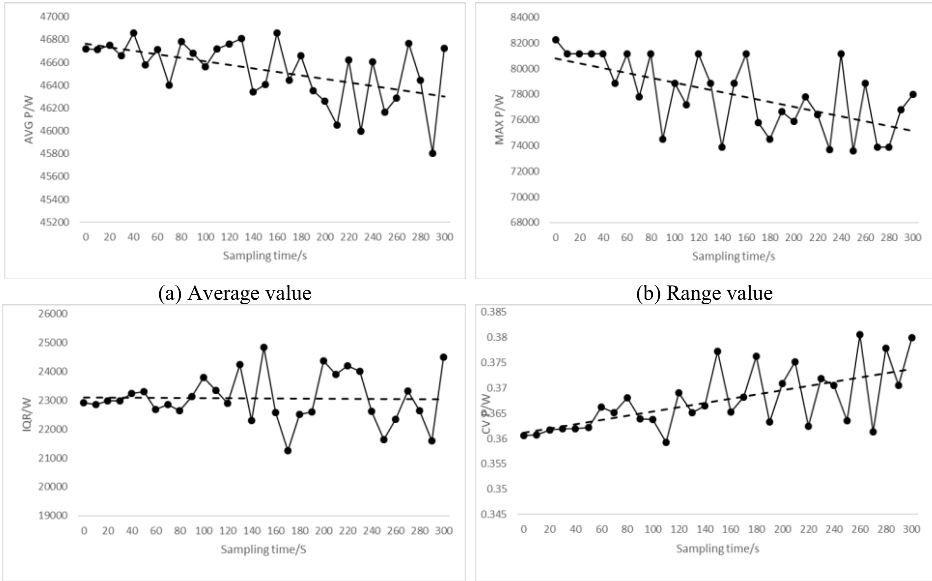
The variation coefficient can reflect the discrete degree of power within a certain period of time.

$$V_s = \frac{\sigma}{P_{AVG}} = \frac{\sqrt{N\sum_{i=1}^{N}(P_i - P_{AVG})^2}}{\sum_{i=1}^{N} P_i} \tag{4}$$

In the equation, V_s is the coefficient of variation and σ is the standard deviation.

4.2. Power Fluctuation Analysis

It can be seen from Figure 2 that the relationship between the discrete index and sampling interval. As the sampling time increases, the average power tends to decrease. The fluctuation is significant within a large sampling time interval, resulting in a decrease in the credibility of the average power. The maximum power fluctuates greatly with the change of sampling interval, with a small fluctuation within 60s, and decreases overall with the increase of sampling interval. The overall quartile difference remains stable, with significant fluctuation after more than 60s. The coefficient of variation is relatively stable within 60 s and increases within a larger sampling interval, indicating that power fluctuation increase as the sampling interval increases.



(a) Average value (b) Range value

(c) Quartile difference (d) Coefficient of variation

Figure 2. Relationship between the discrete index and sampling interval.

4.3. Selecting the Sampling Interval

In this paper, the entropy weight method is used to calculate the index weight. For an indicator, the entropy value can be used to determine the degree of dispersion of the indicator. The smaller the information entropy value, the greater the degree of dispersion of the indicator, and the greater the impact of the indicator on a comprehensive evaluation, that is, the greater the weight.

4.3.1. Normalization Processing

The dimensionless processing of data scales the ratio between the maximum and minimum values to between [0, 1].

$$X_i = \frac{P_i - P_{\min}}{P_{\max} - P_{\min}} \tag{5}$$

In the equation, X_i is a dimensionless value.

4.3.2. Proportion

The proportion of indicators in each time scale is calculated as follows.

$$Y_i = \frac{X_i}{\sum_{i=1}^{N} X_i} \tag{6}$$

In the equation, Y_i is a proportion.

4.3.3. Information Entropy

The information entropy is calculated as follows.

$$E_j = -\ln(N)^{-1}\sum_{i=1}^{N} Y_i \ln Y_i \tag{7}$$

In the equation, E_j is the information entropy of the indicator, if Y_i=0, we define E_j=0.

4.3.4. Weight

The weight of each indicator is calculated as follows.

$$\omega_i = \frac{1-E_j}{k-\sum E_j} \tag{8}$$

In the equation, ω_i is the weight value of each indicator, and k is the number of evaluation indicators. After calculation, the weight value of average value, range value, quartile difference, and coefficient of variation are 0.137411696, 0.400483427, 0.266557104, and 0.195547545.

4.3.5. Comprehensive Fluctuation Coefficient

The comprehensive fluctuation coefficient is calculated as follows..

$$S_i = \sum_{j=1}^{k} \omega_i \bullet X_i \tag{9}$$

In the equation, S_i is a comprehensive fluctuation coefficient.

It can be seen from Figure 3 that the relationship between comprehensive fluctuation coefficient and sampling interval, within the sampling time of 60 s, the variation of the comprehensive fluctuation coefficient of the tidal current power generation is relatively stable. When it is greater than 60 s, the fluctuation coefficient changes from 0.1 to 0.7, with significant fluctuation.

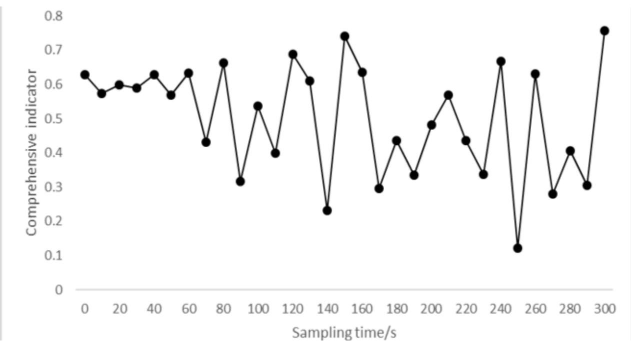


Figure 3. Relationship between comprehensive fluctuation coefficient and sampling interval.

4.4. Deviation Check

The smaller the sampling interval, the more truly the measured data reflect the power characteristics of tidal current power generation. As the sampling interval increases, the value of the comprehensive index deviating from the minimum sampling interval also increases. To analyze the degree of deviation, takes 1 s as the minimum sampling interval and calculates the relative error of other sampling intervals. It can be seen from Figure 4 that the relationship between the relative error of comprehensive index and sampling interval, the relative error of the comprehensive index is less than 10% within 60 s.

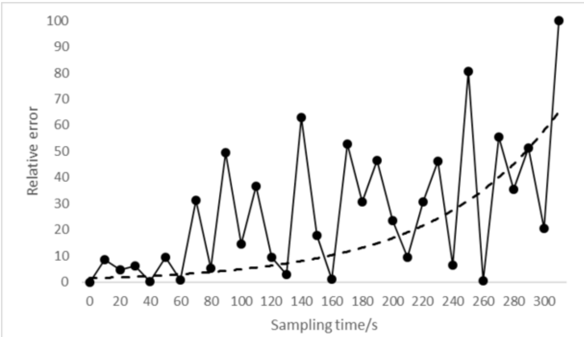


Figure 4. Relationship between the relative error of comprehensive index and sampling interval.

4.5. Power Curve Similarity Analysis

Using the power data at rising tide as a sample, plot trend lines of power scatter points with sampling intervals of 1 s, 60 s, 180 s, and 300 s, respectively. It can be seen from Figure 5 that the power curve similarity analysis.The fitting degrees of calculated scatter points and trend lines are 0.935, 0.924, 0.901, and 0.898. The fitting degree decreases as the sampling interval increases, and the fitting effect becomes worse. Then, based on the trend line with a sampling interval of 1 s, calculate the similarity of the remaining three curves. The principle of the curve similarity algorithm is based on comparing the distances between the two curves. The smaller the distance, the higher their similarity. The similarity of trend lines with a sampling interval of 60 s and 1 s is greater than 0.95, which can truly reflect the distribution of power scatter points.

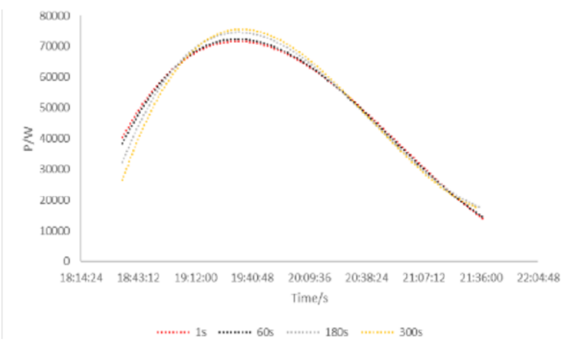
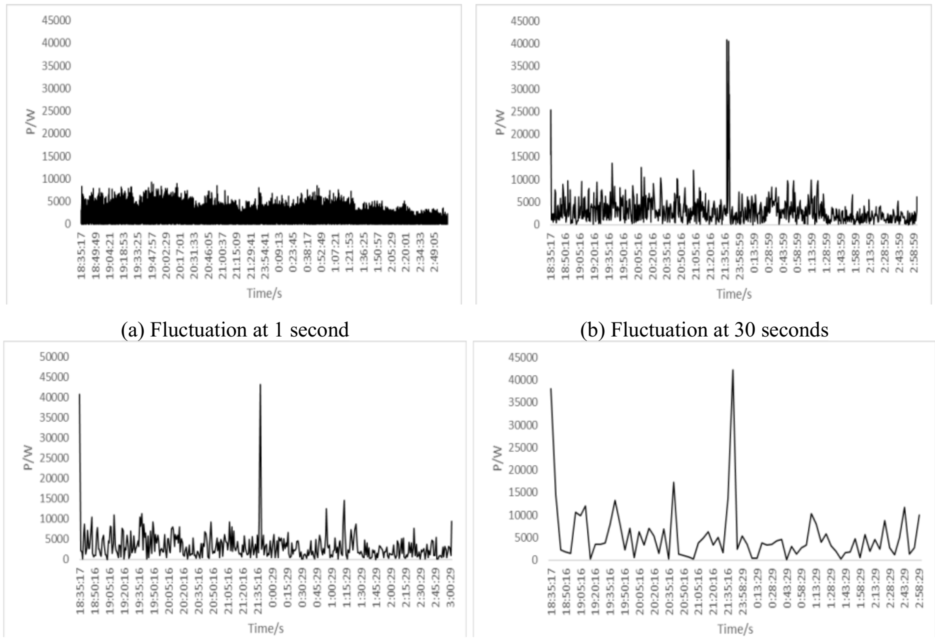


Figure 5. Power curve similarity analysis.

5. First Order Difference Component Analysis

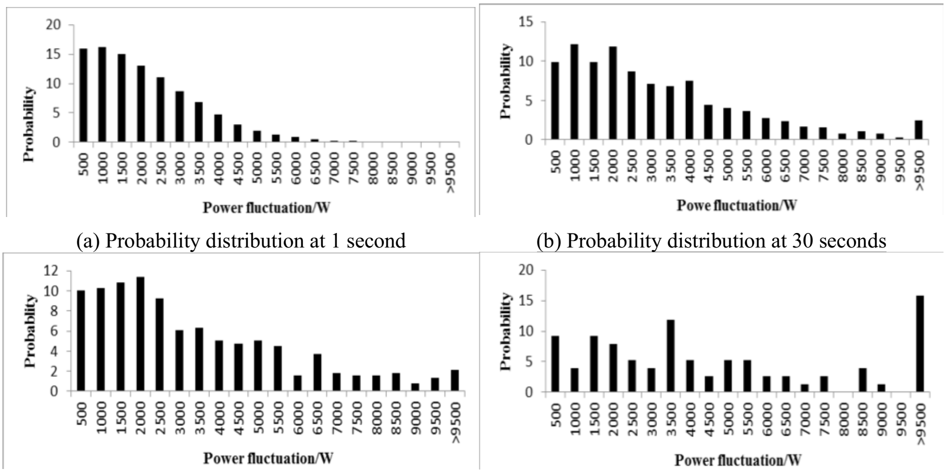
In the analysis, the corresponding power fluctuation and its probability distribution are calculated based on the sampling intervals of 1 s, 30 s, 60 s, and 300 s. It can be seen from Figure 6 that the variation of power fluctuation with sampling interval, when the sampling interval is 1 s, the fluctuation is less than 9 kW, the concentration degree is high, and the distribution probability is as high as 100%. When the sampling interval is greater than 30 s, the fluctuation occurs multiple times, and the maximum fluctuation when switching into the grid is 40 kW. It can be seen from Figure 7 that the probability distribution of power fluctuation at different sampling intervals, the distribution probability of power fluctuation in the small power variation range decreases, while the distribution probability in the large power variation range increases. Comparing the sampling interval of 60 s with 1 s, the concentration of fluctuation is relatively scattered, and the main distribution range is not obvious. However, the distribution probability of less than 9 kW is greater than 95%, which can truly reflect the power fluctuation. When the sampling interval is 300 s, the distribution probability of fluctuation greater than 9 kW is 16%. In summary, with the increase of time scale, the power fluctuation is also increasing, the distribution probability of the first order difference component gradually dispersed, and the distribution probability of large fluctuation increases.



(a) Fluctuation at 1 second

(b) Fluctuation at 30 seconds

Figure 6. Variation of power fluctuation with sampling interval.



(a) Probability distribution at 1 second
(b) Probability distribution at 30 seconds
(c) Probability distribution at 60 seconds
(d) Probability distribution at 300 seconds

Figure 7. Probability distribution of power fluctuation at different sampling intervals.

6. Conclusion

The power fluctuation characteristics of tidal current power generation are analyzed from different sampling intervals, and the following conclusions are obtained:

Analyzing the discrete indicators of power fluctuation, it can be concluded that the numerical changes are relatively small within 60s, and as the sampling interval increases, the fluctuation increase. By using the entropy weight method to comprehensively evaluate discrete indicators, it can be concluded that the relative error of the comprehensive indicators is less than 10% within 60 seconds. Compared with the minimum sampling time of 1s, the data volume is 1/60 of it, and the engineering calculation amount is reduced accordingly.

Analyzing the first-order difference component of power fluctuation, it can be concluded that as the time scale increases, the power fluctuation also increases. The distribution probability of the first-order difference component gradually disperses, and the distribution probability of large fluctuation increases.

This paper comprehensively proposes a recommended sampling interval of 60s, which can reduce the amount of data processing and truly reflect the inherent characteristics of power fluctuation in tidal current power generation.

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