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# Research on Intelligent Control Strategy of Smart Power Assurance System Based on Edge Computing

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**Abstract** The increasing size of the power grid and the growing demand for grid security have put forward higher requirements for the performance of power protection systems. Edge computing method is selected as the power relay protection algorithm to design the system framework of relay protection. Meanwhile, the relay protection algorithm based on sinusoidal function model is introduced to calculate the RMS value, phase difference and circuit parameters of the input signal, thus completing the design and construction of the intelligent power protection system. Build the collection process of basic power consumption information of users, and obtain the power consumption pattern of users. On the basis of users' basic power consumption information, artificial intelligence technology is used to automatically predict the grid load, analyze the power stability, and realize the intelligent control of power protection strategy. Compared with similar systems, the intelligent power protection system designed in this paper maintains the output current between 0 and 0.21A after 2.6s in practical application, showing more excellent stability.

**Index Terms** edge computing, power protection system, sinusoidal function model, artificial intelligence

## I. Introduction

The power system is closely related to the production and life of the people, and is an important foundation for social stability and economic development. But it can also cause major catastrophic accidents in an instant, because the power operation failure leads to large-scale power outage, which will cause huge losses [1]. Especially the scale of the power system is getting bigger and bigger, the structure of the power system is getting more and more complex, the safe operation of the power system is getting more and more important, and more and more can not be ignored [2], [3].

When a power system failure occurs, the low sharing of power data and poor real-time, will lead to the power protection personnel can not get the accurate information of the faulty circuit in time, which seriously affects the maintenance efficiency [4], [5]. This requires an intelligent power protection system to assist in accomplishing the functions of detecting power data, managing end users, transforming, and controlling electrical equipment, etc., which helps the power protection personnel to fully understand the actual production situation, and to grasp the most real and effective data on the safe operation of the power system [6]-[9]. It can be said that the security system of the power system is the basis for the safe operation of the power system, and once the anomaly occurs, it is necessary to start the stabilization control of the power system, so as to ensure the safety and stability of the power system [10]-[12]. Therefore, the daily operation of the power system should strengthen the security, build a strong smart grid structure, design the optimal automation system, and scientifically plan the operation of the power system to ensure that the power system is not disturbed or malfunctioned [13]-[15]. And once a fault occurs, it is necessary to carry out the stabilization control of the power system, and design the corresponding intelligent control strategy to make the power system return to stability, to prevent the occurrence of large-scale blackout accidents [16], [17].

In this paper, in the context of the application of the edge computing method, the framework of relay protection system is designed to address the shortcomings of the traditional power grid relay protection. It also discusses in detail the arithmetic process and steps of the relay protection algorithm based on the sinusoidal function model, and constructs a power protection system by calculating and comparing the changes of various power parameters in the power grid to provide data reference for the intelligent control strategy. Based on this power protection system, the collection process of basic power consumption information of users is elaborated. Adopt artificial intelligence technology to automate the prediction of grid load and analyze power stability. Combined with the user's power consumption law to put forward the control strategy, to form the intelligent power protection system.

Finally, the reliability of the system is examined by evaluating the performance of the intelligent power protection system in predicting the fault characteristics of the power grid and the overall operational performance. Application simulation experiments are carried out to verify the feasibility of the proposed system.

## II. Power Assurance System Based on Edge Computing

### *II. A.Edge Computing Based Relay Protection System Framework*

The development of edge computing is fully in line with the power grid to promote the goal of informationization and intelligence, the traditional power grid relay protection is generally based on the basic electrical characteristics to perform the corresponding protection operation, and then the key data through the grid protocol transmission to the backend master station analysis and processing, the backend master station's processing instructions and then through the same process to the corresponding equipment to perform, this process in the delay, real-time deficiencies exist. This thesis for the existence of this deficiency, the proposed edge computing relay protection system based on Figure 1. relay protection equipment and other intelligent terminals will be the key data transmitted to the edge device, the edge device to access the terminal first verification, verification through the protocol analysis of the data and processing, to give the corresponding feedback, and finally the data can be done to predict the results and recommendations to be delivered to the backend master station. In traditional relay systems, only data from a recent period of time can be utilized for simulation and prediction, and the data sample size is limited. Under edge computing, by accessing the electric power private cloud, data samples can be extracted from the near, medium, and far future, and more scenarios of simulation and prediction can be done.

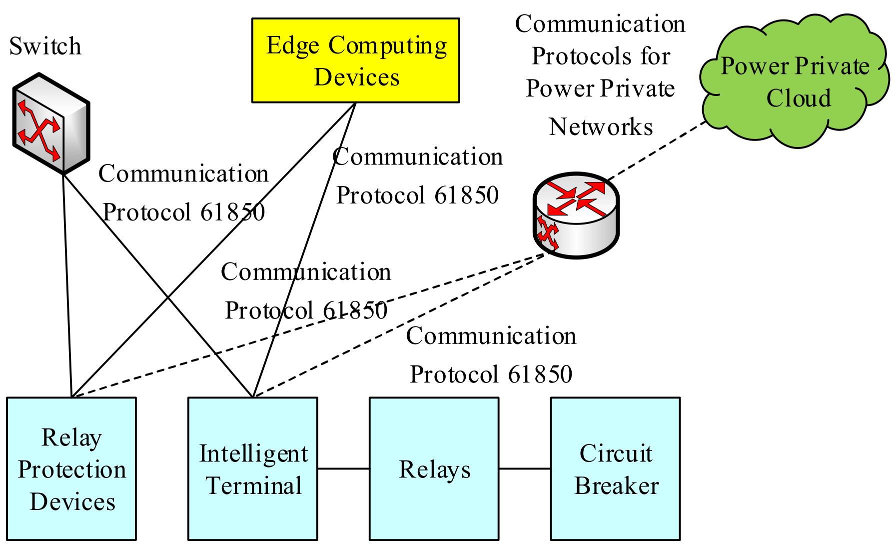



Figure 1: The framework of relay protection system based on edge computing

### *II. B.Relay protection algorithm based on sinusoidal function modeling*

When the current and voltage signals collected by the samples are all sinusoidal, the corresponding characteristics of the sinusoidal function can be used to calculate the value of the measured impedance, power, phase, current and voltage amplitude, etc., and then to complete a large number of protection functions by comparing and judging the collected values.

In fact, for the power system in the event of a fault in the voltage and current all exist a large number of transient components, while the collection of data system will also introduce a variety of errors, so you need to determine the accuracy of the calculation of digital filtering devices, eliminating high-frequency components and non-periodic components brought about by the role of interference before the algorithm can be selected, otherwise it will lead to the calculation of a serious error.

Two-point product algorithm is mainly through the two sampling values multiplied by the means of anti-group, voltage and current phase angle and negative value and other related parameters, because the algorithm is only through the two sampling values to preview the state of the entire curve, so it is a curve-fitting method, the biggest advantage is that the calculation of the determination of the time cost is relatively low. The operation flow of the two-point product algorithm is shown in Figure 2.

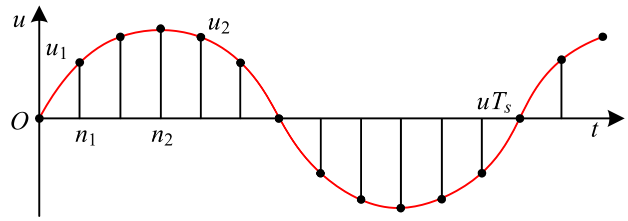



Figure 2: Sampling illustration of the two-point product algorithm

Calculated for voltage, if $u_2$ as well as $u_1$ are two sampled values with moment interval $\pi / 2$ respectively, then there are equations (1)-(2):

$$u_1 = U_m \sin(\omega t_n + \alpha_{0u}) = \sqrt{2} U \sin\theta_{1u} \tag{1}$$

$$u_2 = U_m \sin(\omega t_n + \alpha_{0u} + \pi / 2) = \sqrt{2} U \cos\theta_{1u} \tag{2}$$

where $\theta_{1u} = \omega t_n + \alpha_{0u}$ is the phase angle of the voltage at the $t_n$ sampling moment, which may be any value.

Quadraticizing and summing Eq. (1) as well as Eq. (2) yields Eq. (3):

$$2U^2 = u_1^2 + u_2^2 \tag{3}$$

Dividing Eq. (1) as well as Eq. (2) gives Eq. (4):

$$\tan\theta_{1u} = \frac{u_1}{u_2} \tag{4}$$

In equations (3) and (4), by determining the instantaneous value of any two sinusoids separated by $\pi / 2$, the phase and RMS value of the sinusoid can be determined.

If it is necessary to determine the impedance, it is only necessary to measure the voltage and current together for the two sinusoids with an interval of $\pi / 2$, according to the above method, then there are equations (5)-(6):

$$Z = \frac{U}{I} = \frac{\sqrt{u_1^2 + u_2^2}}{\sqrt{i_1^2 + i_2^2}} \tag{5}$$

$$\alpha_Z = \alpha_{1U} - \alpha_{1I} = \arctan\frac{u_1}{u_2} - \arctan\frac{i_1}{i_2} \tag{6}$$

There are inverse trigonometric functions in Eq. (6), so a simple calculation is to determine the reactance and resistance components of the impedance first, and then describe the voltage and current in complex form, so that Eqs. (7)-(8) are available:

$$\dot{U} = U\cos\theta_{1u} + jU\sin\theta_{1u} \tag{7}$$

$$\dot{I} = I\cos\theta_{1i} + jI\sin\theta_{1i} \tag{8}$$

According to equations (1) and (2), it is possible to determine (9)-(10):

$$\dot{U} = \frac{u_2 + ju_1}{\sqrt{2}} \tag{9}$$

$$\dot{I} = \frac{i_2 + ji_1}{\sqrt{2}} \tag{10}$$

Hence there is equation (11):

$$\frac{\dot{U}}{\dot{I}} = \frac{u_2 + ju_1}{i_2 + ji_1} = \frac{u_1 i_1 + u_2 i_2}{i_1^2 + i_2^2} + j\frac{u_1 i_2 - u_2 i_1}{i_1^2 + i_2^2} \tag{11}$$

Within Eq. (7) $R$ is the real part and $X$ is the imaginary part, hence Eqs. (12)-(13):

$$R = \frac{u_1 i_1 + u_2 i_2}{i_1^2 + i_2^2} \tag{12}$$

$$X = j\frac{u_1 i_2 - u_2 i_1}{i_1^2 + i_2^2} \tag{13}$$

Since Eq. (8) as well as Eq. (9) are derived from the product of two sampled values, it is called the two-point product method.

Where the phase angle difference between $\dot{U}$, $\dot{I}$ determines Eq. (14) according to Eq. (10):

$$\tan\theta = \frac{u_1 i_2 - u_2 i_1}{u_1 i_1 + u_2 i_2} \tag{14}$$

The product of the above is calculated by taking two samples spaced $\pi/2$ apart, the time required is 1/4 cycle, which is 5ms at 50Hz of the industrial frequency.

The circuit is illustrated in Fig. 3. When the voltage input is measured as $v(t) = 100\sin(\omega t)$, then the current input is $i(t) = 50\sin(\omega t - \pi/6)$, and the number of samples collected during all cycles $N = 12$, the circuit parameters, phase difference of the signal inputs, and the RMS are calculated by the two-point product method. Calculation.

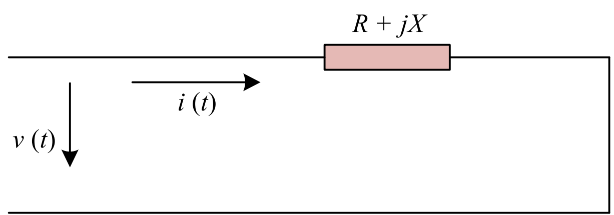



Figure 3: Example circuit

The flow of calculating the RMS value, phase difference and circuit parameters of the input signal using the two-point product method is shown in Fig. 4.

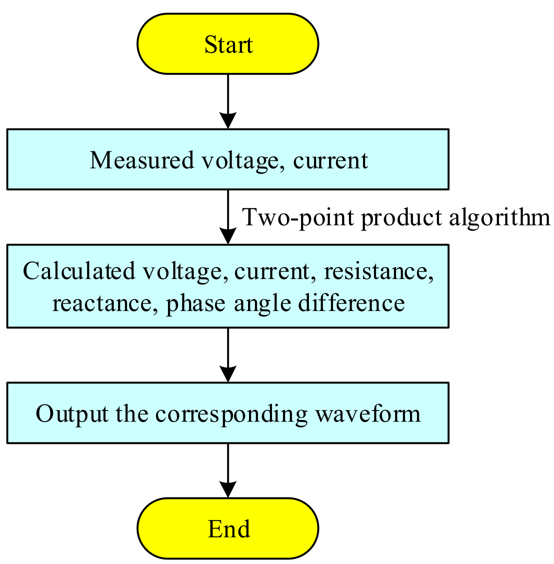



Figure 4: The calculation process of each parameter of the input signal

## III. Intelligent control strategy of intelligent power protection system

### *III. A. Collection of basic electricity consumption information of users*

Intelligent power system can realize the collection of power consumption information for each user through a large number of induction devices arranged at the equipment layer. For example, for a single user's peak power consumption, single valley value, average daily power consumption, power vacuum, average monthly power consumption, etc., for the region within the overall user's overall power consumption peaks, valleys, average power consumption and other information, for the transformer temperature changes in the power equipment and the average value, the harmonic frequency of high-voltage into the line in each time period, and so on.

The function in the power supply guarantee is mainly reflected in the role of improving the relevance of the power supply service. In the context of modern electricity consumption, single-user electricity consumption is gradually rising, and electricity consumption between various regions will show a more obvious time gap, the traditional, indiscriminate uniform power supply mode in the current stage of application will cause greater pressure on the power supply enterprises, the need to make targeted improvements.

First of all, the intelligent power system through the collection and analysis of personal and regional user power data can be derived from the user power law, based on the power law for targeted power allocation, reduce the pressure on the power supply of electric power enterprises. Such as in the collection of data shows that the local area collective power in the valley, or even vacuum period, the power system can optimize the configuration of power in the line, more resources will be applied to the time period of power demand is more concentrated in the region, to enhance the efficiency of the use of resources. When the same period of time in multiple regions in the peak power consumption, intelligent power monitoring system can be based on the collection of the average value of the power resources based on the proportion of the distribution of power resources to different regions, to enhance the scientific use of power resources. Avoid the traditional power distribution mode, the front section of a large number of regional power, resulting in the back end of the regional power supply is obviously insufficient, the production and life can not be carried out normally.

Secondly, the intelligent power system can realize the early distribution of power resources based on the collected information. Analyzing the information collected by the intelligent power system, it is not difficult to find that the peak power use is usually concentrated in a fixed period of time. Therefore, the intelligent power system can mobilize power resources in advance to meet the peak power demand of all the people in the region and improve the quality of user services. Finally, the information collected by the intelligent power system can guide the replacement of relevant power equipment and conductors. Intelligent power system will automatically compare the collected information with the historical information, if it is found that part of the conductor compared with the historical data, the gap between the temperature change amplitude is more obvious, then it means that the conductor has been aging internally, and needs to be replaced as soon as possible. Such as the collection of data in the transformer centralized power time temperature is too high, it shows that it can not be well adapted to the regional power supply needs, the need for timely replacement or performance enhancement of the relevant personnel. So that the power equipment is always able to better meet the needs of the power supply, to avoid the occurrence of overload power outage phenomenon, to enhance the stability of the power supply.

## *III. B. Power system automation control strategy based on artificial intelligence*

### III. B. 1) Automated load forecasting

Automated load forecasting using artificial intelligence is carried out to ensure power production, optimize power distribution, improve the efficiency of the system, and strengthen system reliability. Historical load data, weather information, date and time (weekdays, weekends, holidays), socio-economic data, and other data directly related to load consumption are collected, and the collected data are cleaned, normalized, and feature-selected to improve the quality of input data for the forecasting model. Valuable information such as trend components, cyclical components, seasonal variations, and patterns of electricity consumption at specific times of the year are extracted from the raw data, and data mining and statistical analysis methods are used to identify features that are closely related to electricity load. Machine learning models such as linear regression, support vector machine (SVM), random forest, or deep learning models such as long and short-term memory network (LSTM) are selected to train the model using historical data, and the model parameters are adjusted through a repeated iterative process to ultimately identify a highly accurate load forecasting model. The performance of the model is evaluated using cross-validation techniques to ensure that the model has good generalization ability, and the algorithm parameters are adjusted, regularization terms are added, and feature transformations are applied during the validation process. After completing the model iterations, the trained model is used for actual load forecasting. The system will iterate the prediction and continuously adjust the model according to the actual load situation to achieve more accurate prediction. To further improve the accuracy of prediction, the prediction results of multiple models can be combined by integrated learning methods, and models such as integration tree, bagging or boosting methods can be fused to take advantage of the strengths of multiple prediction models and improve the prediction accuracy.

In practice, load forecasting is often fine-tuned to each area and even to each building and household, and the effects of different load forecasting techniques vary, so it is necessary to select the appropriate dimensions when choosing a technique for targeted application.

#### III. B. 2) Power stability analysis

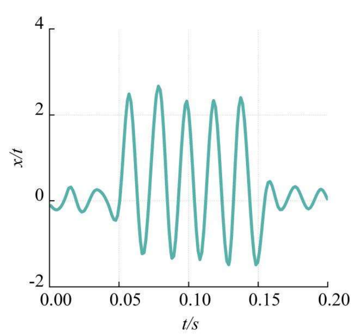
Utilizing artificial intelligence technology to assess system steady-state and transient stability, strengthen the scale of analysis, capture key variables, and improve the quality of grid operation. Based on synchronous vector measurement units, intelligent meters and other sensors, it collects data from various substations, voltage and current data from various terminals, power generation, frequency and voltage from power plants, and carries out dynamic simulation after clearing the data to determine the stability of power under different loads and network conditions, and at the same time optimizes the grid dispatch based on the results of prediction and analysis, activates the energy storage system and dynamically adjusts the output of generators in the appropriate circumstances, and And even control the grid-connected status of renewable energy, while self-adjusting the control algorithm based on artificial intelligence technology to realize iterative updating in the actual operation process. At the actual execution level, the grid system will synchronize the current data in each dimension to the dispatcher and other operators, show the data changes in the form of visual charts, and open a number of permissions to the operators, allowing them to make manual adjustments.

## IV. Application and Inspection of Intelligent Safeguard System

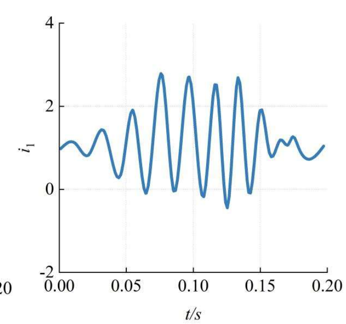
### *IV. A. Prediction of fault characteristics*

Predicting fault characteristics of the IEEE39 node system using an intelligent power assurance system based on edge computing to examine the predictive performance of the system.

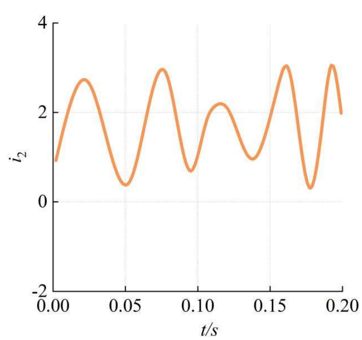
The fault signal comes from the original current signal x(t) of the L4-14 short-circuit fault generated by the Simulink software simulation of the IEEE39 node system, and the relevant line current waveform data is extracted at the fault time of 50ms, and the inherent mode component of the L4-14 fault phase current x(t) after the empirical mode decomposition is shown in Figure 5, and the original fault signal x(t), the decomposed IMF1~IMF4 component and the residual component r(t) are in order from top to bottom. The IMF1 component corresponds to the noise part of the fault signal, and the subsequent four components are smoother, indicating that EMD has a better signal-to-noise separation function.EMD decomposition takes the mutation information during the actual perturbation as the second IMF, and the mutation information can be used to extract the fault features based on the instantaneous spectrum, energy, and amplitude of the IMF2 component.



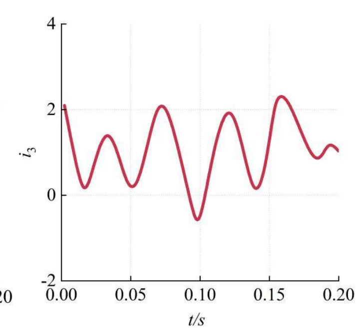

(a) x/t



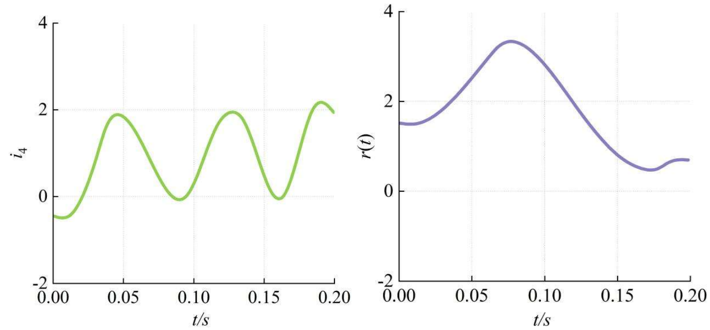

(b) i1




(c) i2




(d) i3




(e) i4 (f) r(t)

Figure 5: Fault current signal's IMF

The IMF2 component fault characteristics are extracted to obtain the marginal spectrum, instantaneous frequency analysis results are shown in Figs. 6-7, respectively.

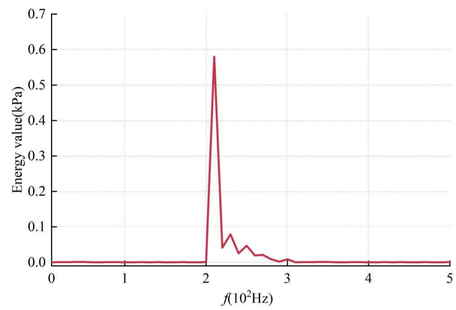



Figure 6: Marginal spectrum

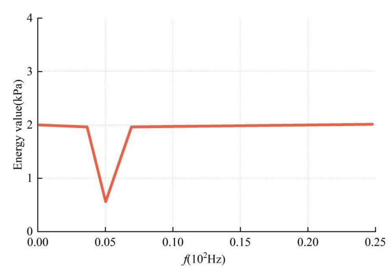



Figure 7: Instantaneous frequency analysis result

### *IV. B. Operational performance test of the system*

Selection Selection of intelligent power protection systems based on three different algorithms: K2, K3, and K4, to compare the performance with (K1) edge computing based intelligent power protection system.

When the number of accessed power terminals is fixed, the amount of tasks is related to the sampling frequency of the differential protection device, the response time, and the faulty line troubleshooting in the distribution network. The initial increase in the number of tasks does not create a large gap between the stochastic and co-processing schemes because the transmission delay has a small impact on the total computational delay. When the task volume becomes more, the edge computing approach is used to schedule more abundant resources to solve the differential protection requirements, which makes the processing latency stable at around 10s under a task load of 2-3, which is lower than the other three systems and has a strong stability. This reflects the superiority of (K1) method in this paper. Where the effect of task load on the average delay is shown in Fig. 8.

Fig. 9 represents the relationship between the distribution network fault points and fault investigation time, excluding the K4 system with high average delay. The circuit breaker delay is set to 40ms, the arc quenching time is 10ms, the protection device processing data time and the protection exit relay delay time is 15ms. the end-to-end delay of the current differential protection service is controlled to be within 20ms, (K1) the maximum delay of the proposed method in this paper's system is 139ms, and the number of end-to-end interactions in this paper is 3 in the case of the 85ms baseline reaction time, then the single end-to-end delay is about 18.5ms, in the case of lower number of enemy obstacles, the delay will be controlled in a smaller range, so (K1) the method in this paper is in line with the actual development situation. Taking 150ms as the upper limit of fault contingency processing, when a fault occurs, the troubleshooting time is determined by the communication delay of the longitudinal channel on the basis of the above time. When the number of fault points increases, only the SCADA processing time increases abruptly, and when there are too many faults at the same time, the processing time exceeds the emergency processing upper limit requirement. When the number of fault points continues to increase, if there are other fault points between two fault points, the fault areas will be merged and the fault investigation time tends to converge.

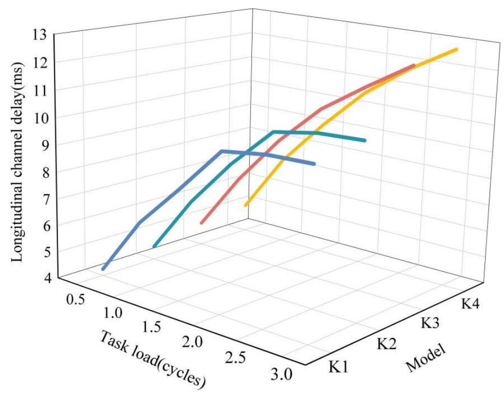



Figure 8: The influence of task volume on average delay

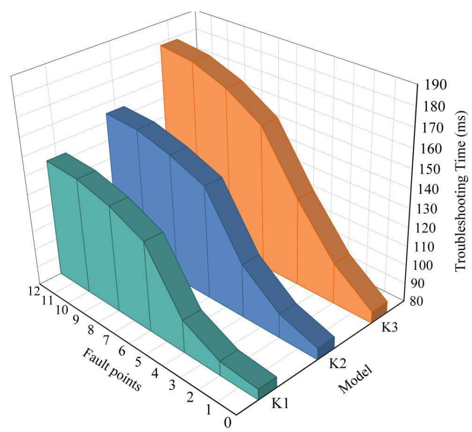



Figure 9: The connection between the number of faults and the troubleshooting time

### IV. C. Application performance of the system

This section unfolds the simulation experiments on the performance of the proposed intelligent system approach for the application of moving edge calculation and delay control of distribution network differential protection. The moving edge of the distribution network differential protection is calculated and the output stabilized voltage equalization curve is obtained as shown in Fig. 10.

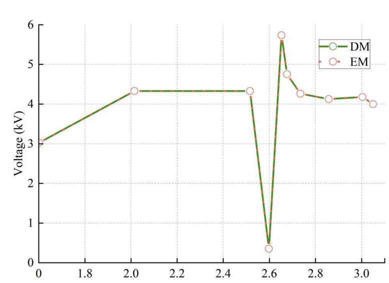



Figure 10: Output the voltage stabilization and equalization curve

Analyzing Fig. 10, it can be seen that when the time is 2s, the output voltage of the proposed method rises from 3.02kV to 4.23kV and stays constant in the time period of 2~2.4s, and after 2.4s, it first drops to 0.51kV and then rises to 5.51kV, and then stays constant at about 4kV, which can be seen that the proposed method of the output voltage stabilization of the moving edge calculation of the differential protection of the distribution network has a good performance. On this basis, the test output current is shown in Fig. 11.

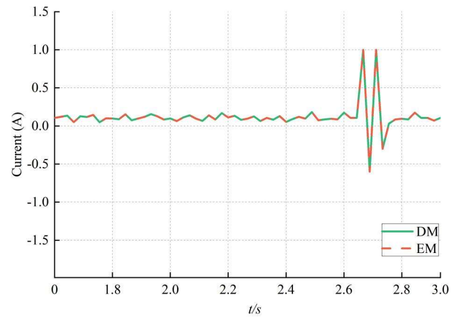



Figure 11: Output current test

Analyzing Fig. 11 shows that the output current of the proposed method fluctuates around 1 to 0.81 A when the time is 2.4 to 2.6 s, while the output current has been kept between 0 and 0.21 A during the rest of the time period, which shows that the proposed method of the mobile edge calculation of the output current of the differential protection of the distribution network has a better stability because the edge calculation analysis method used combines the parameters of the aggregation ring and the access loop The reliability control function is obtained by combining the fusion results, which results in better output voltage stabilization and current stability.

## V. Conclusion

In this paper, an intelligent power assurance system that can effectively dominate the intelligent control strategy is proposed by combining the edge computing analysis method and artificial intelligence technology. The system is able to effectively extract the fault characteristic information in the faulty grid nodes and provide sufficient data support for the intelligent control strategy. And compared with similar systems, the average delay in processing tasks is stabilized within 10s. In the simulation experiment of distribution network differential protection, the output current of the control grid is kept within 0~0.21A most of the time, showing strong robustness.

The research in this paper further improves the intelligent level of intelligent power protection, and provides a strong theoretical reference and technical support for the construction of a new type of power system.

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