

Research Article

The Principle of Intelligent Switch Composition and Algorithm of the Built-In Electronic Voltage Transformer

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Received 24 September 2020; Revised 23 April 2021; Accepted 6 May 2021; Published 2 July 2021

Academic Editor: Qiankun Song

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With the rapid development of the social economy, people's demand for energy is increasing. Global warming has made people pay more attention to the importance of energy saving and emission reduction. The power grid is the system responsible for the transmission and distribution of electric energy. Therefore, in the context of energy saving and emission reduction, there are higher requirements for substations in the power grid. For this reason, an intelligent switch with built-in electronic voltage transformer is designed. The concept and key technical characteristics of the electronic voltage transformer intelligent switch are introduced; the overall design scheme of the built-in electronic voltage transformer intelligent switch is expounded; the hardware and software system of the device is designed; the management and control strategy of the design device is such as transformer tangent control, voltage and reactive control; and the operating system is ported. Finally, the simulation test of the system proves that the system has high effectiveness and stability. The research can provide reference for the realization of efficient, economic, stable, safe, and environmentally friendly distribution of power in a power grid.

1. Introduction

With the development of urban construction in recent years, the power consumption in cities has been increasing constantly, and the transmission and configuration system in a power system has also ushered in the opportunity of technological innovation and equipment renewal [1]. In recent years, the birth and promotion of the concept of intelligent substation have put forward higher intelligent control requirements for key node devices in the power system [2]. Based on this, a built-in electronic voltage transformer device is proposed as an intelligent switch, and an artificial intelligence algorithm is added for information planning and processing of the device. This research is a driving force for the construction and promotion of smart grids and is conducive to promoting energy structure optimization and sustainable economic and social development. It is the embodiment of the scientific development of the power industry. In the research method, the hardware circuit scheme and system software scheme of intelligent switch device of transformer

are designed. A fuzzy neural network algorithm is used to solve the problem of voltage and reactive power integrated control in a substation. A genetics algorithm is used to find the best switching scheme in a finite period of transformer. Finally, an intelligent electronic transformer switching system with automatic control and artificial intelligence is formed. The design feature of this study is that the built-in electronic voltage transformer is used for real-time data acquisition in substations. On this basis, the artificial intelligence algorithm is applied to the self-diagnosis and fault analysis of substation, which realizes the intelligent goal of substation distribution link and effectively promotes the coordinated interaction of information, maintenance, and dispatch of substation equipment. The research is divided into three parts. The first part is a summary of other scholars' research on intelligent substation electronic transformer. The second part is about the scheme design of the intelligent switch of the built-in electronic voltage transformer in this research. It mainly includes the software and hardware scheme design of the electronic voltage transformer and the

artificial intelligence algorithm (fuzzy control, neural network algorithm) of the substation automatic control system. The third part is the simulation test of the improved voltage reactive power control of fuzzy neural algorithm and the improved transformer switching control of genetic algorithm.

2. Related Work

With the progress of science and technology, a substation in a power system has gradually changed from automation technology to today's intelligent technology. In order to meet the needs of intelligent power grid, the intelligent switchgear of electronic transformer has also been developed into an intelligent monitoring and control system which can digitally share information of the whole station and support real-time intelligent regulation and control of power grid and online analysis and decision-making [3]. In the process of development and construction of smart substation, the application of electronic transformer is indispensable, which greatly promotes the development of real-time information digitalization of smart grid [4].

Wang et al. developed a test scheme based on a digital physics hybrid simulation model and used the sudden change to detect the initial moment to calculate the electronic transformer error of the transient process to ensure the stability of the system [5]. Tang et al. used the excavated data to calculate the state of the data through the power flow calculation equation and used the L-M algorithm to evaluate the data state and compare the error with the data for a period of time to realize the deviation detection of the transformer [6]. Yang and Guo used a resistor-capacitor shunt voltage divider to provide discharge way for charge, eliminated transient error, and reduced phase error by using the resistance characteristic of positive temperature coefficient to ensure the accuracy of electronic transformer [7]. Gu et al. used the improved digital filtering algorithm to check the steady state of electronic transformer, so as to improve its accuracy [8]. Li et al. used the Q-ARMA error state prediction method to eliminate errors caused by grid fluctuations [9]. Liu et al. developed a voltage follower connected to the voltage divider system and the calibration system to test the harmonic accuracy of the electronic transformer [10]. Mao et al. studied the electronic transformer in the high-cold area. The Hilbert change algorithm was used to solve the impact of low-temperature adaptive device. A quasisynchronous algorithm and multithreaded working mechanism ensured the coexistence of low error and high efficient [11]. Mou et al. studied the signal processing of electronic transformers, improved a fundamental phase synchronization algorithm to reduce the amount of phase calculation, and improved the integral algorithm to solve the problem of poor transient characteristics of electronic transformers [12]. Wang et al. compared the two algorithms of resampling and synchronization of electronic current transformers and found that the parabolic difference algorithm had less impact on the accuracy of the full fiber current transformer [13]. Tian et al. proposed a variable step size integration algorithm to improve the accuracy of voltage drift of electronic current transformers [14]. Bayona et al. proposed a mitigation device using power electronic con-

verter as a resistance simulator to actively alleviate ferroresonance [15].

In the research of electronic transformers, most scholars focus on reducing the errors caused by grid fluctuations and improving the accuracy of transformers. Combining with built-in microprocessing technology, communication technology, and intelligent technology of power station, the optimal control of voltage and reactive power and the optimal switching of transformer are selected by using the fuzzy neural network algorithm and genetic algorithm, which not only solves the problem of inaccuracy caused by charge discharge but also realizes the intelligent automatic control mode of power grid.

3. Scheme Design and Algorithmic Improvement of Intelligent Switch for Built-In Electronic Voltage Transformer

3.1. System Hardware Composition Design. The design scheme of intelligent switch with built-in electronic voltage transformer is divided into two parts: hardware design of control system and software design. The structure principle of the system hardware device is shown in Figure 1. In the hardware design, the main control system uses STM32F407ZGT6 chip to collect, calculate, analyze, evaluate, and display all kinds of information data transmitted by the communication system reaction, so as to realize the operation control and management of the equipment of the whole substation system. In this design, all communication systems are based on an Ethernet interface. On the hardware, choose LAN8720A as the PHY chip of the main control chip. The chip supports automatic identification of indirect network cable and direct network cable and takes less I/O. The built-in electronic transformer has the characteristics of fast response, safe and stable operation, strong anti-interference ability, easy assembly and use, low cost, and so on, which is an important basis for the intelligent power grid. This study includes electronic voltage and current transformers and transformers for fan group fault detection for cooling control.

Because the whole intelligent substation monitoring system needs to collect and process a large amount of information, complex and numerous operations will increase the CPU memory, so the design of external storage circuit, through the main control template peripheral SRAM chip to expand the capacity of the main control board. The FatFs file system is used to manage the SD card data, which is used to store and backup the data of the microcontroller control system, so as to store the real-time data and preset parameters. The human-machine interface system can reflect the real-time data and historical parameters of the substation and modify it. Engineers and other personnel can perform management operations and maintenance operations through the human-machine interface system. The human interface system is constituted by the LCD liquid crystal display touch module and the mouse keyboard.

A switch input and output circuit is the main connection channel between internal weak current and external strong current. Its core content is the isolated input of primary

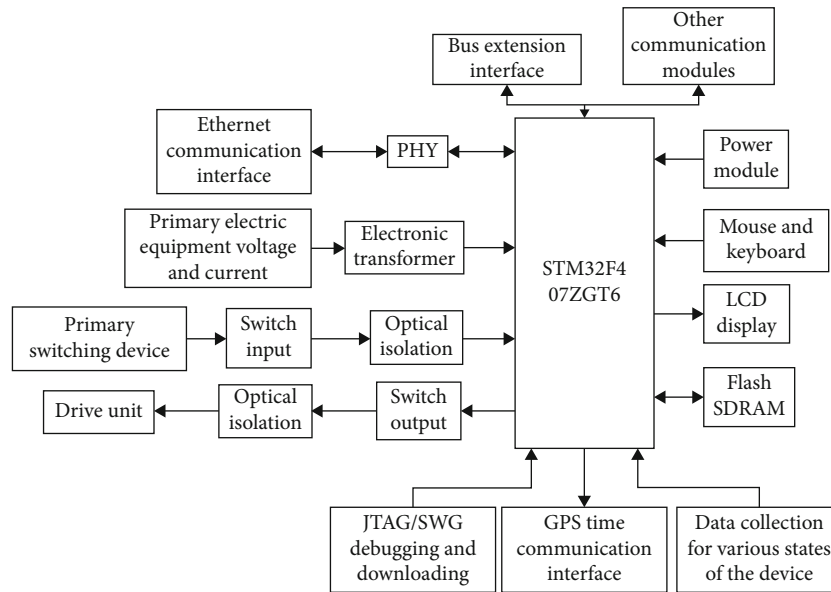


FIGURE 1: Structural schematic of the hardware device.

equipment state signal and the isolated output of action signal. The main task of this circuit is to process and analyze the external switching quantity introduced into the electronic device and then transfer the switching information to relays and other related equipment. After receiving the signal, the electromechanical device will make the response of warning or tripping, so as to protect and control the circuit. An intelligent control logic program needs to decide the execution of behavior according to external switching quantity, so it is very important to detect and acquire switching quantity state in intelligent electronic device. In order to prevent strong electromagnetic interference, in our digital input circuit, the switching signal needs to pass through the RC filter circuit, optocoupler, and circuit and then enter the input pin of the main control chip. Through this circuit, the CPU can judge whether the switch is open or closed according to the state of the external connection point. The switch output circuit is responsible for outputting the strong current signal to the breaker and other strong current equipment to achieve the control effect, but the CPU device I/O port is used to output the low voltage and small current signal, so it is necessary to add a relay device to increase the excitation current of the relay to enlarge the weak current signal and then drive the breaker and other strong current equipment. It is also necessary to use optocoupler to prevent the interference of instantaneous pulse and to improve the reliability of locking when the device fails.

Serial Debugging (SWD) technology is a technology that can debug and download small package microcontrollers with limited pins. It can transfer signal pins from JTAG without risk. In JTAG simulation mode, the debugger can run directly using SWD mode to ensure efficient and standardized data transmission.

3.2. System Software Composition Scheme Design. The core of intelligent substation composed of intelligent transformers is the application of artificial intelligence technology. This

research mainly adopts the fuzzy control, neural network, and genetic algorithm to improve the automatic control, judgment, planning, and execution ability of the monitoring system. The operating system of intelligent substation monitoring system selected in this study is C/OS-II, which is safe and stable, suitable for multitask coordinated management and control, and has high reliability and low power consumption. Therefore, the substation is monitored and processed by the C/OS-II system.

According to the characteristics of $\mu C/OS-II$ system and the actual working condition of the variable electric field, the system software program is designed, including a multi-task scheduling module with ten task modules and three interrupt modules. Task module includes voltage and reactive power control task, transformer switching task, transformer temperature control task, Ethernet data processing and packaging task, serial data processing and packaging task, data monitoring and measurement display task, protection logic judgment task, and self-inspection task. The interrupt module includes three modes: external mode, timing sampling mode, and serial data interrupt mode. The specific software system structure diagram is shown in Figure 2.

3.3. Voltage and Reactive Power Control Based on Fuzzy Neural Network. The core of intelligent substation composed of intelligent transformers is the application of artificial intelligence technology. This research mainly adopts the fuzzy control, neural network, and genetic algorithm to improve the automatic control, judgment, planning, and execution ability of the monitoring system. The fuzzy control system can simply add expert experience to the knowledge model and solve complex judgments which are difficult to solve by traditional methods on the basis of fuzzy semantics, fuzzy logic, and fuzzy sets. It includes four parts: fuzzy generator, fuzzy rule base, fuzzy reasoning, and defuzzification. Fuzzy generation is a mapping of fuzzy sets, and its design rules should pay attention to help overcome noise and simplify

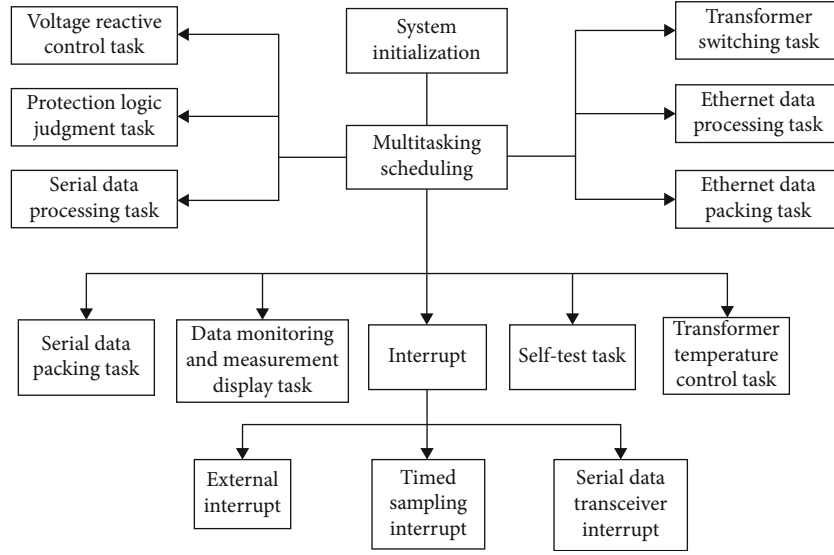


FIGURE 2: Schematic diagram of the software device.

the calculation of fuzzy inference engine. Fuzzy rule base is the core part of the whole control system, and other parts need to implement the rules in the rule set reasonably. The rules generally come from the direct transformation of expert experience and the revision in the process of self-learning. The fuzzy inference engine is a simulation judgment step of performing a synthetic operation of the fuzzy control rule on the fuzzy input variable. Defuzzification is responsible for the accurate conversion of the fuzzy results derived from the inference, reflecting the true distribution of the control quantities in the mapping of the fuzzy space. The neural network is an algorithm model composed of many simple parallel operations of neurons. It uses a distributed structure for information storage and uses multiple neurons in parallel for information judgment and reasoning. Each neuron in the neural network has only one output and can be connected with many other neurons, while each neuron input in the neural network can have multiple inputs. Each ganglion point corresponds to a state variable x_j ; i node and j node can form a connection path, corresponding to the connection weight coefficient w_{ij} .

A fuzzy neural network (FNN) is a neural network system for automatic processing of fuzzy information. It replaces the control and decision system in the fuzzy algorithm by training and learning a lot of the information of FNN. The input-output relationship of the trained neural network can also be well expressed by the "if-then" structure of the fuzzy control. Combining the two algorithms, the fuzzy control has the learning function, and the neural network has the ability of fuzzy information processing, so that the controller can learn by itself in the processing of inaccurate information and achieve the best control. Because the capacitor banks in power system can only be switched on and off in groups and the tap-changer switches of on-load tap-changer can only be adjusted in different stages, which leads to the discreteness of voltage and reactive power changes in substations. Therefore, a nonlinear multivariable time-

varying control problem is formed, which needs to be controlled by an accurate mathematical model. In this study, the fuzzy neural network is used as the mathematical model to realize the automatic control of voltage and reactive power in substation. By adjusting the tap position of transformer and the number of compensating capacitor switching groups, the voltage range of bus at load side is controlled by changing the ratio of voltage transformer, and the reactive power balance of substation is maintained as far as possible. The control system is constructed as shown in Figure 3.

Among them, U is the voltage of the load side, Q is the reactive power flowing into the high-voltage side of the transformer, U_1 is the voltage of the load side after adjustment, Q_1 is the reactive power of the high-voltage side of the transformer after adjustment, K is the number of taps of the transformer on-load tap-changer, Q_c is the number of taps of the compensating capacitor, ΔK is the change of tap position of transformer on-load tap-changer, ΔQ_c is the change of compensation capacitor switching group, $\Delta U = U - U_1$, and $\Delta Q = Q - Q_1$. The output voltage and reactive power are measured according to the value of K and Q_c .

The whole fuzzy neural network control system is divided into five steps: input, fuzzification, fuzzy connection, deblurring, and output. The input value is expressed as x , the output value is expressed as y , net is expressed as net input of hidden layer neurons, $f(\cdot)$ is expressed as neuron conversion function, symbol superscript represents steps, and subscript represents neurons. The output of each step is as follows.

There are two input nodes in the input step. The input value is transmitted to the next layer, and the output results are as follows:

$$y_j^1 = x_j^1, \quad (1)$$

$$y_j^1 = f_j^1(\text{net}_j^1) = \text{net}_j^1. \quad (2)$$

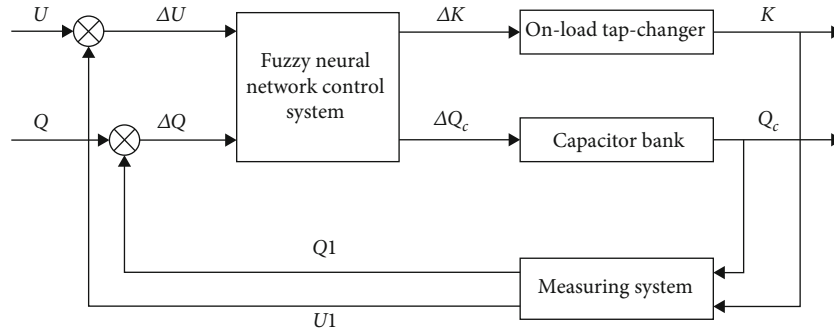


FIGURE 3: Structure diagram of fuzzy neural network control system for substation voltage reactive power.

The node of the fuzzification step is the sum of the fuzzy subsets of each input. The membership function is chosen as a Gauss function to calculate the membership function of the input variable. i denotes the dimension of the input and takes the value $(1, 2, \dots, n)$, j denotes the number of sets of fuzzy segmentation, and the values are $(1, 2, \dots, m)$; m_{ij} is the center of the membership function, σ_{ij} is the width of the membership function, and the output result is as follows:

$$y_{ij}^2 = f_{ij}^2(\text{net}_j^2) = \exp \left[-\left(\frac{x_i - m_{ij}}{\sigma_{ij}} \right)^2 \right]. \quad (3)$$

Each node of the fuzzy connection step represents a control rule, generates a fuzzy rule base, and outputs the result as

$$y_j^3 = \text{net}_j^3 = \prod_1^n x_i^3. \quad (4)$$

The output value of the next step is normalized in the deblurring step, and the output result is as follows:

$$y_j^4 = \frac{y_j^3}{\sum_{j=1}^m y_j^3} = \frac{y_j^3}{S}. \quad (5)$$

The output step is to use the weighted average method to clearly calculate the results after generalization, the output results such as formula (6); w represents the connection weight.

$$y_j^5 = \sum_{i=1}^m w_i^5 y_i^4 = \sum_{i=1}^m w_i^5 \frac{y_i^3}{S}. \quad (6)$$

The self-learning of theological-fuzzy network is to adjust the sample error by a gradient descent method and correct the values of w , σ , and m in the opposite direction, so as to improve the membership function and control rules. y is the actual output value of the neural network, δ is the reference error of the neuron, and η is the learning rate. Its values are $0 < \eta < 1$; Δw , $\Delta \sigma$, Δm are the correction

of w , σ , respectively. The calculation methods of error adjustment correction are as follows:

$$\Delta w_i^5 = \eta \cdot \delta^5 \cdot \frac{y_j^4}{S}, \quad (7)$$

$$\Delta m_y = \eta \cdot \delta_j^3 \cdot \frac{-2(y_i^1 - m_{ij})}{\sigma_{ij}}, \quad (8)$$

$$\Delta \sigma_{ij} = \eta \cdot \delta_j^3 \cdot \frac{2(y_i^1 - m_{ij})^2}{\sigma_{ij}^3}. \quad (9)$$

Because the membership function in this design is Gauss function, the definition domain is $(-\infty, +\infty)$ and the range is $[0,1]$, the output sample of the previous step should be normalized to $(-1, +1)$ in the de-ambiguity step, and the absolute value is in $(0,1)$. Voltage and reactive power are taken as standard values, that is, reactive power value < 1.0 ; voltage value is about 1.0, which needs to be reduced by 1, so that the value after treatment is near 0, and the number of capacitance groups and transformer taps also need to be processed near 0. The normalized samples can be used as the input and output of network learning. The flow chart of reactive power control based on the voltage fuzzy neural network algorithm is shown in Figure 4.

4. Experimental Design and Analysis

4.1. Voltage and Reactive Power Control Test Conditions. In this study, a substation with a 110-10 kV voltage conversion level is taken as an example. The substation intends to change two main transformers with small capacity into two main transformers with large capacity, expand the original load routes and compensation capacitors, and realize the intelligent operation of the equipment. In this study, the simulation environment is constructed by power flow distribution calculation software, and the feasibility of reactive power control of substation based on fuzzy neural network is tested and verified. It is hoped that this control can improve the voltage value of load side.

There are 110 kV on-load voltage-regulated transformers installed between the two nodes of voltage and reactive power control. Specific parameters are as follows: in Table 1, in which one node acts as load-side bus, four groups of 10 kV

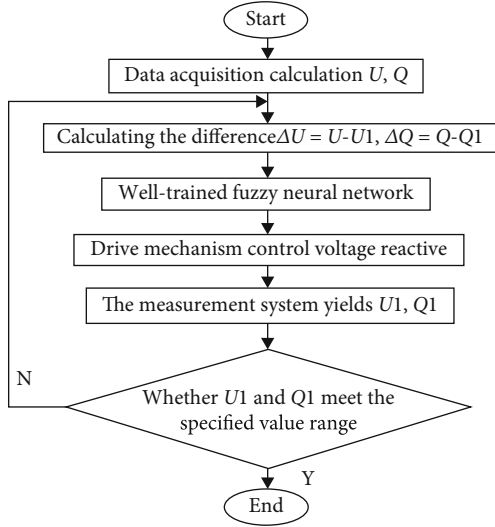


FIGURE 4: Fuzzy neural network voltage reactive power control flow chart.

TABLE 1: 110 kV on-load tap changer transformer parameter table.

| Ratio (kV) | Capacitance (kVA) | Load loss (kW) | No-load current (A) | Short circuit impedance (%) |
|-------------------------------|-------------------|----------------|---------------------|-----------------------------|
| $121 \pm 2.5\% \times 4/10.5$ | 40000 | 250 | 1.30% | 10.5 |

TABLE 2: 10 kV reactive power compensation capacitor parameter table.

| Rated voltage (kV) | Capacitance (kvar) | Predetermined capacitance (μF) |
|--------------------|--------------------|---|
| 10 | 5000 | 395 |

reactive power compensation capacitors are installed, such as Table 2. The voltage of 10 kV bus is limited to 10.1-10.6 kV, and the reactive power range is 0-1.5 Qc. The system load is shown in Table 3.

4.2. Voltage and Reactive Power Control Test Results. When the active power P and the reactive power Q of the bus bar on which the reactive compensation capacitor is mounted are changed, the operating system data of the reactive power flowing through the main transformer from the high voltage side and the voltage value on the low voltage side are as shown in Table 3. According to the data in the table, it can be seen that the reactive power flowing into the main transformer at the high voltage side of the transformer will be larger, while the voltage value at the low voltage side will be at a lower level, so reactive power compensation for the system and voltage value at the low voltage side need to be improved to a reasonable range.

A large amount of data is used to train and learn the learning scheme of the fuzzy neural network designed in this paper. The trained system is used to simulate and test the number of taps of capacitors and transformers. The system is compensated for reactive power and regulated the voltage

TABLE 3: System operation status table (standard value, Sb100MWAR, Vb = 10 kV).

| Time (h) | Active load (P) | Reactive load (Q) | Increased reactive (Q1) | Lower voltage (U1) |
|----------|-----------------|-------------------|-------------------------|--------------------|
| 0:00 | 0.27 | 0.23 | 0.2935 | 0.9721 |
| 1:00 | 0.26 | 0.21 | 0.2501 | 0.9864 |
| 2:00 | 0.25 | 0.2 | 0.2266 | 0.9912 |
| 3:00 | 0.22 | 0.26 | 0.2198 | 0.9111 |
| 4:00 | 0.25 | 0.3 | 0.3011 | 0.9643 |
| 5:00 | 0.31 | 0.28 | 0.3267 | 0.9581 |
| 6:00 | 0.32 | 0.33 | 0.3574 | 0.9531 |
| 7:00 | 0.33 | 0.34 | 0.3849 | 0.9258 |
| 8:00 | 0.42 | 0.41 | 0.4476 | 0.9174 |
| 9:00 | 0.48 | 0.42 | 0.5034 | 0.9075 |
| 10:00 | 0.5 | 0.44 | 0.5075 | 0.9234 |
| 11:00 | 0.54 | 0.44 | 0.5264 | 0.9357 |
| 12:00 | 0.51 | 0.47 | 0.5037 | 0.9374 |
| 13:00 | 0.47 | 0.43 | 0.4629 | 0.9277 |
| 14:00 | 0.46 | 0.41 | 0.4638 | 0.9547 |
| 15:00 | 0.43 | 0.39 | 0.4473 | 0.9538 |
| 16:00 | 0.42 | 0.38 | 0.4127 | 0.9563 |
| 17:00 | 0.39 | 0.37 | 0.4213 | 0.9427 |
| 18:00 | 0.37 | 0.37 | 0.4035 | 0.9378 |
| 19:00 | 0.45 | 0.36 | 0.4131 | 0.9354 |
| 20:00 | 0.56 | 0.35 | 0.4135 | 0.9337 |
| 21:00 | 0.52 | 0.34 | 0.4168 | 0.9358 |
| 22:00 | 0.47 | 0.33 | 0.4076 | 0.9429 |
| 23:00 | 0.38 | 0.32 | 0.0468 | 0.9551 |

at low voltage side. The results of the measurement and regulation of the voltage at the low voltage side of the main transformer by the fuzzy neural network system are shown in Tables 4 and 5, and the results of the measurement and regulation of the reactive power flowing into the high voltage side of the transformer are shown in Table 5.

As can be seen from Figure 5, before adding the fuzzy neural network system to control the voltage of the main transformer's low-voltage side, the value of voltage U1 obviously exceeds the prescribed voltage range and shows a low voltage level under heavy load, which leads to poor stability. After reasonably adjusting the tap position of on-load tap-changer of the main transformer through the calculation of the fuzzy neural network algorithm, the voltage value U2 of the low-voltage side becomes more stable and conforms to the voltage range stipulated in this study. When the load is heavy, the target of high voltage reverse voltage regulation is achieved, and the number of adjustments of transformer voltage regulator switches is effectively reduced.

It can be seen from Figure 6 that before adding the fuzzy neural network system to control the reactive power flowing into the high-voltage side of transformer, the level of reactive power Q1 is too high, and it is beyond the scope of reactive power specified in this study, resulting in a low value of power factor, which is easy to cause more losses to

TABLE 4: Low-voltage side voltage value change after fuzzy neural network control (standard value, $V_b = 10$ kV).

| Time (h) | Variable voltage before control (U_1) | Transformer gear | Number of input capacitor banks | Variable voltage after control (U_2) |
|----------|---|------------------|---------------------------------|--|
| 0:00 | 0.9721 | 0 | 4 | 1.0382 |
| 1:00 | 0.9864 | 0 | 3 | 1.0352 |
| 2:00 | 0.9912 | 0 | 3 | 1.0384 |
| 3:00 | 0.9111 | 0 | 3 | 1.0387 |
| 4:00 | 0.9643 | 0 | 4 | 1.0351 |
| 5:00 | 0.9581 | 0 | 3 | 1.0377 |
| 6:00 | 0.9531 | 0 | 4 | 1.0342 |
| 7:00 | 0.9258 | 0 | 4 | 1.0401 |
| 8:00 | 0.9174 | 2 | 4 | 1.0427 |
| 9:00 | 0.9075 | 2 | 4 | 1.0385 |
| 10:00 | 0.9234 | 2 | 4 | 1.0392 |
| 11:00 | 0.9357 | 2 | 4 | 1.0433 |
| 12:00 | 0.9374 | 2 | 4 | 1.0537 |
| 13:00 | 0.9277 | 1 | 4 | 1.0312 |
| 14:00 | 0.9547 | 2 | 4 | 1.0441 |
| 15:00 | 0.9538 | 1 | 4 | 1.0341 |
| 16:00 | 0.9563 | 1 | 4 | 1.0409 |
| 17:00 | 0.9427 | 0 | 4 | 1.0324 |
| 18:00 | 0.9378 | 1 | 4 | 1.0357 |
| 19:00 | 0.9354 | 1 | 4 | 1.0323 |
| 20:00 | 0.9337 | 2 | 4 | 1.0526 |
| 21:00 | 0.9358 | 1 | 4 | 1.0346 |
| 22:00 | 0.9429 | 1 | 4 | 1.0375 |
| 23:00 | 0.9551 | 1 | 4 | 1.0382 |

transmission lines. After controlling it by a fuzzy neural network, the input group number of compensation capacitors is adjusted for reactive compensation, so that the reactive balance is maintained, and the amount of reactive is in line with the prescribed scope of this study, the number of pitching of the capacitor group is reduced, the loss of reactive loss caused by long-distance transmission is avoided, and the goal of increasing power factor is finally achieved.

5. Conclusion

The research and design of the intelligent switch of the electronic transformer adapt to the national requirements of the intelligent substation, and unlike the traditional transformer, the electronic transformer is a basic equipment of power facilities that combines relay protection, dynamic power grid observation, and digital power system. Firstly, the intelligent electronic device with an electronic transformer as the core is designed. In the design of hardware system, the circuit and control strategy are designed, and the corresponding software system is constructed, the task of operation program is divided, the built-in intelligent switch of electronic voltage transformer is composed of hardware and software system. In order to realize the intelligent automation of the whole

TABLE 5: Changes in reactive power flowing through the high pressure side after being controlled by a fuzzy neural network.

| Time (h) | Increased reactive before control (U_1) | Transformer gear | Number of input capacitor banks | Increased reactive after control (U_2) |
|----------|---|------------------|---------------------------------|--|
| 0:00 | 0.2935 | 0 | 4 | 0.0433 |
| 1:00 | 0.2501 | 0 | 3 | 0.0507 |
| 2:00 | 0.2266 | 0 | 3 | 0.0369 |
| 3:00 | 0.2198 | 0 | 3 | 0.0487 |
| 4:00 | 0.3011 | 0 | 4 | 0.0758 |
| 5:00 | 0.3267 | 0 | 3 | 0.0995 |
| 6:00 | 0.3574 | 0 | 4 | 0.1042 |
| 7:00 | 0.3849 | 0 | 4 | 0.1853 |
| 8:00 | 0.4476 | 2 | 4 | 0.2167 |
| 9:00 | 0.5034 | 2 | 4 | 0.2364 |
| 10:00 | 0.5075 | 2 | 4 | 0.2057 |
| 11:00 | 0.5264 | 2 | 4 | 0.2023 |
| 12:00 | 0.5037 | 2 | 4 | 0.2569 |
| 13:00 | 0.4629 | 1 | 4 | 0.2234 |
| 14:00 | 0.4638 | 2 | 4 | 0.2127 |
| 15:00 | 0.4473 | 1 | 4 | 0.2129 |
| 16:00 | 0.4127 | 1 | 4 | 0.2164 |
| 17:00 | 0.4213 | 0 | 4 | 0.1631 |
| 18:00 | 0.4035 | 1 | 4 | 0.1675 |
| 19:00 | 0.4131 | 1 | 4 | 0.1534 |
| 20:00 | 0.4135 | 2 | 4 | 0.2382 |
| 21:00 | 0.4168 | 1 | 4 | 0.2184 |
| 22:00 | 0.4076 | 1 | 4 | 0.2079 |
| 23:00 | 0.0468 | 1 | 4 | 0.1942 |

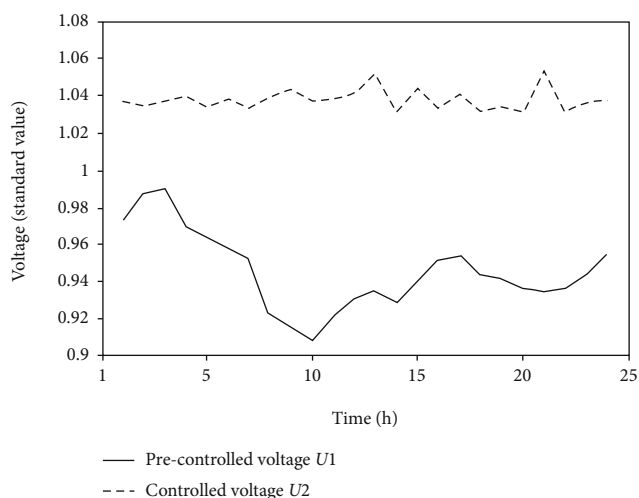


FIGURE 5: Comparison of voltage curves of low voltage side of main transformer before and after control.

intelligent electronic device, the fuzzy control and neural network algorithm are introduced. By using the algorithm's ability of fuzzy information processing and strong self-adaptive

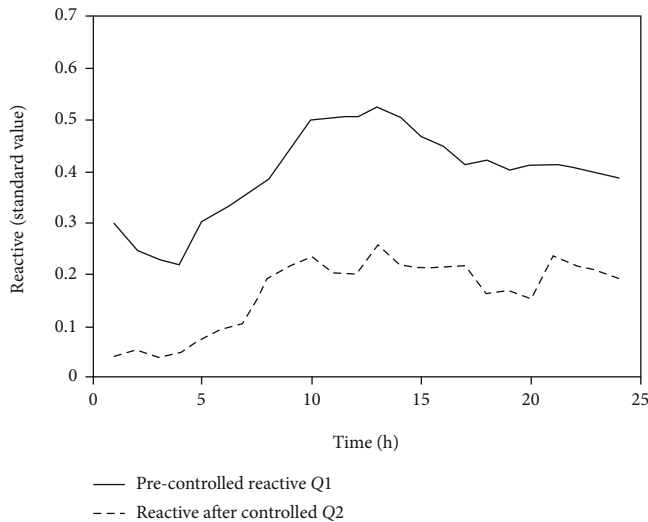


FIGURE 6: Comparison of reactive power curves flowing into the main transformer before and after control.

learning, the integrated automatic control of discrete varying voltage and reactive power in substation is completed, and the voltage and reactive power are adjusted to a specified range to reduce substation losses. Finally, the intelligent switch system of electronic transformer and the control effect of the fuzzy neural network algorithm are tested. The test results show that the device effectively adjusts the voltage and reactive power to the specified range, has high stability and effectiveness, and realizes the monitoring and self-checking function of intelligent switch system of electronic transformer. However, the lack of nonelectrical test data for transformers and circuit breakers in this study is not comprehensive enough. In the actual operation of intelligent switch systems, more intelligent operation management solutions should be added. These issues require further research to improve.

Data Availability

The applied mathematics data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The study was supported by the Project Name Research and Application Project No. 5230JY18000H of Intelligent Integrated Switch Based on High Voltage Capacitance Technology and Primary and Secondary Fusion in Distribution Network.

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