Research Article

Qian Zhang*

Relay vibration protection simulation experimental platform based on signal reconstruction of MATLAB software

https://doi.org/10.1515/nleng-2021-0037
Received Jul 17, 2021; accepted Oct 08, 2021

Abstract: For conceptual analysis of the principle of relay vibration protection, this article establishes the simulation system model of directional current protection in MATLAB/Simulink environment through the protection algorithm. Various outcomes have been achieved for the proposed approach during the faulty conditions. The outcomes obtained during the fault period reveals that the waveform of three-phase current changes greatly, and the amplitude of three-phase current at power supply side increases sharply. After 0.02s signal acquisition and processing, the action signal acts after 0.07s, and the fault is removed. In case of two-phase short-circuit, two-phase grounding short-circuit and other faults, the fault can be removed smoothly after signal acquisition and processing. In this paper, the directional current protection simulation system based on microcomputer protection model is built, and the changes of voltage, current and action signal are demonstrated through GUI interface, and analyzed and verified.

Keywords: Relay vibration protection; MATLAB; signal acquisition; simulation analysis; GUI interface.

1 Introduction

With the rapid development of power system, microcomputer relay vibration protection has been widely used in the line and equipment management of substations and power plants with various voltage levels. Its performance and the skill level of relay vibration protection staff are related to the safe operation of power grid [1]. The power system is composed of power plants, substations, transmission lines, distribution lines and power users. Power generation, transmission, transformation, distribution and utilization of electricity are almost carried out at the same time. If any link fails, the users will not get qualified power or lose power, resulting in certain economic losses and serious social impact. To ensure the safe and stable operation of power system and prevent the occurrence and expansion of accidents, the correctness and reliability of relay vibration protection device is very important [2].

Relay vibration protection device is an important part of the power system, which is one of the important technical measures to ensure the safe and reliable operation of the power system. With the continuous expansion of the scale of the power grid, the degree of automation of the power system continues to improve with the development of technology, and the power grid control problems become more and more complex, so the relay vibration protection device is required to have high performance. Before the relay vibration protection device is put into use, it is necessary to carry out tests in various environments to ensure the reliability of the protection device. However, the traditional theoretical analysis methods and physical experiment methods have certain limitations. The actual power system test has some problems though, such as insufficient technology, affecting the stability of power supply and equipment safety, and so on [3–5]. Therefore, the digital simulation technology of relay vibration protection can only be used to solve these problems. In this paper, the research of relay vibration protection simulation experimental platform based on MATLAB software signal reconstruction is very meaningful [6–9].

This article proposes a relay vibration protection system for studying its principle and establishing the simulation system model of directional current protection in MATLAB/Simulink environment through the proposed protection algorithm [10–14]. The output obtained for the proposed algorithm during the fault period indicates that the waveform of three-phase current changes greatly and the amplitude of three-phase current at power supply side increases sharply. This article provides an effective technique in which fault can be removed smoothly after signal acquisition and processing. The directional current protection sim-

***Corresponding Author: Qian Zhang:** Intelligent Manufacturing School, Sanmenxia Polytechnic Henan Sanmenxia, 472000, China; Email: QianZhang15@outlook.com

ulation system based on microcomputer protection model is built in this article and the changes of voltage, current and action signal are demonstrated through GUI interface.

The rest of this article is organized as: Section 2 provides the literature review of the various state-of-the-art relay protection systems. The research methods explaining the overall architecture of experimental platform and construction of directional current protection model is provided in Section 3. The research results and analysis are presented in Section 4 followed by the concluding remarks in Section 5.

2 Literature review

Power system simulation is used to model and analyze power system, and then analyze the action characteristics of relay vibration protection device under various fault and abnormal conditions of power system, which is the basis of relay protection simulation research. Through the accurate test of relay protection device, the hidden software and hardware errors can be detected as soon as possible, so as to avoid mis-operation and refuse to operate of relay protection device, which is of great significance for the safe and stable operation of power system [15]. It is also a feasible method to study the new algorithm and principle of relay vibration protection and evaluate the adaptability of specific power grid by using relay protection simulation system. At present, many domestic universities and research institutions have developed a number of simulation systems. Based on the electromagnetic transient calculation results of the grid side ddrts system, Feng Zhengwei realized the relay protection simulation considering the power grid model by exchanging data in real-time database, and established the model algorithm library of various secondary equipment by using dynamic link library technology, and established the simulation model of relay protection device. Through friendly visual operation interface and relay protection simulation based on setting value discrimination method, the working principle and action process of relay vibration protection device can be truly reproduced, which can be used for training of relay protection operators. Liao Xiaohui has developed a visual simulation platform of microcomputer distance protection based on modular design. The system has good openness, high integration and good visualization function, which is conducive to observe the internal action of protection and analyze the dynamic characteristics of relay protection device. Li Jianhai used high-speed data acquisition card and virtual instrument technology to realize the test and analysis device of microcomputer-based relay protection tester, which can give an objective evaluation on the performance of relay vibration protection tester applied in the field. Foreign research is more advanced than domestic research, and the application experience is more mature. In foreign countries, simulation software was developed to carry out experimental teaching. The interactive software developed by the State University of New Mexico illustrates the principle and related problems of relay vibration protection. The system has good visibility, can use animation to show the real system operation, so as to enhance students' understanding. At present, the system has been successfully applied to teaching and technical training in colleges and universities. With the emergence of virtual technology, people gradually apply it to the field of relay vibration protection. A relay protection test system based on virtual instrument technology is developed by Georgia Institute of technology. Students can use the system to design the experiment content and study more actively [16].

The innovation of this paper is that in view of the shortcomings of the existing relay vibration protection experimental platform, a simulation model design based on MATLAB platform is proposed, and the experimental platform is built by using the transmission line model, so as to study the principle of relay vibration protection.

3 Research methods

3.1 Overall architecture of experimental platform

The experimental platform consists of PC, DSP control board and circuit simulation device. 380V power supply is adopted, and the load current is not more than 5A. During the experiment, through the GUI interface of MATLAB, you can enter different types of experimental projects, link the Simulink simulation environment, open the simulation model of the experimental project, observe the composition of the model, set and adjust the simulation parameters in the corresponding sub interface to carry out the simulation test; after the simulation is finished, open the corresponding simulation model with DSP module, and use the real time work shop provided by MATLAB.RTW) automatically generates DSP engineering file code, starts DSP debugging software, generates DSP executable file (.Out) after compiling correctly, and downloads it into DSP chip of hardware system to cooperate with line model operation to verify the principle of line protection. The simulation platform can be used for the experiment of microcomputer protection algorithm and directional current protection.

The experimental platform consists of two parts: software design and hardware design. The PC (upper computer) designed by software is connected with the measurement and control unit designed by hardware. The simulation unit (transmission line model) is used to set the fault type of transmission line and simulate the current, voltage and other electrical quantities generated by the actual transmission line. It is transmitted to the input terminal of DSP control unit through the measurement unit, and then the circuit breaker on the line model is controlled by the protection algorithm to realize the microcomputer protection experiment. The data parameters are uploaded to PC through the measurement and control unit, which can demonstrate the fault waveform and action characteristics. The structure of line protection experimental platform is shown in Figure 1.

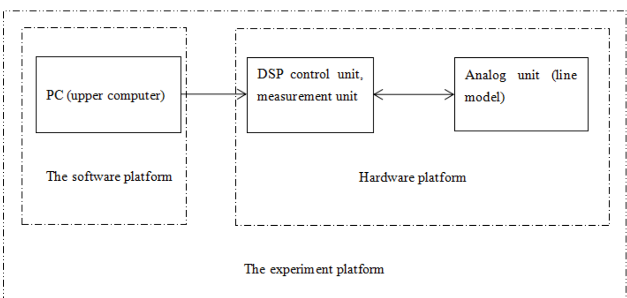

Figure 1: Protection experiment platform architecture

3.2 Directional current protection

In order to cut off the fault on the transmission line of both sides of power supply or single-phase loop network, circuit breakers and corresponding protection are installed on both sides of the line. If current protection is installed, the selectivity of action cannot be guaranteed. In order to solve the problem of selectivity, a directional element (power directional relay) is installed on the basis of the original current protection. Regulation: the direction of power flow from bus to line is positive, and from line to bus is negative [17]. At the power direction relay, when the power direction is positive, if not, the above process is called directional current protection.

1) Set value judgment

Taking instantaneous directional current quick break protection as an example, Figure 2 shows the short-circuit current curve of bilateral power supplies. When a fault occurs

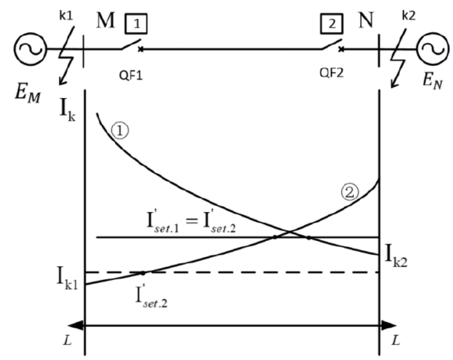

Figure 2: Short-circuit current curve of bilateral power supply

outside the protected area, such as K1 point, for example, when $I_{k2.max} > Ik1.amx$

$$I'_{set.set.1} = I'_{set.set.2} = K'_{rel}I_{k2.max} \tag{1}$$

As shown in Figure 2, if the setting method of Eq. (1) is used, the protection range of protection 2 at small power supply side will be reduced. The method to solve this problem is to install directional elements at protection 2, and the setting direction is that the bus flows to the protected line, so that the action of protection 2 can be set without the short-circuit current at K1 point, that is:

$$I'_{set.set.2} = K'_{rel}I_{k1.max} \tag{2}$$

As shown by the dotted line in Figure 2, the protection range of protection 2 is greatly increased than before.

2) Direction judgment

In microcomputer relay vibration protection, the premise to meet the selectivity is to be able to analyze and judge the fault direction, so the fault direction judgment element is very important in the relay vibration protection device. The commonly used methods of fault identification elements are: 90° connection protection in voltage and current protection, zero sequence power protection in grounding fault protection, and negative sequence power protection in high frequency protection [18].

In directional current protection, the power directional relay is usually used to judge the fault direction. Its working principle is: when the short-circuit power $P_k > 0$, the fault point can be judged to be in the positive direction of the protection; when the short-circuit power $P_k < 0$, the fault point can be judged to be in the opposite direction of the protection.

So far, the operation criterion of phase-to-phase current protection can be deduced as follows:

$$\begin{cases} I_{k1} > I_{set} \\ -90^\circ < \left(\frac{\dot{U}_r e^{-j\psi_{sen}}}{\dot{I}_r}\right) < 90^\circ \end{cases} \quad (3)$$

In the above formula I_{k1} is the measured value of phase-to-phase current protection; I_{set} sets value of current protection current; ψ_{sen} is the sensitive angle. The value range is $0 < \psi_{sen} < 90^\circ$, $\dot{U}_r$ and $\dot{I}_r$ to protect the voltage and current at the installation.

Figure 3 is the action characteristic diagram of directional current protection. Compared with the three-section current protection, there is only one more power direction judgment. For example, for section I protection, when the starting element determines that it should act, the current detection value is greater than the current setting value, and the direction discrimination element is also determined as positive direction. Only when these conditions are met at the same time, can the trip be started, and the protection element acts [19]. The protection process of Section 2 and Section 3 is the same as that of Section 1.

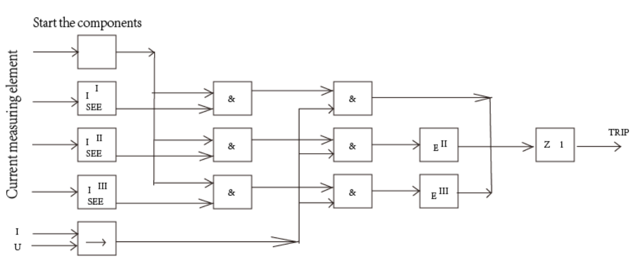

Figure 3: Action characteristics of directional current protection

3.3 Construction of directional current protection model

Figure 4 is the model diagram of the directional current protection module. There is a current quick break module and a direction selection and discrimination module. In order to show the protection action principle in detail, the logical operator module is used to reflect the logical judgment of the "or" relationship between the two modules [20].

Figure 5 is the model diagram of power directional element. The power directional element model built by functional modules is divided into three parts: the first part is data acquisition, which mainly makes the data output in

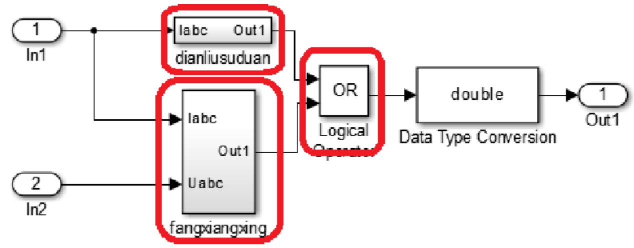

Figure 4: Model of directional current protection module

the form of complex number; the second part is data processing, which mainly measures the phase angle; the third part is the logic judgment part, which mainly compares with the setting value and the three-phase "or" relationship.

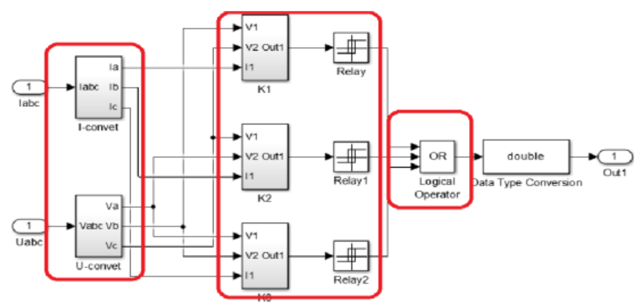

Figure 5: Power directional element model

(a) Data acquisition module

In the simulation, the output signals of voltage and current should be in complex form, so the u-convert and i-convert subsystems are designed to obtain the complex form of voltage and current. Figure 6 shows the composition of the i-convert subsystem. The u-convert subsystem and i-convert subsystem have the same structure.

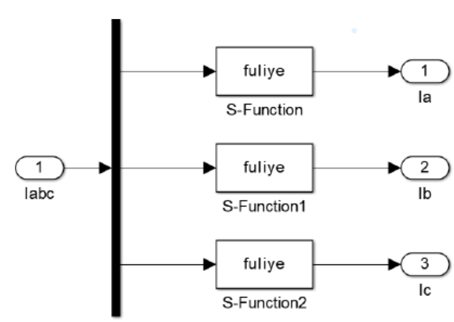

Figure 6: Composition of subsystem i-convert

(b) Data processing module

Figure 7 is the component model diagram of “90° wiring”, connecting the relay to the $\dot{I}_A$, $\dot{U}_{BC}$, $\dot{I}_B$, $\dot{U}_{CA}$, $\dot{I}_C$, $\dot{U}_{AB}$. The power direction measurement angle is calculated by using the mathematical operation module group “reciprocal”, “cross number” and “complex number operation”. The calculation formula is as follows:

$$-90^\circ - \alpha < \arg\left(\frac{\dot{U}_r}{\dot{I}_r}\right) < -90^\circ - \alpha \tag{4}$$

Where α is the inner angle of the power direction relay.

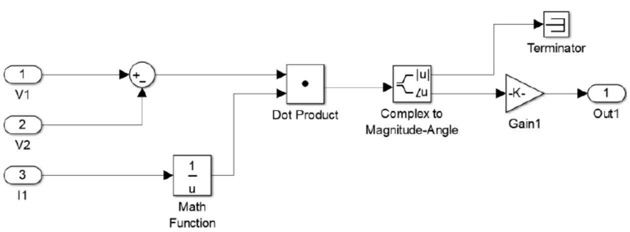

Figure 7: “90° wiring” component model

Figure 8 is the data processing module diagram of distance protection. The data processing algorithm not only needs to solve the power angle, but also needs to judge it.

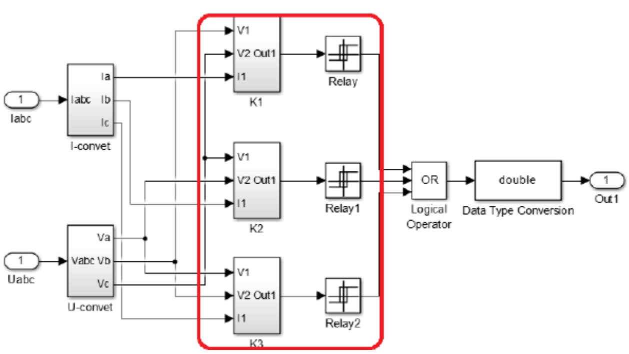

Figure 8: Distance protection data processing module

4 Result analysis and discussion

In this paper, 110 kV directional current protection is used to simulate and analyze the microcomputer protection model. In the experiment of directional current protection, the protection 1 device is analyzed for three-phase short-circuit, two-phase short-circuit, two-phase grounding short-circuit, and single-phase grounding short-circuit [21].

The 110kV double terminal power supply system is selected as the experimental model, as shown in Figure 9.

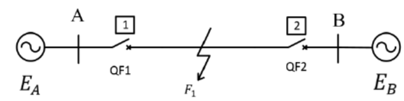

Figure 9: 110kV double terminal power supply system

According to Figure 9, the simulation model of 110kV double terminal power supply system is built by using MATLAB/Simulink.

The parameters of the two power modules are the same, the voltage is 115kV, the frequency is 50 Hz, and the phase angle is 0°.

Subsystem is a microprocessor-based protection algorithm module of directional current protection simulation model, which is built by using the microcomputer protection model written by s function.

4.1 Analysis of three-phase short-circuit

In case of three-phase short-circuit, the voltage, and current waveforms of power supply e_A side are shown in Figure 10.

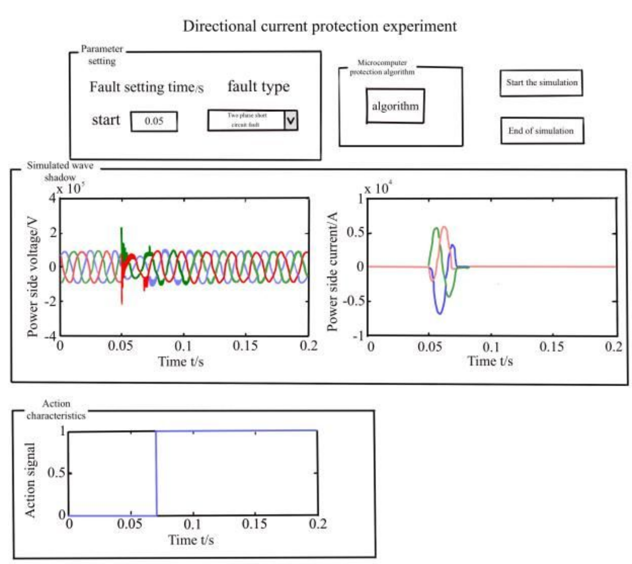

Figure 10: Voltage, current and action signals of power supply eA

It can be concluded from Figure 10 that the stable voltage amplitude of the circuit is about 90KV, and the three-phase short-circuit fault occurs at 0.05, and the three-phase voltage amplitude at the power supply side decreases slightly. The current waveform shows that during the fault, the waveform of three-phase current changes greatly, and the amplitude of three-phase current at power supply side increases sharply. After 0.02s signal acquisition and processing, after 0.07s action signal action, fault removal.

4.2 Analysis of two-phase short-circuit

In case of two-phase short-circuit, the voltage and current waveforms of E_A side are shown in Figure 11.

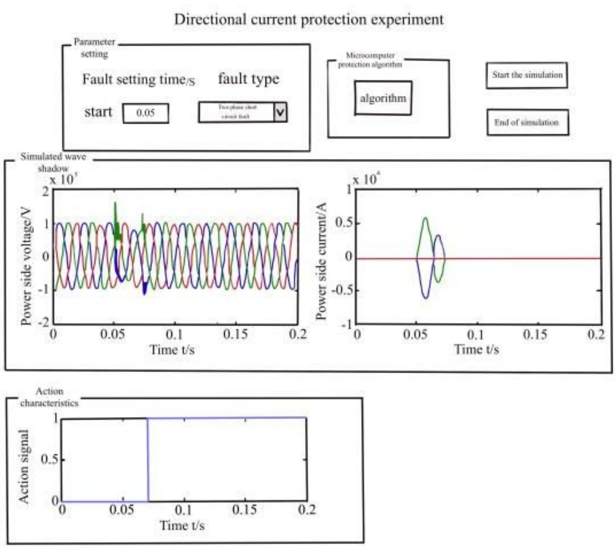

Figure 11: Voltage, current and action signals of power supply eA

The following conclusions can be drawn from Figure 11: in steady state, the voltage waveform shows that the stable voltage amplitude of the circuit is about 90KV, and two-phase short-circuit fault occurs at 0.05, the voltage amplitude of phase A and phase B on the power side decreases slightly, and the voltage amplitude of phase C on the power side remains unchanged. According to the current waveform diagram, when two-phase short-circuit fault occurs at 0.05, the waveform of three-phase current changes greatly. The current of a and B phases on the power side increases, while the current of phase C remains unchanged, and the amplitude of three-phase current increases. After 0.02s signal acquisition and processing, the fault is removed after 0.07s.

4.3 Analysis of two-phase grounding short-circuit

In case of two-phase grounding short-circuit, the voltage and current waveforms of power supply e_A side are shown in Figure 12.

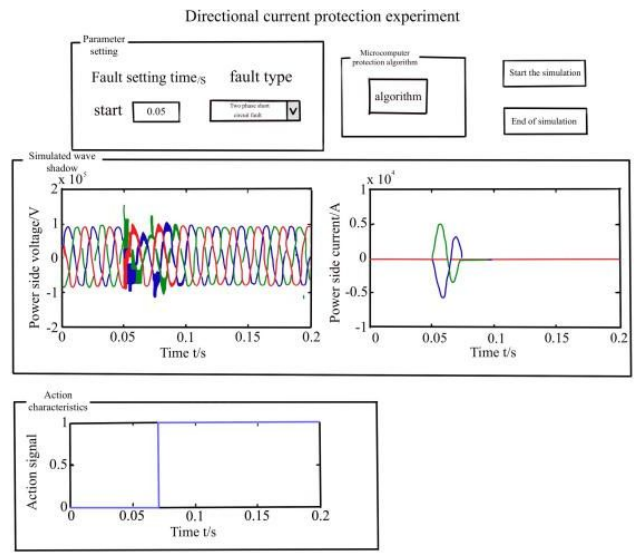

Figure 12: Voltage, current and action signals of power supply eA

4.4 Analysis of single-phase short-circuit grounding

Taking a single-phase grounding short-circuit as an example, the voltage and current waveforms of power supply e_A side are shown in Figure 13.

The following conclusions can be drawn from Figure 13: in steady state, the voltage waveform shows that the stable voltage amplitude of the circuit is about 90kV, and when the single-phase ground short-circuit fault occurs at 0.05, the amplitude of phase a voltage on the power side is slightly reduced, and the amplitude of phase B voltage and phase C voltage phase voltage on the power side remain unchanged. The current waveform shows that in the process of single-phase grounding short-circuit fault, the A-phase current of power supply side increases rapidly. After signal acquisition and processing, the fault is removed after 0.07s [19].

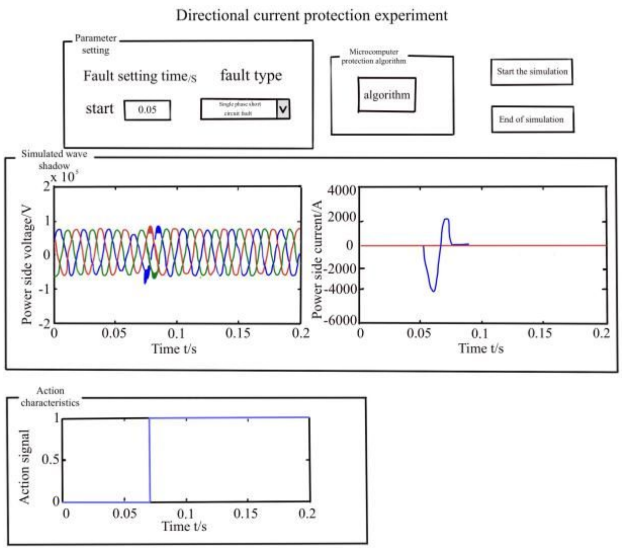

Figure 13: Voltage, current and action signals of power supply eA

5 Conclusions

Protection is an important part of the power system, which plays a decisive role in the safe and stable operation of power system. With the increasing complexity of power grid structure, relay protection is faced with higher requirements. The method of relay vibration protection experiment platform can reduce the cost and risk of experiment and realize the goal of studying and researching relay protection principle. In view of the shortcomings of the existing relay protection experimental platform, this paper proposes the design of simulation model based on MATLAB platform and uses the transmission line model to build the experimental platform, so as to study the principle of relay vibration protection. This paper mainly introduces the research background and significance of the project and analyzes the research status of experimental platform and model design. Based on the research status, a relay vibration protection experimental platform based on model design is proposed [20, 21]. Simulation system of directional current protection is built by using microcomputer protection model. The changes of voltage, current and action signal are demonstrated through GUI interface, and analyzed and verified.

The experimental platform introduced in this paper needs further improvement“ and can extend many new research directions. The analysis of this research work can be extended from the protection of transmission line towards the protection of important electrical equipment. The simulations can perform for transformer faults and generators while analyzing the protection. Because of the time relationship, this paper carries on the simulation verification to the microcomputer protection model, which can further be extended to the correlation experimental analysis to the experimental platform, unifying the theory and the practice.

Funding information: The authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: The authors state no conflict of interest.

References

[1] Andreev MV. Investigation of processes in the measuring part of digital devices of relay protection in the MATLAB software package. Russ Electr Eng. 2019 Jul;90(7):530–7.
[2] Sharma A, Kumar R. Risk-energy aware service level agreement assessment for computing quickest path in computer networks. Int J Reliab Saf. 2019;13(1-2):96–124.
[3] Ruihua L. Research and Analysis on the specialty of relay protection and automation technology in power system. International Conference on Wireless Communications and Smart Grid (ICWCSG); 2020 Jun 12-14; Qingdao, China. IEEE; 2020 p. 275-278.
[4] Wang Y, Ma J, Sharma A, Singh PK, Gaba GS, Masud M, et al. An Exhaustive Research on the Application of Intrusion Detection Technology in Computer Network Security in Sensor Networks. J Sens. 2021.
[5] Qi H, Ling L, Li-kun X, Yang T. Research on the characteristics of open winding brushless DC motor. 22nd International Conference on Electrical Machines and Systems (ICEMS); 2019 Aug 11-14; Harbin, China. IEEE; 2019 p. 1-6.
[6] Gianey HK, Ali M, Vijayakumar V, Sharma A, Kumar R. Low Cost and Centimeter-Level Global Positioning System Accuracy Using Real-Time Kinematic Library and Real-Time Kinematic GPSA. Recent Adv Comput Sci Commun. 2021;14(2):360-7.
[7] Lee B, Zhu ZQ, Huang L. Investigation of torque production and torque ripple reduction for six-stator/seven-rotor-pole variable flux reluctance machines. IEEE Trans Ind Appl. 2018;55(3):2510–8.
[8] Chen R, Sharma A. Construction of complex environmental art design system based on 3D virtual simulation technology. Int J Syst Assur Eng Manag. 2021;1-8.
[9] Huang Q, Luo L, Zhang Y, Cao J. Commutation Torque Ripple Suppression in Three Phase Brushless DC Motor Using Open-end Winding. Int J Control Autom Syst. 2021;1–2.
[10] Liu H, Sharma A. An efficient CAD based design system for spatial CAM reducer. Comput Aided Des Appl. 2022;19 S2:134–43.
[11] dos Santos G, Bitencourt A, Queiroz AT, Martins FG, Sass F, Dias DH, et al. Tests and recovery under load simulations of a novel

bifilar resistive SFCL having undulated shape configuration. Supercond Sci Technol. 2021;34(4):045009.
[12] Xu X, Li L, Sharma A. Controlling messy errors in virtual reconstruction of random sports image capture points for complex systems. Int J Syst Assur Eng Manag. 2021;1-8.
[13] Pérez-Chávez JJ, Trillaud F, Castro LM, Queval L, Polasek A, de Andrade R Junior. Generic model of three-phase (RE) BCO resistive superconducting fault current limiters for transient analysis of power systems. IEEE Trans Appl Supercond. 2019;29(6):1–1.
[14] Kannan S, Dhiman G, Natarajan Y, Sharma A, Mohanty SN, Soni M, et al. Ubiquitous vehicular ad-hoc network computing using deep neural network with iot-based bat agents for traffic management. Electronics. 2021;10(7):785.
[15] Wang PF, Yu CZ, Xiong W. Adaptive Algorithm on Break-variable Detection in Line Protection [J]. Proc Chinese Soc Univ Electr Power Syst Autom. 2012;3.
[16] Huo L, Yang G, Liu Y, Yao S. Design and Implementation of Universal Platform for Teaching Experimental of Microcomputer Relay Protection. Proceedings of the 2020 International Conference on Computers, Information Processing and Advanced Education; 2020 Oct 16-18; Ottawa, Canada. Association for Computing Machinery: New York; 2020 p. 306-311. https://doi.org/10.1145/3419635.3419639.
[17] Kiaei I, Lotfifard S, Ghanaatian M. Current-only directional overcurrent protection using postfault current. Texas Power and Energy Conference (TPEC); 2019 Feb 7-8; College Station, USA. IEEE; 2019 pp. 1-5.
[18] Guillen D, Salas C, Trillaud F, Castro LM, Queiroz AT, Sotelo GG. Impact of resistive superconducting fault current limiter and distributed generation on fault location in distribution networks. Electr Power Syst Res. 2020;186:106419.
[19] Bo ZQ, Lin XN, Wang QP, Yi YH, Zhou FQ. Developments of power system protection and control. Prot Control Mod Power Syst. 2016;1(1):1–8.
[20] Xu N, Dong J, Zheng S. The impact analysis of current transformer's saturation to relay protection. 2014 China International Conference on Electricity Distribution (CICED); 2014 Sep 23-26; Shenzen, China. IEEE; 2014 p. 1-4.
[21] Mahat P, Chen Z, Bak-Jensen B, Bak CL. A simple adaptive overcurrent protection of distribution systems with distributed generation. IEEE Trans Smart Grid. 2011;2(3):428–37.