INTELLIGENT SWITCHING, PROTECTION AND MONITORING SYSTEM BASED ON THE INTERNET OF THINGS TECHNOLOGY

TỦ ĐIỆN GIÁM SÁT, ĐÓNG CẮT VÀ BẢO VỆ THÔNG MINH TRÊN NỀN TẢNG INTERNET VẠN VẬT

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ABSTRACT

Nowadays, modern equipment installed in both civil and industrial domains is becoming increasingly expensive. As a result, it is essential to prioritize the safeguarding of these valuable assets during their implementation and operational phases. This challenge is compounded by the growing range of potential mishaps, necessitating a proportional increase in protective measures. Additionally, monitoring and documenting such incidents requires specialized systems. To address these complexities, our research group has developed a smart electrical cabinet that serves a dual purpose: it detects anomalies and offers an autonomous circuit-breaking feature, thereby mitigating the impact of possible disruptions on connected loads. The research outcome aims to design an electrical cabinet that includes various mechanisms to detect, and safeguard loads from potential incidents, while also being capable of collecting operational data, recording incident occurrences, and integrating with the central management system at the construction site.

Keywords: *Smart electrical cabinet, intelligent protective switching, fault warning detection.*

TÓM TẮT

Ngày nay, các thiết bị hiện đại được lắp đặt trong cả lĩnh vực dân dụng và công nghiệp ngày càng trở nên đắt đỏ hơn. Do đó, việc ưu tiên bảo vệ những tài sản quý giá này trong các giai đoạn triển khai và vận hành là rất cần thiết. Thách thức này càng trở nên phức tạp hơn bởi sự gia tăng của các sự cố tiềm ẩn, đòi hỏi các biện pháp bảo vệ tương ứng phải được tăng cường. Ngoài ra, việc giám sát và ghi nhận các sự cố này yêu cầu các hệ thống chuyên dụng. Để giải quyết những phức tạp này, nhóm nghiên cứu của chúng tôi đã phát triển một tủ điện thông minh với hai chức năng: phát hiện các sự cố và đồng thời hướng đến việc tự động đóng cắt nhằm bảo vệ các phụ tải khỏi các sự cố diễn ra. Kết quả nghiên cứu hướng đến việc thiết kế một tủ điện bao gồm nhiều cơ chế khác nhau để phát hiện và bảo vệ phụ tải khỏi các sự cố tiềm ẩn, đồng thời có khả năng thu thập dữ liệu vận hành, ghi lại các sự cố phát sinh và tích hợp với hệ thống quản lý trung tâm tại công trình.

Từ khóa: *Tủ điện thông minh, đóng cắt bảo vệ thông minh, phát hiện cảnh báo sự cố.*

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1. INTRODUCTION

In the modern 21st century, electricity has become one of the indispensable factors for the development of society and the economy. From providing energy for everyday electronic devices to driving advancements in industry and technology, electricity plays an undeniable role [1, 2]. However, the societal demand for electricity is overwhelming, leading to overloaded power lines, resulting in unforeseen accidents and harm to both individuals and assets. Businesses are becoming increasingly aware of this and are placing greater emphasis on safeguarding and monitoring their electrical systems [3]. With the emergence of modern technology, businesses are showing more favor towards smart devices to manage their electrical systems. Therefore, the advent of new technologies such as smart electrical cabinets is attracting significant attention. Smart electrical cabinets not only improve energy distribution but also represent a significant step forward in optimizing electricity usage and protecting electrical systems. By integrating technologies such as sensors, artificial intelligence, and the Internet of Things

(IoT), smart electrical cabinet can automatically detect, diagnose, and control energy-related issues, from predicting and preventing incidents to optimizing energy usage [4].

In the past, traditional electrical cabinets operated based on mechanical principles and required manual intervention from operators to monitor and control the electrical system. Components in traditional electrical cabinets were often configured rigidly and lacked flexibility to adapt to specific requirements or system fluctuations. Moreover, traditional electrical cabinets often lacked network connectivity or remote interaction capabilities, limiting remote monitoring and management, and requiring the physical presence of operators to address issues [5]. In contrast, smart electrical cabinets integrate automation technology and network connectivity, enabling them to automatically detect and respond to events in the electrical system more autonomously and flexibly. This capability not only helps optimize system performance but also minimizes risks from incidents and downtime. Additionally, the remote interaction and management capabilities via network connectivity of smart electrical cabinet are significant improvements, enhancing convenience and flexibility in remote monitoring and management of the system, while providing detailed and easily adjustable operational information according to actual needs. These qualities highlight smart electrical cabinets as a practical and cutting-edge option, well-suited for various industrial and modern infrastructure needs.

In this study, the research team designed and developed a new electrical cabinet aimed at detecting and protecting loads from hazardous electrical incidents. It incorporates multiple safety mechanisms to ensure system stability. The objective is to create a smart cabinet that detects risks, alerts users, and collects operational data. By integrating with a management system, it becomes a crucial tool for maintaining system performance and safety.

2. THEORETICAL FRAMEWORD/METHODS

Recent research on smart electrical cabinets aims to improve their monitoring and protection capabilities. Currently, common protection methods include electronic protective relays, known for their high reliability and flexible function adjustment. However, they can be costly and rely on power sources. Smart sensors offer precise measurements and easy installation but may have limited functionality and require regular maintenance. For monitoring, SCADA is widely used due to its flexibility and integration capabilities with various electrical devices and systems, along with remote monitoring capabilities. Yet, it demands careful investment and management. Another method, IoT, utilizes diverse sensors but heavily depends on the internet and requires a complex data management system. In this article, the research team proposes a cost-effective IoT-based approach, integrating data like SCADA, to enhance management and monitoring convenience.

2.1. Overview

The smart electrical cabinet system consists of a set of 4 functional blocks:

- Measurement and fault detection block: monitoring the consumption parameters of the power source, identifying current-related issues (overcurrent, short circuit, harmonic currents), voltage-related issues (overvoltage, undervoltage, phase loss, short-term voltage drop, short-term overvoltage, unbalanced phase voltage, and voltage harmonics).
- Protection action block: closing and opening protection of the electrical system through contactor control.
- Central operation block: collecting, processing data, and controlling the system.
- Display block: receiving data from the central operation block and displaying system parameters and statuses on the screen.

From the gathered electrical data, the system processes and analyses information to issue warnings and enact protective measures in case of anomalies. Simultaneously, it stores and displays this data on the screen interface for user access and monitoring.

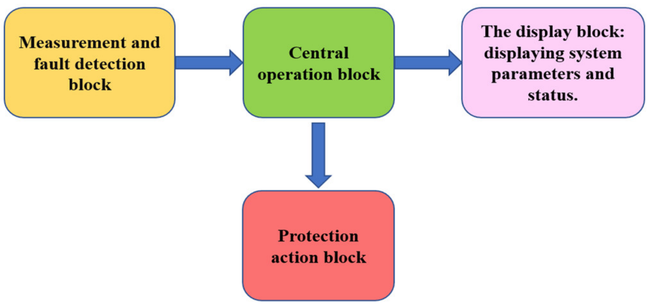


Fig. 1. Smart electrical cabinet's functional blocks

2.2. The principles behind identifying and the protective features of various incidents

2.2.1. Current overload

Overcurrent protection is activated when the current surpasses a set limit, triggering the contactor to switch states. The time it takes from the occurrence of the fault to the moment the contacts of the contactor switch state is known as the operation time of the contactor. Higher fault currents demand quicker responses to shield downstream devices. The overcurrent protection characteristics of relay protection devices within the system are precisely outlined in the IEEE C37.112-1996 standard. This standard delineates the standardized characteristics of an overcurrent protection relay (Fig. 2) [6].

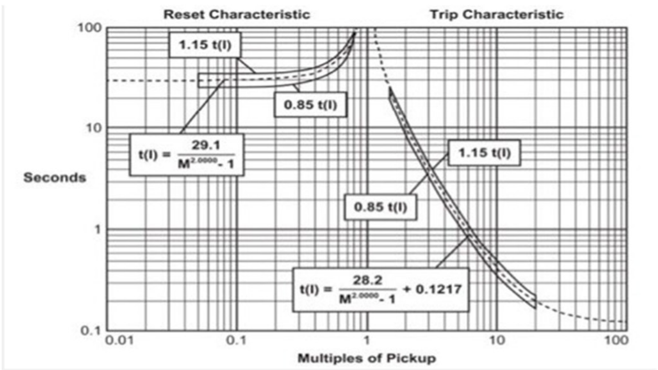


Fig. 2. The curve represents the overcurrent protection characteristics of a relay as specified by the IEEE C37.112-1996 standard

The overcurrent protection features of the protective device encompass two primary aspects: impact region traits (during an event) and rest region traits (recuperation).

- **The impact region traits**: the operating region is defined as when the overload current, I, exceeds the preset current, Ip (I/Ip > 1). The time characteristic of the operation, based on the magnitude of the load current, is determined by the following formula:

$$t(I) = \frac{A}{(\frac{I}{Ip})^{p} - 1} + B \quad (1)$$

Where: t(I) represents the duration from the occurrence of the fault current I until the contact state transitions.

A, B, P are coefficients selected based on the fast or slow impact modes of the protective device specified according to IEEE standards in the characteristic curve.

When current value is greater than the set current Ip, the protective relay device will begin to operate in the impact area. The impact time corresponding to a determined fault current value is calculated according to equation (1). The larger the I/Ip ratio, the faster the cutting time must be to protect the equipment promptly. This period is also to ensure that the device can filter transient incidents in a very short time, without affecting the equipment, without needing to cut off the current [6].

- **The rest zone:** The rest zone is defined as the current passing through the relay being smaller than the set current Ip (0 < I/Ip < 1). The time characteristic for the relay recovery in this zone is determined by the following equation:

$$t(I) = \frac{t_r}{(\frac{I}{Ip})^{2} - 1} \quad (2)$$

Where: t(I) is the time it takes for the protective relay device to return to its initial state after experiencing an overcurrent event but before reaching the operation time, during which no overcurrent occurs anymore.

t_r is a system that depends on the characteristics in the characteristic curve.

When there is a change in current passing through the relay, we employ the following conditional equation to determine the moment when the protective device activates:

$$\int_0^{T_0} \frac{1}{t(I)} dt = 1 \quad (3)$$

Where: T_o is the moment the relay operates; t(I) - determined by equation 1 when I > Ip, or by equation (2) when I < Ip

2.2.2. Short circuit

The short-circuit incidents in the system are detected based on the characteristic curve of the overcurrent Type C (designed for normal loads) of the Panasonic MCB. When the consumed current exceeds 5 times the rated current, the protective device will confirm a short-circuit incident and act to protect the electrical system [8].

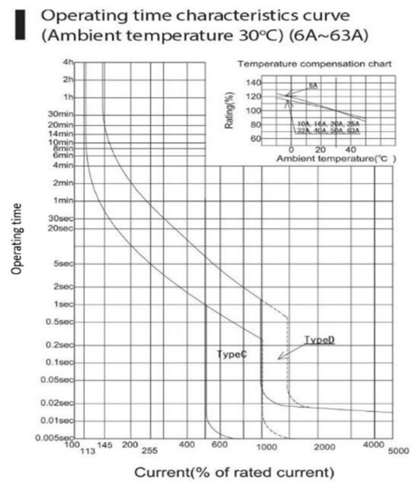


Fig. 3. Impact characteristic curve of MCB

2.2.3. Phase lost incident

The phase loss event occurs when one or more phases experience an open or complete loss of power in the electrical system. Depending on various conditions and scenarios, the system can adjust the protection response time when a phase loss incident occurs, ranging from 0.1 to 15 seconds [9].

2.2.4. Incident of phase voltage imbalance

Phase voltage imbalance occurs when there's a significant difference in voltage between phases. Under different conditions and scenarios, the system can adjust the protection response level for phase voltage imbalances, ranging from 5% to 25%, with response times between 0.1 and 10 seconds [10].

2.2.5. Overvoltage, undervoltage, short-term overvoltage, and short-term voltage sag incidents

Table 1. The table of prescribed time for voltage incidents to occur [7]

Type of disturbance	Disturbance subtype		Time	Range	
				Min Value	Max Value
Voltage	Sag	Short	10ms - 1s	0.1U	0.9U
		Long	1s - 1min		
		Long time disturbance	> 1min		
	Under Voltage	Short	< 3min	0.99U	
		Long	> 3min		
	Swell	Temporary short	10ms-1s	1.1U	1.5kV
		Temporary long	1s-1min		
		Temporary long-time	> 1min		6kV
		Over-voltage	< 10ms		

Overvoltage occurs when the phase voltage exceeds the standard 230V + 10% [11]. To confirm this, the voltage must stay high for over a minute, going beyond 110% of the standard [7]. Undervoltage happens when the phase voltage falls below the standard 230V - 10% [11]. It's identified if the voltage remains between 10 - 90% of the standard for over a minute. Short-term voltage sags occur when voltage ranges from 10 - 90% of the standard for periods from 10ms to 1 minute. During these times, the system will quickly alert the operators. Short-term overvoltage incidents arise when voltage exceeds 110% of the standard for periods from 10ms to 1 minute. The system promptly notifies operators about these occurrences.

2.2.6. Harmonic waves in the system

Harmonic waves are characterized by cyclical voltage and current patterns resembling sine waves, but with frequencies that are multiples of the fundamental frequency of 50Hz. According to Article 7 of Circular No. 39/2015/TT-BCT issued by the Ministry of Industry and Trade, the total harmonic distortion must not exceed 8% for voltage and 20% for current [12].

2.3. Operating principles of the system

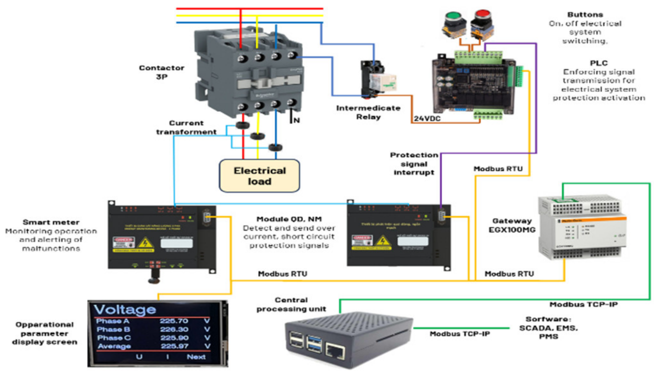
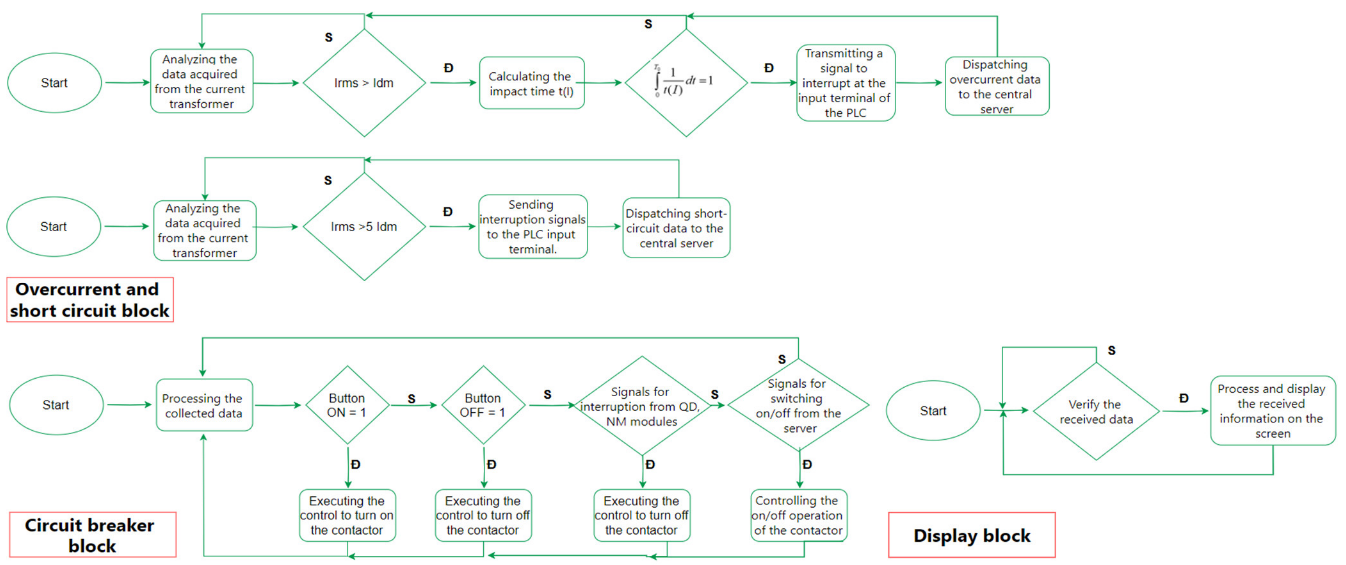


Fig. 4. The principle of smart electrical cabinet

The main algorithm of the blocks in the electrical cabinet is:



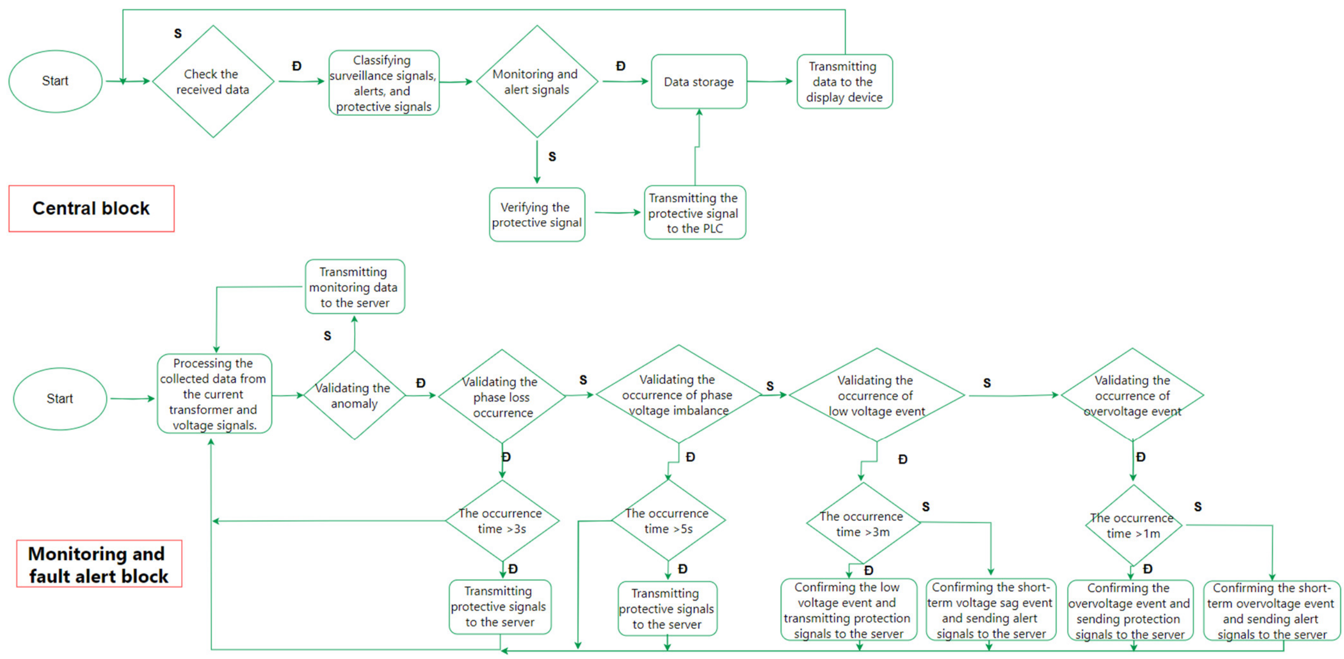


Fig. 5. The main algorithm of the blocks in the electrical cabinet

Measurement, fault detection, protective action, and display modules communicate through Modbus RTU to a gateway device. This device converts the signal to Modbus TCP-IP for interaction with the central server. However, the overcurrent and short-circuit module, needing quick response times, directly sends action signals to the server without any conversion.

3. RESULTS AND DISCUSSION

3.1. Installation results for the equipment in the electrical cabinet

Outlined below are the results obtained after incorporating components into the smart electrical cabinet system, following its operational principles. Inside the smart electrical cabinet, you'll find devices from measurement and fault detection groups, protection mechanisms, and central processing units. Outside the smart electrical cabinet are display devices, like phase indicator lights and units showing operational details and alerts, along with control buttons for power management.

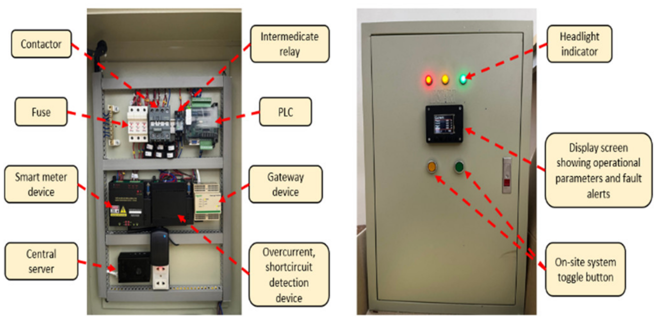


Fig. 6. Results of installing devices inside and outside the electrical cabinet

3.2. System operation results

The system's operational data will be measured and displayed through the screen on the electrical cabinet. This data includes voltage, current consumption, power consumption, energy consumption, voltage harmonic distortion, and current harmonic distortion.

Fig 7. The characteristic quantities of the power source in the system are displayed on the screen

3.3. Operational alert and protective action outcomes in the event of incidents

3.3.1. Overcurrent protection

In the event of an overcurrent, the short-circuit overcurrent protection device promptly detects it and initiates time calculations based on the protection characteristic curve of the affected phase. Upon reaching the intervention time with the overcurrent persisting, the device sends a signal to activate the power source protection to the central processing unit. The central processing unit promptly executes protective measures to mitigate the overcurrent incident and subsequently sends a warning signal to the display screen.

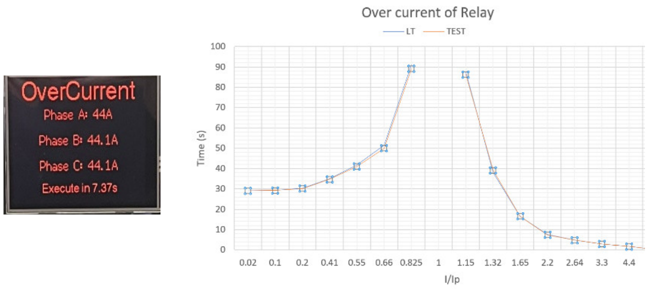


Fig. 8. The display screen has encountered an overcurrent fault,the practical overcurrent characteristic curve from the device has been compared to the theoretical one

To verify whether the device's tripping time aligns with the overcurrent characteristic curve, the team adjusts the overcurrent of the load at various levels. The obtained results indicate close alignment between the measured and theoretical data, demonstrating the device's precise operational accuracy.

3.3.2. Short-circuit protection, Short-term under-voltage and over-voltage fault alerts

Upon occurrence of a short-circuit fault on one or multiple phases, the overcurrent and short-circuit protection device directly detects it and sends a signal to activate power source protection to the central processing unit. The central processing unit will immediately execute protective actions to safeguard the electrical system from the fault and subsequently send a warning signal to the display screen.

When the voltage drops below or exceeds predetermined thresholds, the smart meter promptly detects the anomaly and promptly sends an alert to the system. Subsequently, the system displays the alert on the monitoring screen for technicians to promptly identify and address, mitigating the risk of prolonged under-voltage or over-voltage occurrences.

Fig. 9. The display screen indicates a short circuit fault and shows a warning of short-term under-voltage and over-voltage faults occurring in the electrical system

3.3.3. Low-voltage, Overvoltage, phase loss, and voltage imbalance fault protection

When a voltage sag occurs below a predefined threshold, the smart meter will immediately detect and initiate intervention time calculation for protection. If the voltage remains below the specified level for a minute, it is considered a low voltage event. Similarly to low voltage protection, overvoltage protection, phase loss, unbalance voltage loss. when faults occur, the smart meter will promptly detect them. After a predetermined period, if the fault persists, the device will send a protection activation signal to the central processing unit. Subsequently, the device will activate power protection, sending a signal to the central processing unit. The central processing unit will immediately take protective measures to shield the electrical system from the event and then forward the warning signal to the display screen, indicating the low voltage event, the measured voltage, and the occurrence time.

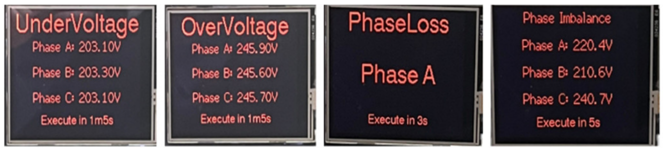


Fig. 10. The display screen shows the errors that have occurred in the electrical system along with the intervention time

4. CONCLUSIONS

Based on the results of operational and fault protection testing, it's clear that the system operates in line with established principles of measurement, processing, data storage, display, and timely intervention, meeting industry standards. Integrating the smart electrical cabinet into the broader management system of external electrical installations not only provides automated incident protection but also enables continuous monitoring, data collection, and incident logging. This proactive approach helps anticipate and mitigate potential issues in the electrical system. Moving forward, the research team aims to further enhance system accuracy and expand harmonic fault detection capabilities to refine the electrical cabinet. Additionally, integration with the building's BMS system will centralize monitoring of electrical points and improve data analysis, ultimately optimizing system operation and maintenance efficiency.

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THÔNG TIN TÁC GIẢ

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