Multi-parameter fusion diagnosis for medium and lower voltage switchgear cabinet based on UHF and Infrared Camera Method

Yifei Li[1)2)] Yang Gao[1)] Cheng Gong[1)2)] Tianle Li[1)2)] Quanmin Dai[3)] Dongying Zhang[4)]
1) Electric Power Research Institute, State Grid Beijing Electric Power Company,Beijing,100075, China
2) Beijing Dingcheng Hongan Technology Development Co. Ltd, Beijing,101399,China
3) College of urban rail transit and logistics, Beijing Union University, Beijing, 100101, China
4) Institute of Electrical and Electronics Engineering,North China Electric Power University, Beijing,102206,China
4) Author to whom correspondence should be addressed: zdyingmail@163.com

ABSTRACT

Multi-parameter live detection and fusion diagnosis of medium and lower voltage switch-gear cabinet (M-LVSC) is an important technology for identification the operating status of power equipment. Under the operating conditions, a single sensor(UHF,thermal infrared,ultrasonic partial discharge detection) in the distribution equipment cannot judge the complex faults.The objective of this research is to develop fusion diagnosis and techniques for detect the state of 10kV and 400V distribution equipment in the switch-gear and its bus, identifying any abnormal conditions, by the infrared camera method and UHF partial discharge detection. The condition data of the equipment from these sensors is collected and analyzed to from the operating conditions by intelligent monitoring data technology for power distribution equipment.Under the background of big data cloud platform, overheat defects and discharge defects were captured and deeply analysis by UHF and infrared camera method. Fusion diagnosis provides an intelligent decision scheme for power distribution equipment fault diagnosis under operating conditions. The fusion recognition by comprehensive detect for a M-LVSC contactors power line and terminal board were verified in power distribution site.

I. INTRODUCTION

For new power system, green and smart medium and lower voltage switchgear cabinet (M-LVSC) is an important public infrastructure for national economic and social development[1-2]. Users' requirements for power supply quality and reliability are also getting higher and higher. Intelligent monitoring of power M-LVSC involves the use of advanced technologies and tools to monitor and analyze the performance and condition of power distribution systems in real-time[3]. The goal of intelligent monitoring is to ensure the efficient,reliable,and safe operation of the power distribution system by identifying potential problems and taking corrective actions before they cause power outages or other disruptions [4]. The rapid development of intelligent technology has also promoted the construction of new power systems.

The condition monitoring of medium and lower voltage switchgear cabinet (M-LVSC) is the key intelligent technology to grasp the state of M-LVSC and support active emergency repair, including Infrared and visible image[5].With the development of national smart grid technology, live detection technology has emerged, which can detect the insulation state under the premise of continuous power supply. According to the production needs, the detection is carried out twice a year, but it will consume a lot of manpower and material resources, and the timeliness is still poor.

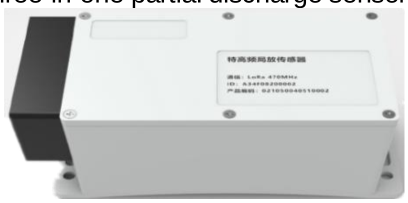
In recent years, the on-line monitoring technology of power equipment has gradually emerged[6-7]. This method can monitor the partial discharge of the monitored equipment by adding an on-line monitoring partial discharge sensor, and can timely grasp the basic situation and insulation performance of the equipment in operation[8-9]. However, the traditional station monitoring system still has the following problems in the actual work.

The gateway equipment and sensing equipment are fixed installation, and the investment cost is large. The benefits of intelligent monitoring of power distribution systems include increased reliability, improved safety, reduced downtime, and lower maintenance costs[10]. By providing real-time data and insights into the performance and condition of power distribution equipment, intelligent monitoring enables operators to identify potential problems and take corrective actions before they result in power outages or other disruptions.

II. M-LVSC intelligent sensing method

The sensors of collected M-LVSC operation condition information includes partial discharge ultrasonic sensor, partial discharge UHF sensor,infrared camera, wireless temperature sensor. Three types of ultra-high frequency partial discharge sensor is diplayed in figure 1, including the three-in-one partial discharge sensor, UHF partial discharge sensor and space ultra-high frequency partial discharge sensor. They will monitor the operating condition of M-LVSC all-round by UHF partial discharge. The flexible installation UHF sensors is shown in figure1(a),(b),(c). The infrared camera is demonstrated in figure2, which can inspect the local overheating defects in the outside of M-LVSC, such as contacts. As typical deployment mode UHF sensors, the typical deployment mode of detection sensors in substation station is shown in figure3, which installed in the distribution box shell and roof inside substation.The UHF sensor is connected to the power edge control tool through wireless communication methods, and all adopt fast magnetic adsorption installation methods.

a) Three-in-one partial discharge sensor



b)UHF partial discharge sensor

c) Space ultra-high frequency partial discharge sensor

Fig1 M-LVSC intelligent UHF sensors

Fig2 M-LVSC Infrared camera sensors

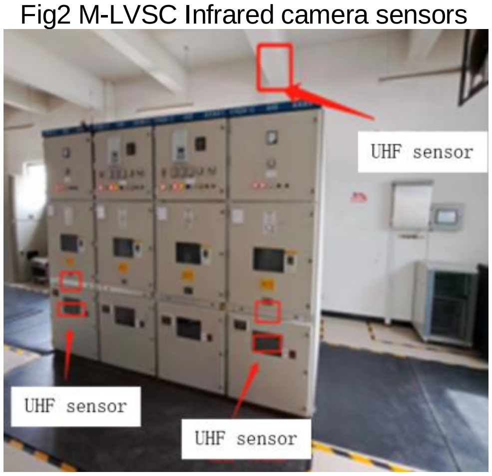


Fig3 Typical deployment mode of station building

As presented in table 1, installation type of Three-in-one partial discharge sensor intelligent sensors in M-LVSC equipment mainly adopted magnet magnetic type installation way between the front and middle or front and bottom of the incoming switch cabinet. Other intelligent sensors are similar as UHF partial discharge sensor, space ultra-high frequency sensor,electric power edge control device.

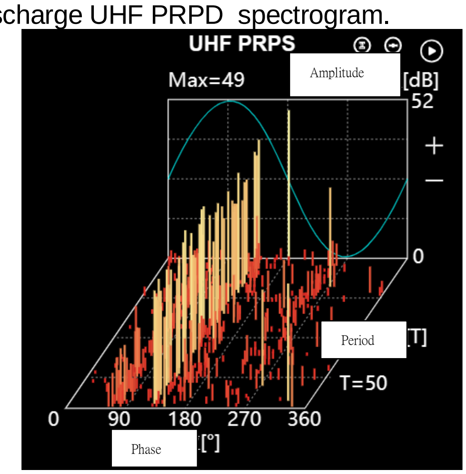
Table1 Installation of M-LVSC intelligent sensors

	Sensor type	Number	Installation way	Installation site
1	Three-in-one partial discharge sensor	2	magnetic type	Installed in the gap between the front and middle or front and bottom of the incoming switch cabinet.
2	UHF partial discharge sensor	2	magnetic type	Installed in the observation window of the front cabinet door of the incoming switch cabinet.
3	Space ultra-high frequency sensor	1	The top of the wall	Installed in the corner of the ceiling facing the switch cabinet
4	Electric power edge control device	1	The top of the wall	Placed in the terminal power supply box, the terminal power supply box is fixed on the wall or placed safely.

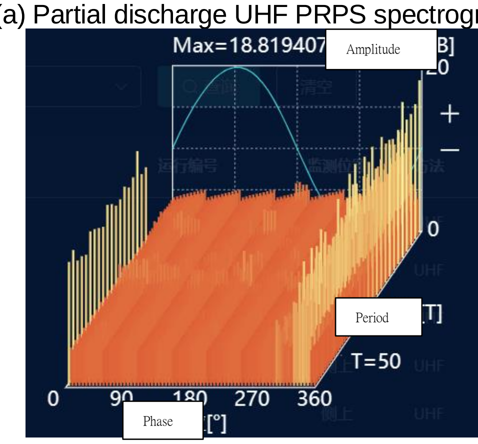
III. Intelligent fusion diagnosis technology of power M-LVSC equipment

A. Characteristics of discharge defects in switch-gear cabinet

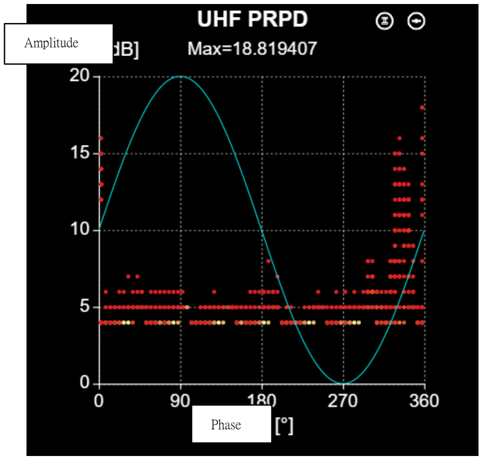
The UHF signal of partial discharge in switch-gear cabinet were real-time monitoring by power distribution network big data cloud platform monitoring system.As presented in the figure 4, the UHF signal of one partial discharge defects in switch-gear cabinet were real-time monitoring,including partial discharge UHF PRPS spectrogram, partial discharge UHF 3D spectrogram, partial discharge UHF PRPD spectrogram.



(a) Partial discharge UHF PRPS spectrogram



(b) Partial discharge UHF 3D spectrogram



(c) Partial discharge UHF PRPD spectrogram

Fig4 UHF characteristics of discharge defects in switch-gear cabinet

B. Characteristics of overheat defects in switch-gear cabinet

In recent years, with the continuous development of smart grid power equipment condition monitoring, infrared imaging technology has played an indispensable role in the fields of M-LVSC equipment overheat fault diagnosis and temperature monitoring, which makes the application of infrared imaging technology of great significance. The infrared thermal imager has been widely used in substations. Figure 5 shows the infrared thermal imager and the infrared image of the typical M-LVSC contactor.

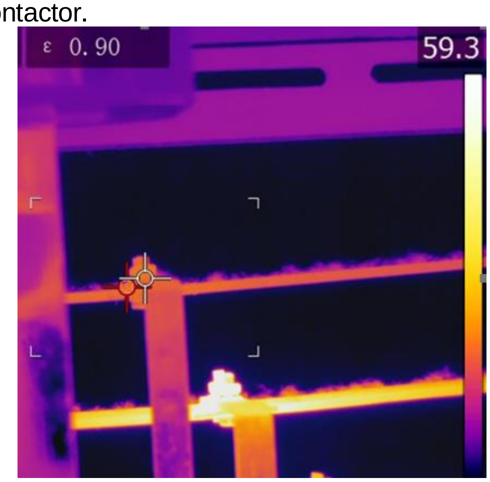


Fig 5 Box conversion 400 V low voltage cabinet bus

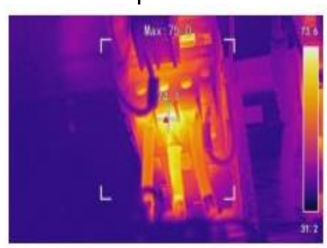
Based on live monitoring of distribution equipment by transient ground voltage partial discharge detection, ultrasonic partial discharge detection, UHF partial discharge detection and infrared thermal imaging detection, the multi-parameter identification and analysis technology to electrical power equipment condition to identify potential faults and anomalies. In the power M-LVSC, such as switchgear and transformers, multi-parameter identification and analysis can be used to detect and diagnose a wide range of issues, including insulation degradation, arcing, and overheating. Some of the parameters that can be monitored using multi-parameter identification and analysis technology include: temperature, vibration, current, voltage, partial discharge and others. For example, the multiple feature value of UHF, AE and ultrasonic sensors for the partial discharge monitoring can be sampled, uploaded, analyzed and displayed for evaluation the insulation condition of power equipment. As a result, by collecting data from multiple sensors and parameters and analyzing this data using machine learning and other advanced algorithms, it is possible to identify patterns and correlations that can indicate potential faults and anomalies in medium voltage power equipment.

This can help to enable proactive maintenance and reduce the risk of equipment failure and downtime. Multi-parameter identification and analysis technology is a powerful tool for electrical power equipment condition monitoring, enabling the detection and diagnosis of a wide range of issues and helping to ensure the safe and reliable operation of medium voltage power equipment.

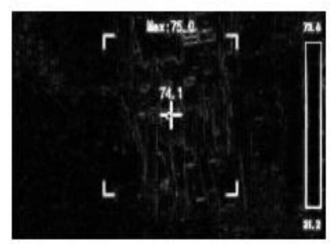
1) Comprehensive detection and fusion diagnosis for contactor power line

For example, transient ground voltage partial discharge detection, ultrasonic partial discharge detection and infrared thermal imaging detection are used to diagnose the condition of 10 kV switch cabinet and 10 kV distribution transformer. No abnormality is found in transient ground voltage partial discharge detection, and no abnormality is found in ultrasonic partial discharge detection. Infrared thermal image detection was used to find abnormalities in the equipment.

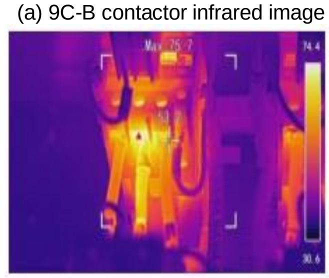
As shown in figue6, the infrared imaging of contactors are extracted edge feature by laplacian algorithm. As shown in figue7, the infrared imaging of contactors are extracted gray feature by algorithm.The temperature of the lower port of the power line of the 9 C contactor in the distribution room is abnormal. The maximum temperature of the B phase is 75 °C, and the normal temperature of the C phase is 53.2 °C. The temperature of the upper port of the power line of the 4 C contactor in the power distribution room is abnormal. The maximum temperature of the A phase is 233 °C, and the normal temperature of the C phase is 79.9 °C.



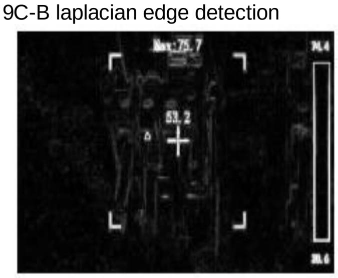
(a) 9C-B contactor infrared image



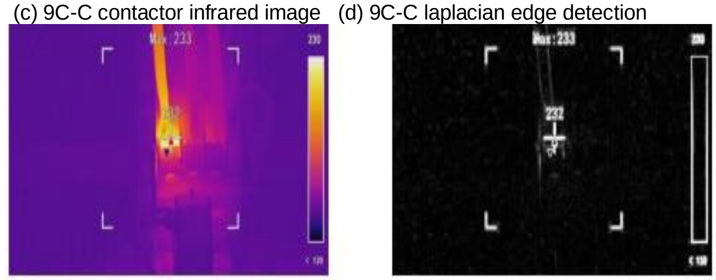
(b) 9C-B laplacian edge detection



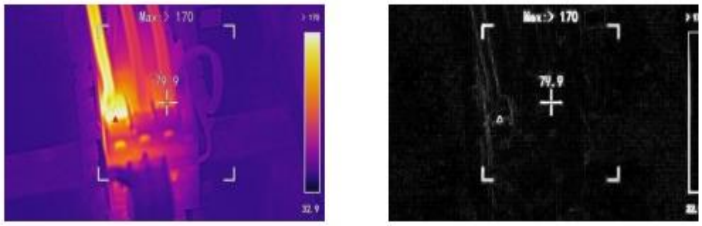
(c) 9C-C contactor infrared image



(d) 9C-C laplacian edge detection

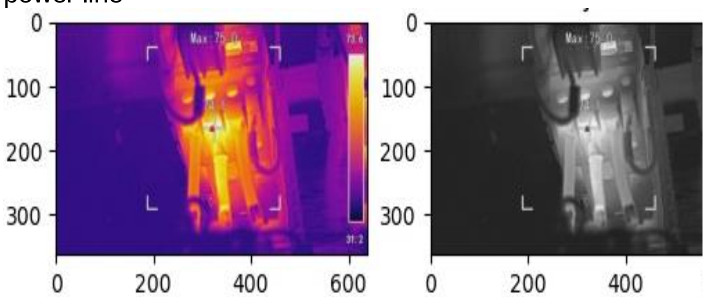


(e) 3C-A contactor infrared image (f) 3C-1 laplacian edge detection

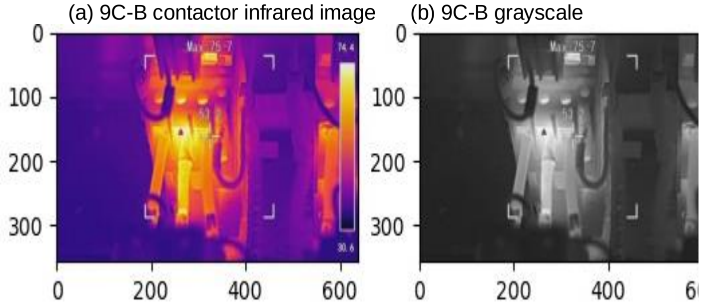


(g) 4C-C contactor infrared image (h) 4C-C laplacian edge detection

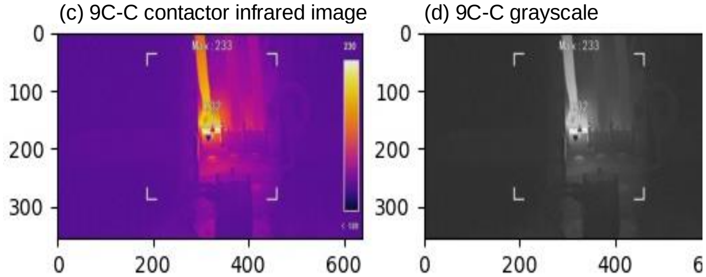
Fig 6 the infrared imaging edge feature for contactor power line



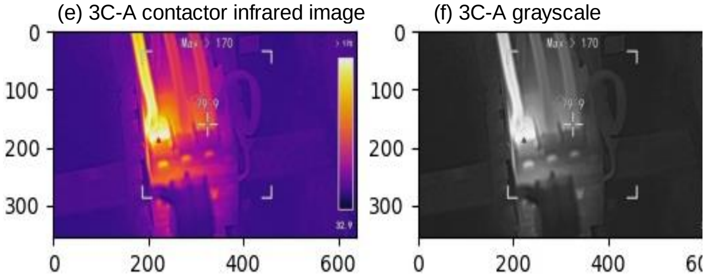
(a) 9C-B contactor infrared image (b) 9C-B grayscale



(c) 9C-C contactor infrared image (d) 9C-C grayscale



(e) 3C-A contactor infrared image (f) 3C-A grayscale



(g) 4C-C contactor infrared image (h) 4C-C grayscale

Fig 7 the infrared imaging grayscale feature for contactor power line

The temperature characteristics of the infrared image of the distribution equipment are extracted, and the experiment is carried out with the distribution equipment, and good results are obtained. The maximum temperature, the minimum temperature, the maximum temperature rise and the average temperature are determined to form the diagnostic characteristic quantity of the fault state of the distribution equipment.

The temperature of phase B at the lower port of the power supply line of the 9 C contactor in the distribution room is abnormal, and the temperature of phase A at the upper port of the power supply line of the 4 C contactor is abnormal. The temperature difference between phases exceeds 15 K, and the hot spot temperature is greater than 130 ° C, which is a critical defect. Inspection is recommended.

Both the feature of UHF and ultrasonic partial discharge detection (AE) for this contactors are normal and negative feature result, while the two locations infrared image feature in contactors such as 9C-B and 3C-A are abnormal as shown in figure 7. The infrared imaging feature are extracted by grayscale and laplacian edge detection.

As shown in figure 8, the comprehensive detection and fusion diagnosis method is integrated the extraction features TEV, AE and infrared image. It is effective method to discover the over-heat defects in power distribution equipment. The infrared thermal imaging detection are positive used to diagnose the condition of contactor power line. The detection both transient ground voltage partial discharge detection and ultrasonic partial discharge detection were negative and normal feature. By the fusion recognition diagnosis model, the output result of 9C-B and 3C-A contactor power line are positive and over-heated defect.

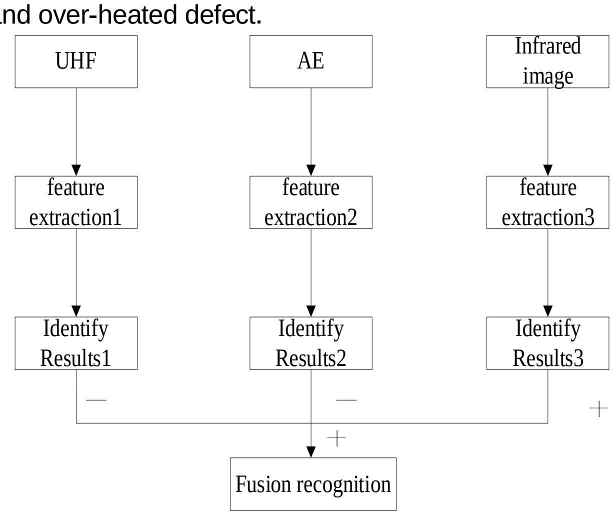
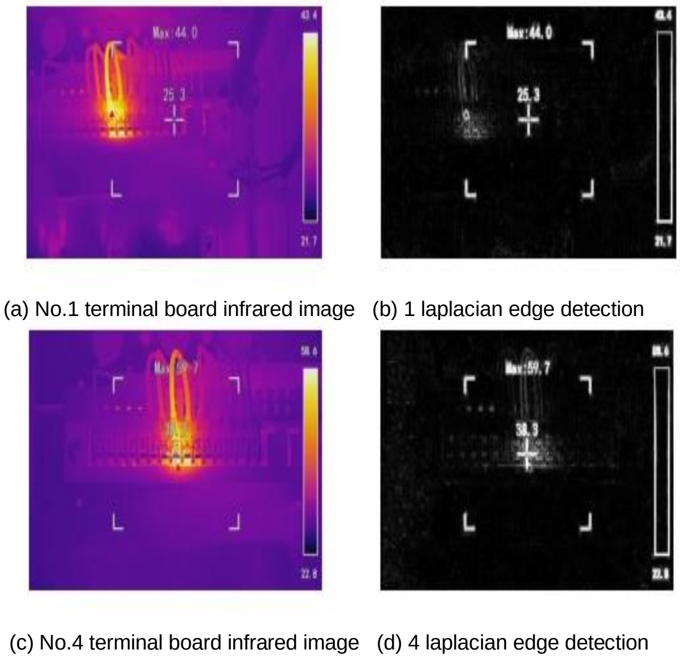


Fig8 Comprehensive detection and fusion diagnosis of M-LVSC

2) Comprehensive detection and fusion diagnosis for terminal board

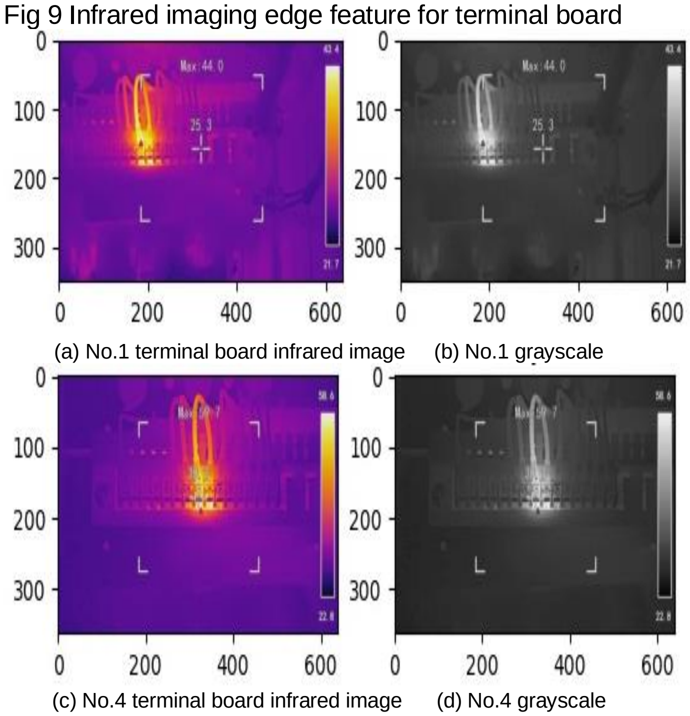
As shown in figure9, the infrared imaging of the 380V terminal board are extracted edge feature by laplacian algorithm. As shown in figure10, the infrared imaging of terminal board are extracted gray feature by algorithm. The temperature of the secondary terminal row of the low-voltage cabinet is abnormal. The maximum temperature of the 1 terminal is 59.7 °C, as shown in figure 10(c),9(d). And the temperature of the 2 terminal is 25.3 °C, presented in figure 10(a),(b). Both the feature of transient ground voltage partial discharge detection(TEV) and ultrasonic partial discharge detection (AE) for this contactors are normal and negative feature result. Based on the comprehensive detection and fusion diagnosis method, the low-voltage cabinet 1 terminal board is abnormal .The temperature difference between phases exceeds 15 K, and the hot spot temperature does not reach 90 ° C, which is a general defect.



(a) No.1 terminal board infrared image (b) 1 laplacian edge detection

(c) No.4 terminal board infrared image (d) 4 laplacian edge detection

Fig 9 Infrared imaging edge feature for terminal board



(a) No.1 terminal board infrared image (b) No.1 grayscale

(c) No.4 terminal board infrared image (d) No.4 grayscale

Fig 10 Infrared imaging grayscale feature for terminal board

The feature quantity of the operating state of the distribution equipment is constructed by infrared spectrum feature extraction, TEV and AE features, and the diagnosis result is output by data fusion algorithm.

IV. Conclusion

The health status assessment technology of M-LVSC equipment is a technology that makes use of sensors, monitoring systems, data analysis and artificial intelligence to monitor, diagnose and forecast the running status of M-LVSC equipment in real time. Under operating conditions, the signal of a single sensor(UHF, AE, thermal infrared, etc) in the distribution equipment cannot judge the complex faults, and it is difficult to reflect all the faults.

This paper provide a real-time monitoring system for power distribution equipment to detect overheat detects and partial discharge defects.The condition of distribution equipment could be collected and analyzed from intelligent UHF and infrared camera monitoring technology.Under the background of big data cloud platform, overheat defects and discharge defects were captured and deeply analysis. Fusion diagnosis provides an intelligent decision scheme for power distribution equipment fault diagnosis under operating conditions. The fusion recognition by comprehensive detect for a M-LVSC contactors power line and terminal board were verified in power distribution site.

Under the background of big data cloud platform, multi-signal mode intelligent fusion diagnosis provides an intelligent decision scheme for power distribution equipment fault diagnosis under operating conditions. The fusion recognition by comprehensive detect for ac contactors power line and terminal board were verified in power distribution site.

REFERENCES

[1] X. Chen, X. Chen, C. Wang, N. Zhang, Y. Yan and W. Guo, "New Technology of the Substation Green Construction under the New Power System," 2022 IEEE/IAS Industrial and Commercial Power System Asia (I&CPS Asia), Shanghai, China, 2022, pp. 899-903.

[2] X. Suo, S. Zhao, Y. Ma and L. Dong, "New Energy Wide Area Complementary Planning Method for Multi-Energy Power System," in IEEE Access, vol. 9, pp. 157295-157305, 2021.

[3] F. Hengfu, Z. Bo, X. Chongyou and Z. Meng, "Research on Infrared Detection Method for Distribution Equipment Based on Cloud Edge Collaboration," 2023 IEEE 5th International Conference on Power, Intelligent Computing and Systems (ICPICS), Shenyang, China, 2023, pp. 22-27

[4] A. Wang, W. Li, Z. Huang, X. Wu, F. Jie and R. Tao, "Prior-Guided Data Augmentation for Infrared Small Target Detection," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 15, pp. 10027-10040, 2022.

[5] X. Feng, K. Hu and X. Lou, "Infrared and Visible Image Fusion Based on the Total Variational Model and Adaptive Wolf Pack Algorithm," in IEEE Access, vol. 8, pp. 2348-2361, 2020

[6] B. Wang et al., "Automatic Fault Diagnosis of Infrared Insulator Images Based on Image Instance Segmentation and Temperature Analysis," in IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 8, pp. 5345-5355, Aug. 2020

[7] F. Hu, H. Chen and X. Wang, "An Intuitionistic Kernel-Based Fuzzy C-Means Clustering Algorithm With Local Information for Power Equipment Image Segmentation," in IEEE Access, vol. 8, pp. 4500-4514, 2020

[8] Y. Peng, S. Huang, Y. He and X. Guo, "Eddy Current Pulsed Thermography for Noncontact Nondestructive Inspection of Motor Winding Defects," in IEEE Sensors Journal, vol. 20, no. 5, pp. 2625-2634, 1 March1, 2020

[9] G. Y. Odongo, R. Musabe, D. Hanyurwimfura and A. D. Bakari, "An Efficient LoRa-Enabled Smart Fault Detection and Monitoring Platform for the Power Distribution System Using Self-Powered IoT Devices," in IEEE Access, vol. 10, pp. 73403-

73420, 2022

[10] W. Huo, F. Liu, L. Wang, Y. Jin and L. Wang, "Research on Distributed Power Distribution Fault Detection Based on Edge Computing," in IEEE Access, vol. 8, pp. 24643-24652, 2020