Design of Explosion-Proof Switch Safety Assessment System

Yukun Wang [1, 2, 3], Hongkui Zhang [1, 2, 3, *]

[1] CCTEG Shenyang Research Institute, Fushun, CO 110178, China

[2] State Key Laboratory of Coal Mine Safety Technology, Fushun, CO 110178, China

[3] Fushun CCTEG Inspection Center Co. Ltd, Fushun, CO 110178, China

* Corresponding Author Email: 18940021505@126.com

Abstract. Explosion-proof switches are essential electrical devices in explosive environments and serve as a critical guarantee for safe production in such locations. Based on an analysis of the status of safety assessment technologies both domestically and internationally, this paper proposes a safety assessment technology for explosion-proof switches, grounded in the inverse relationship between contact lifespan and interruption current. Additionally, it designs the overall structure of the safety assessment system for explosion-proof switches and establishes methods for result evaluation, providing a reference for the assessment technology of explosion-proof switches.

Keywords: Explosion-proof switch; Fault current; Wear; Safety assessment.

1. Introduction

Explosion-proof switches refer to switching devices used in environments containing explosive gases and dust, such as coal mines and petrochemical facilities. They play a dual role in controlling and protecting electrical networks. Explosion-proof switches include explosion-proof high-voltage distribution devices, low-voltage feeder switches, low-voltage electric control boxes, and explosion-proof high-voltage electromagnetic starters, all of which are crucial equipment in the power supply, distribution, and control processes within explosive environments. The safety of explosion-proof switches directly impacts the smooth execution of safety production operations in explosive areas; therefore, conducting research on safety testing and assessment technologies for explosion-proof switches holds significant theoretical and practical importance. Figure 1 illustrates a low-voltage feeder switch.

Figure 1. Explosion-proof low-voltage feeder switches

Dr. Li Shiguang from China University of Mining and Technology summarized issues related to frequency conversion drive systems under explosive conditions from three aspects: system structure and safety, explosion-proof frequency converters, and explosion-proof motors. He discussed problems encountered in research on various components of the system as well as their applications in special environments. Furthermore, he explored reliability under extreme conditions, safety assessment techniques for frequency conversion drive systems in explosive environments, and prospects for new integrated technologies for explosion-proof frequency drives. Yang Wenyu from

Nanyang Explosion-Proof Electrical Research Institute studied experimental methods for comprehensive safety assessments of explosion-proof instruments. By analyzing potential safety risks arising from structural failures such as those in explosion-proof enclosures, junction boxes, and cable entry devices, along with mechanical performance failures, surface temperature failures, and material failures, he constructed a safety assessment index system for explosion protection. Wang Bo from Harbin University of Science and Technology established a dust mass concentration prediction model. This model optimizes the initial weights of an extreme learning machine (ELM) using a Golden Eagle optimization algorithm before training the sample data with ELM to accurately predict dust mass concentration over any time interval within 30 minutes. Wu Yunjie from Chongqing University's National Key Laboratory for Power Transmission Equipment Technology developed an aging model for capacitor equivalent series resistance (ESR) and capacitance value. He inferred the usage duration of capacitors along with their current ESR values and incorporated these into an established field-circuit collaborative simulation electro-thermal coupling model to calculate capacitor temperature. The proposed remaining life model predicts the current remaining lifespan of capacitors.

2. Safety Assessment Method

The safety assessment system for explosion-proof switches shown in Figure 2 primarily consists of a display unit, control panel, power supply, reset circuit, clock circuit, crystal oscillator circuit, PIC (Peripheral Interface Controller), driver module, explosion-proof switch, signal processing circuit, current sensor, analog-to-digital conversion unit, stroke sensor, voltage sensor, communication circuit, industrial computer, and data storage unit.

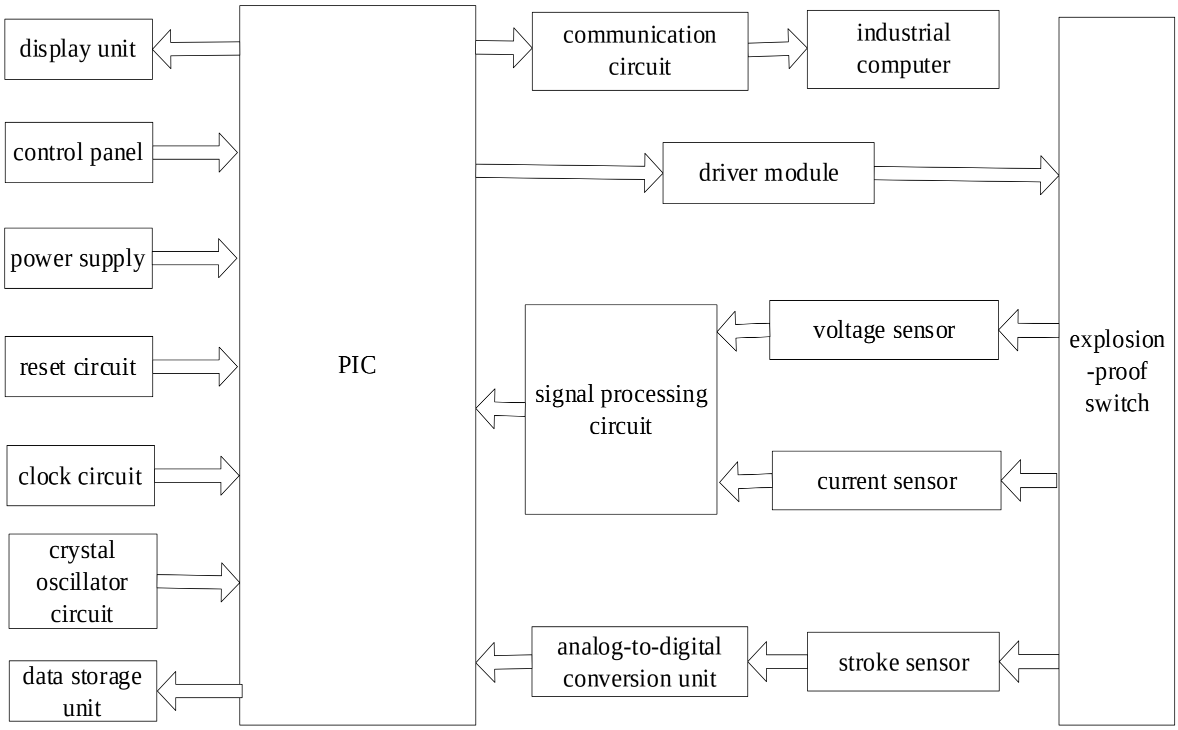

Figure 2. Structure sketch of the safety assessment system for explosion-proof switches

The safety assessment system for explosion-protected switches uses an inversely proportional relationship between contact wear and electrical life, i.e., the greater the contact wear, the shorter the electrical life. The greater the breaking current of the explosion-protected switch, the greater the contact wear. The breaking current of an explosion-proof switch is divided into rated current, overload current and short-circuit current, and the effect of breaking different currents on the contacts varies greatly. Breaking rated current belongs to the normal breaking, life prediction when the number of statistics and the actual number of breaking consistent; overload current on the contact damage is far greater than the rated current, breaking overload current according to the actual value of the breaking current and the ratio of the rated current plus a weighting factor; short-circuit current on the damage to the contact is far greater than the overload current, breaking overload current according to the actual value of the breaking current and the ratio of the rated current plus a weighting factor; explosion-proof switch operation process on the contact loss:

$$Q = M + KEN + PFW \tag{1}$$

Where, Q is the contact wear of the explosion-proof switch; M is the number of interruptions at rated current; N is the number of interruptions at overload current; K is the weighting factor for overload current (typically taken as 3); E is the ratio of overload current to rated current; W is the number of interruptions at short-circuit current; P is the weighting factor for short-circuit current (typically taken as 5); F is the ratio of short-circuit current to rated current.

The calculation method for the ratio “E” of overload current to rated current for explosion-proof switches is as follows:

$$E = \frac{I_g}{I_e} \tag{2}$$

Where I_g is the overload current of the explosion-proof switch, and I_e is the rated current of the explosion-proof switch.

The calculation method for the ratio “F” of short-circuit current to rated current is as follows:

$$F = \frac{I_d}{I_e} \tag{3}$$

Where I_d is the short-circuit current of the explosion-proof switch.

Based on formulas (1), (2), and (3), the actual contact wear during the operation of the explosion-proof switch can be determined.

$$Q = M + \frac{KNI_g}{I_e} + \frac{PWI_d}{I_e} \tag{4}$$

As shown in Figure 3, in the safety assessment system for explosion-proof switches, the PIC collects interruption current and stroke data. It calculates the actual contact wear (Q) during operation based on the type of interruption current, stroke, and rated interruption current. This data is displayed on the display unit. Additionally, it retrieves the rated wear data for the contacts (Q_z) of the explosion-proof switch and compares it with the actual wear (Q) calculated by the PIC. If the actual wear exceeds the rated wear(ie: $Q \geq 0.9Q_z$), it is deemed that a fault will occur in the explosion-proof switch, triggering an alarm through both the display unit and industrial computer. During each interruption operation of the explosion-proof switch, actual stroke data is collected. This data is then compared with rated stroke data stored in a database. If the actual stroke data is less than 50% of the rated stroke data, it indicates a failure in interrupting current, causing the safety assessment system to stop functioning and issue an alarm via both the display unit and industrial computer.

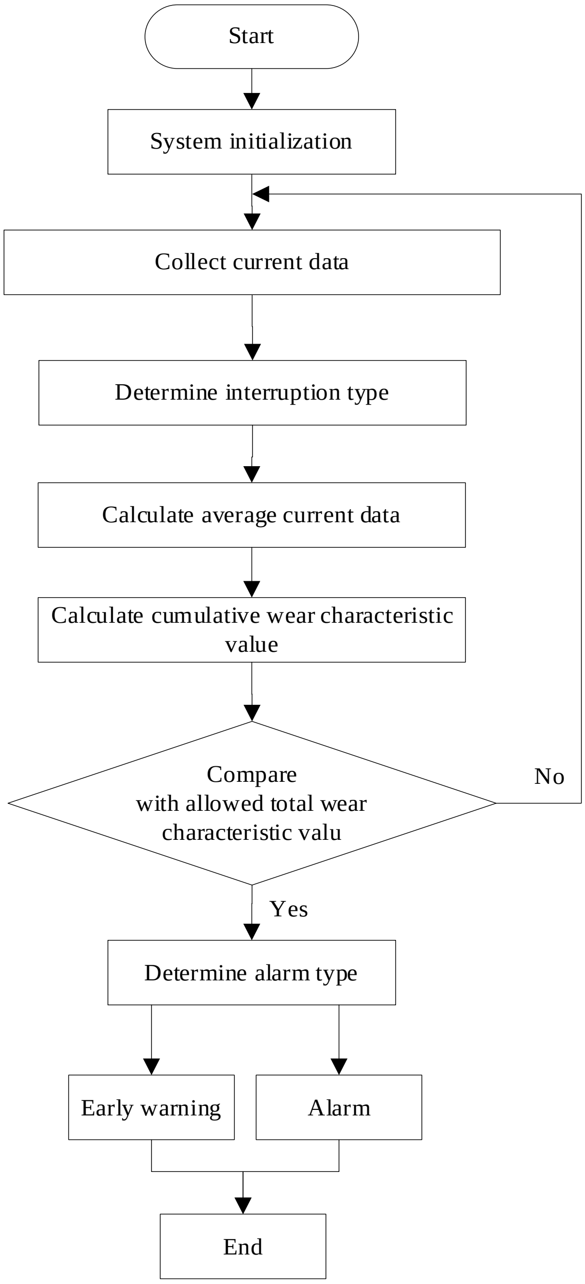

Figure 3. Flow chart of safety evaluation system for explosion-proof switch

The rated stroke data for explosion-proof switches stored in the database is crucial to ensuring the reliability and stability of the safety assessment system. This rated stroke data is obtained by collecting operational stroke data L_i (L_1 , L_2 ,……, L_n) during system operation, followed by calculations and data processing as detailed below:

$$\overline{L} = \frac{L_1 + L_2 + \cdots + L_n}{n} \tag{5}$$

Where $\overline{L}$ represents the average stroke value of an explosion-proof switch, and L_n represents n-th stroke data for each switch.

$$\Delta L = \frac{\left| L_i - \overline{L} \right|}{\overline{L}} \tag{6}$$

Where ΔL is the ratio between the absolute value of the difference between the i-th explosion-switch travel data and the average explosion-switch travel value and the average explosion-switch travel value.

Given that different explosion-proof switches may have significant variations in their stroke values, it is generally accepted that if ΔL >0.2, then corresponding stroke data (L_i) for that explosion-proof switch is considered anomalous. Such outlier data (L_i) will be discarded when establishing the rated stroke database for explosion-proof switches.

3. Conclusion

The development direction for safety production in explosive environments is towards automation and intelligence, with explosion-proof switches serving as the electrical assurance for this intelligent advancement. This paper presents a safety assessment method for explosion-proof switches and designs the structure and evaluation methods of the safety assessment system. These efforts enhance the stability and safety of explosion-proof switches, thereby providing technical support for the safe operation of equipment in explosive environments.

References

[1] B. Wu, J. Jiang, X. Zhou and Z. Tian, "Research and Application of Synthesis Safety Evaluation and Intelligence Decision System on Coal Mine," 2009 WRI Global Congress on Intelligent Systems, Xiamen, China, 2009, pp. 280-284

[2] A. A. Abdellatif and F. Holzapfel, "Model Based Safety Analysis (MBSA) Tool for Avionics Systems Evaluation," 2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC), San Antonio, TX, USA, 2020, pp. 1-5

[3] S. Xu, H. Zeng, X. Jiang, G. Qi and G. Han, "Reliability Evaluation of Dual Stator Switched Reluctance Motor System Based on Enhanced Reliability Model," 2023 26th International Conference on Electrical Machines and Systems (ICEMS), Zhuhai, China, 2023, pp. 3651-3656

[4] J. Huan, C. Yongfeng, L. Bin, G. Chunhui and L. Huibin, "Research on Vibration Measurement Technology and Safety Evaluation Method of Outdoor Isolating Switch," 2022 IEEE 6th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), Beijing, China, 2022, pp. 513-517

[5] J. Si, E. Tang and G. Xu, "Safety Research in Typical Connection Models of Distribution System," 2010 Asia-Pacific Power and Energy Engineering Conference, Chengdu, China, 2010, pp. 1-4

[6] Y. Li et al., "Experimental Evaluation of Dynamic On-resistance and Switching Performance of Cascode GaN HEMTs," 2023 14th International Conference on Reliability, Maintainability and Safety (ICRMS), Urumuqi, China, 2023, pp. 682-686

[7] G. K. S, S. R. Kakarlapudi and R. Sultana, "Design of Digital Twin for Safety Systems in Electric Vehicles," 2023 International Conference on Next Generation Electronics (NEleX), Vellore, India, 2023, pp. 1-6

[8] M. Biao and X. Hu, "Quantitative Evaluation of System Safety Assessment Considering EWIS Failures," 2022 2nd International Conference on Electrical Engineering and Control Science (IC2ECS), Nanjing, China, 2022, pp. 975-978