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Study on Data Fusion-Based Online Monitoring System for Mechanical Characteristics of Circuit Breaker

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Abstract

To satisfy the requirements of smart power grids for online monitoring intelligent switchgear cabinets, this paper designed an online monitoring system for mechanical characteristics of circuit breaker with the multi-sensor fusion technology, realized the online monitoring of the characteristics including travel, over travel, speed at instant of contacts separating (touching), switch-off (on) time, bounce times, bouncing time and average speed; the results of field and remote tests showed that the developed monitoring device enabled real time and accurate monitoring of mechanical characteristics of circuit breakers.

Keywords: *Circuit Breaker; online monitoring; data fusion; mechanical characteristics*

1. Introduction

Switchgear cabinet is a kind of electrical equipment widely used in our country, and intelligent switchgear cabinet refers to the one with high performance, high reliability, certain self-diagnosis and automatic control functions, and network communication capability, the key component of which is high-voltage circuit breaker. The online monitoring system for mechanical characteristics of circuit breaker requires the online monitoring of the characteristics including travel, over travel, speed at instant of contacts separating (touching), switch-off (on) time, bounce times, bouncing time and average speed of circuit breaker during the operations of switching on[1] and off, recording and uploading the relevant data, as well as high reliability and real-time capability due to the importance of power system.

The online monitoring system for mechanical characteristics of circuit breaker realizes the online monitoring of the characteristics including travel, over travel, speed at instant of contacts separating (touching), switch-off (on) time, bounce times, bouncing time and average speed of circuit breaker in switchgear cabinet by detecting the linear displacement signal and angular displacement signal, provides evaluation of the mechanical part of circuit breaker, and it usually has a communication interface, able to provide data support for intelligent maintenance of circuit breaker, and applies the sensor fusion method to improve the monitoring data accuracy while circuit breaker is under strong electromagnetic interference.

2. Principles of System

The switch-on and switch-off actions of circuit breaker are realized by the rectilinear motion of the moving contact part of the main contact of circuit breaker driven by the iron core of electromagnetic mechanism passing the corresponding transmission mechanism, the motion of which is driven after powering on the corresponding coil.[2]

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When the mechanism has a motion, which drives the movement of the motion part of linear displacement and angular displacement sensors, the resistance value of sensors will change correspondingly, thus under the function of stable external power supply, the mechanical signal of the mechanism motion could be transformed to electrical signal that can be easily processed. Since the friction needed to be overcome for the movement of both sensors is very small, its impact on the mechanical characteristics of the entire system could be neglected. Given the actual space layout conditions of circuit breaker, online monitoring of circuit breaker can be realized through the indirect monitoring of the rectilinear motion of electromagnet iron core and the rotation angle of rotating shaft of transmission mechanism.

3. System Structure

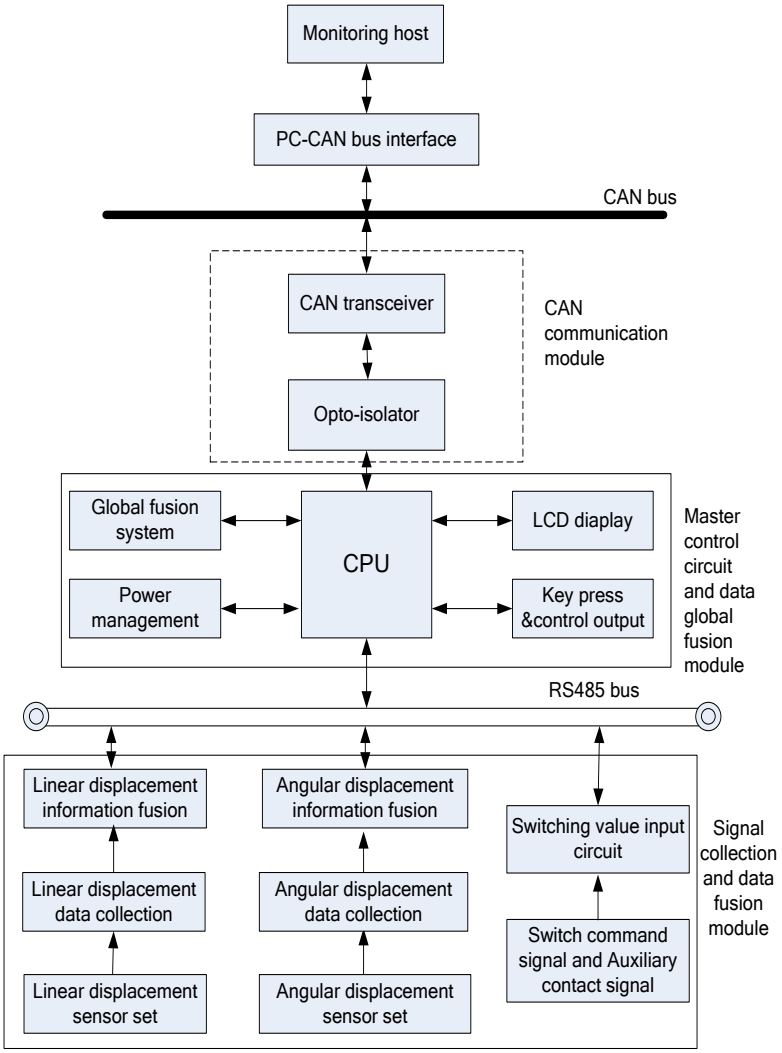

Figure 1. Structure of Monitoring System for Mechanical Characteristics of Circuit Breaker

The system structure is shown in Figure 1, the switching value input circuit unit of data processing board is connected in series to the switch button loop which is connected with PIE101 on-off controller, to collect the switch command signal of circuit breaker, then the signal will be transferred to the CPU interrupt pin of the monitoring unit after optoelectronic isolation through the switching value input circuit, and activate the AD of CPU to perform data collection. The switch on/off status of the

auxiliary contact of circuit breaker is used as another switching value input signal, also transferred to the CPU interrupt pin of the monitoring unit or the interrupt input pin of the capture unit, as well as the general I/O interface, after optoelectronic isolation through the switching value input circuit of data processing board, which enables the identification of the switch on/off status of circuit breaker, and the representation of switch on/off time of circuit breaker by calculating the time difference between the two interrupts[3].

The linear displacement sensor and the angular displacement sensor will sample the displacement information of moving contacts of the circuit breaker, transfer it to the AD convector of CPU board, process the collected data, and obtain the required mechanical characteristic indexes including travel, over travel, speed and time which represent the mechanical status of circuit breaker, and help make appropriate maintenance strategy. The CPU board has communication isolating circuit which enables the communication isolation from the upper computer.

4. Hardware Design

The hardware design of the system includes the design of operating circuit of main control chip, signal data collection circuit, power management circuit, CAN bus communication circuit, display circuit and output control circuit.[4] The data collection part mainly consists of sensors, amplifying and filtering circuits, optocouplers. The power module supplies power for single-chip microcomputer and sensors. The monitoring host is responsible for the management of the entire system, and communicates with the single-chip microcomputer with PC-CAN interface.

The device consists of mechanical part, electrical part and electronic part, and each part all contains certain errors, the error of the resistance of electron components is usually around ±1%, the common error of filter capacitors is around ±20%～±2%, the error of the mechanical part usually depends on its machining level and elastic deformation of materials, and the error of the electrical part is related to the performance, homogeneity and manufacturing technique of magnetic materials, thus under the condition of allowing ±3% error, we selected DSP of TMS320F2812 series to constitute the minimal system for online monitoring[5].

4.1. Data Collection

4.1.1. Displacement Signal Collection

If the mechanical characteristic signal of circuit breaker is collected by sensors, the accuracy of sensors will directly influence the accuracy of the subsequent part of the system, thus under the permitting condition the higher the accuracy of sensors is, the better. And given that the travel change detected by the linear displacement sensor in switch on-off operation is 26 mm, the angle of angular displacement is 15°, over travel exists in the motion which is around 43% of the travel, the measurement range of linear displacement sensors should be over 49mm and close to 49 mm as far as possible, the measurement range of angular displacement sensors should be over 30°and close to 30°as far as possible. In the term of insulating characteristic, as all the displacement sensors are connected with transmission mechanism which has a reliable connection with the ground, meeting the general withstand voltage and insulation requirements for electronic equipment is adequate.

According to the above requirements, we selected WDL-50-2 linear displacement sensors and angular displacement sensors of precise conductive plastic potentiometer. The installation is shown in Figure 2.

(a) Installation of linear displacement sensors

(b) Installation of angular displacement sensors

Figure 2. Installation of Displacement Sensors

4.1.2. Design of Switching Value Input Circuit

The device needs to transfer the switch on/off signal and the signal of auxiliary contact of circuit breaker to the corresponding ports of DSP, for which optoelectronic isolation is required due to safety and reliability; the switching value signals are combined with the output signal of the sensors for detection, to analyze the various mechanical characteristics.

4.2. Design of Data Fusion

Considering the structure of high-voltage switch cabinet and the particularity of the environment, we proposed a distributed multi-sensor architecture and two-level fusion model suitable for monitoring in the strong magnetic environment. The system fusion architecture is shown in Figure 3.

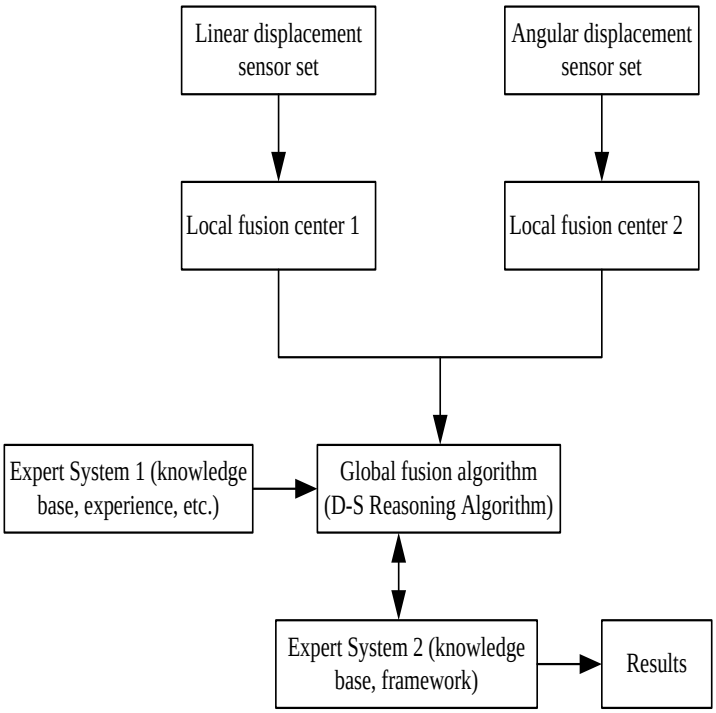

Figure 3.System Fusion Architecture

In the local fusion center [6], the algorithm combining the multi-sensor arithmetic mean value and batch estimation is adopted, which fuses the multi-source data from multiple sensors of the same kind in time and space. On the space level, when certain or even several sensors are out of work in certain plane domain, accurate result can still be obtained depending on the information provided by the other sensors that work normally. On the time level, comprehensive and accurate measurement results can be obtained by fusing the data collected in different time.

The system mainly applies D-S evidence reasoning theory[7] to fuse the primary parameters including the travel, over travel, speed at instant of contacts separating (touching), switch-off (on) time, bounce times, bouncing time and average speed of circuit breaker in the global fusion center. First, based on the possible states of circuit breaker, a reasonable identification framework is defined by Expert Knowledge System 2, and the multi-sensor data passing the local fusion center are assigned by Expert Knowledge System 1 according to basic probability; second, after the fusion under D-S evidence reasoning theory, the results of global fusion are then sent to Expert Knowledge System 2 to combine with the experience of the experts in the corresponding field to serve as the evidence of the reasoning of the expert knowledge system, which enables accurate judgments for the real-time conditions of strong magnetic environment, realizes online monitoring of the mechanical characteristics of circuit breaker, thus realizes online monitoring of switch cabinet.

4.3. Communication Design

4.3.1. Design of RS-485 Interface Circuit

The system adopts RS-485 bus technology for the communication between the control part and collection module [8]. RS-485 interface combines a balance driver and a difference receiver, with strong resistance against common mode interference. SN75176 is used as the bus driver chip. RS-485 interface circuit is shown in Figure 4.

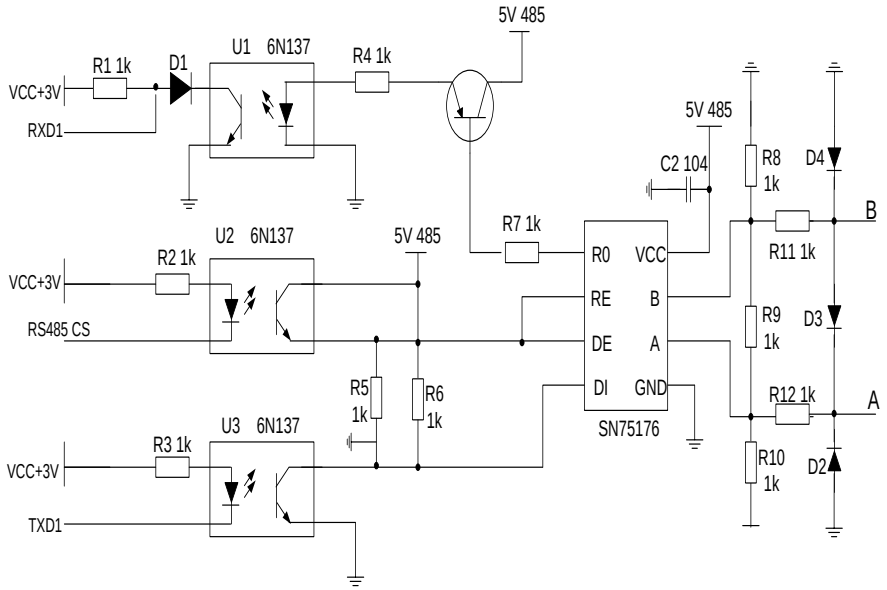

Figure 4. Schematic Diagram of RS-485interface Circuit

As shown in the figure, the sending and receiving functions of SN5176 chip are controlled by RE and DE of the chip; in order to prevent the interference on the single chip microcomputer, the SN5176 chip and the single chip microcomputer are isolated by optocoupler[9]. At the signal output end, the end B is pulled down and the end A is pulled up, to guarantee that when the entire bus is under receiving state, R_0 of chip is at high level, to prevent the error of nodes leading to receiving interruption. The sending and receiving control end is connected with pull-down resistor, to guarantee that the SN5176 chip is under receiving state when the system is reset, to avoid the interference on the bus communication. The end of the bus is connected with a matched resistor which can absorb the reflected signals of the bus, to guarantee that the normal signals are clean. Although the SN5176 chip itself is integrated with effective protective measures, since the switch cabinet has a lot of interference sources, a bi-directional voltage stabilizing diode is additionally set on the output end of the circuit to better protect the circuit.

4.3.2. CAN Interface Design

The system uses the upgraded bus transceiver TJAl050CAN[10] developed by Philips which is fully compatible with the CAN bus standards, and the bus interface circuit is shown in Figure 5. The CAN receiving and sending signal of microprocessor is connected with CAN transceiver chip TJAl050 after isolated by a high-speed optocoupler 6N137.

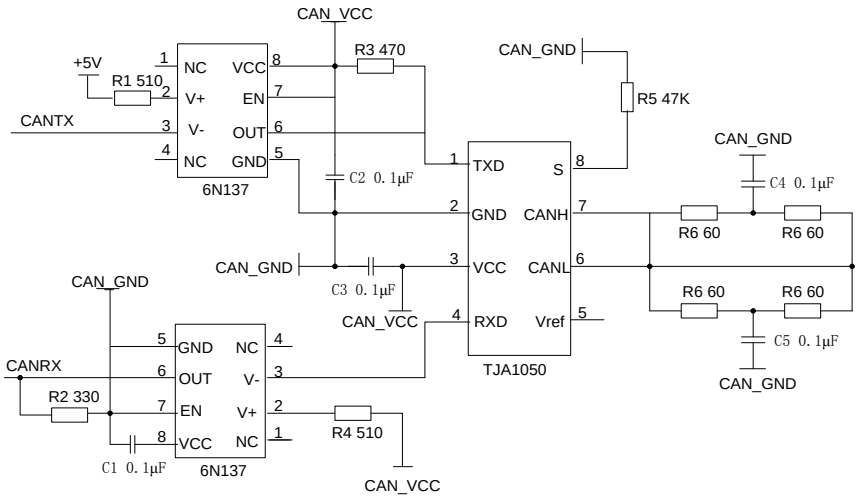

Figure 5. CAN Bus Interface Circuit

4.3.3. Communication between CAN Bus and Upper Computer

The underground substation of monitoring system needs to communicate with the upper computer through CAN bus, which requires the design of the communication conversion interface for CAN bus and PC. A simple solution is to design CAN-232 convertor. The schematic diagram of CAN232 conversion interface is shown in Figure 6.

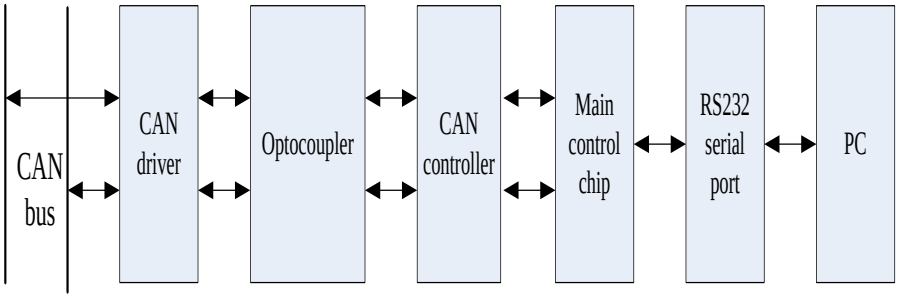

Figure 6. Schematic Diagram of CAN232 Conversion Interface

5. Software Design

The software system of the online monitoring unit of mechanical characteristics of circuit breaker should be able to collect, store and process the signals sent by the displacement sensors which satisfy the requirements, extract and display the characteristic quantity, as well as communicate with the equipment at bay level. The main components include data collection module, digital filtering module, data processing module, data display module, clock management module, data management module, and data communication module.

5.1. Design of Data Collection Module

The function of data collection module is to receive the analogue data sent by liner displacement sensors in the appointed time period, sample and quantize the data; read the switch command signal and the circuit breaker state signal which is sent by the auxiliary contact of circuit breaker.

5.2. Design of Data Processing Module

5.2.1. Design of multi-sensor Data Processing Program

Figure 7 shows the subprogram of data processing, which conducts fusion processing in the local and global fusion centers with the environmental parameters collected by multi-sensors.

5.2.2. Design of Characteristic Parameter Data Processing Program

The function of data processing module is mainly to process the mechanical characteristic signals after filtering and the time difference signals sent by interruption mode,extract the mechanical characteristic quantity for analysis and display. The travel of circuit breaker can be calculated by summing the speed signals in the transient process; over travel can be calculated by first summing the speed signals between the start time of motion and the first time of zero speed signal, then deducting the travel; speed at instant of contacts separating (touching) can be represented by the average speed within 10 ms after the motion; switch-off (on) time can be represented by the time difference between the time when switch-off (on) signal is sent by XINT1 and the time when displacement signal of the auxiliary contact of circuit breaker is sent by XINT2; bouncing time can be represented by the time period from the time when the summation result of speed signals after motion equals to the travel, to the time when the entire transient process of speed signal representation ends; bounces can be can be represented by the zero passage times of speed signals after motion; average switch-off (on) speed can be represented by the average of the absolute values of speed in the transient process; and movement time is the time of soft clock when receiving the action command. The flows are shown in Figure 8.

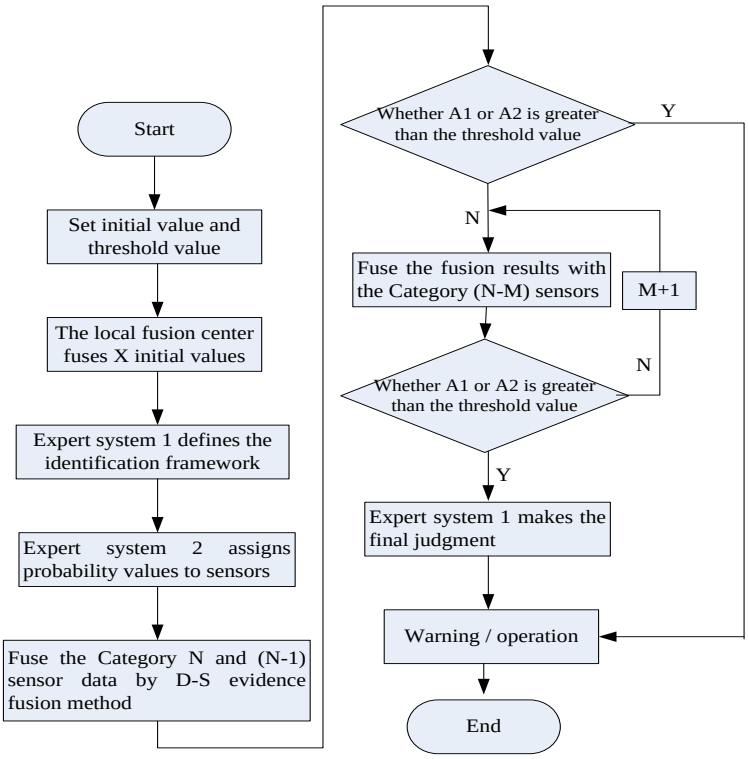

Figure 7.Subprogram of Data Fusion Processing

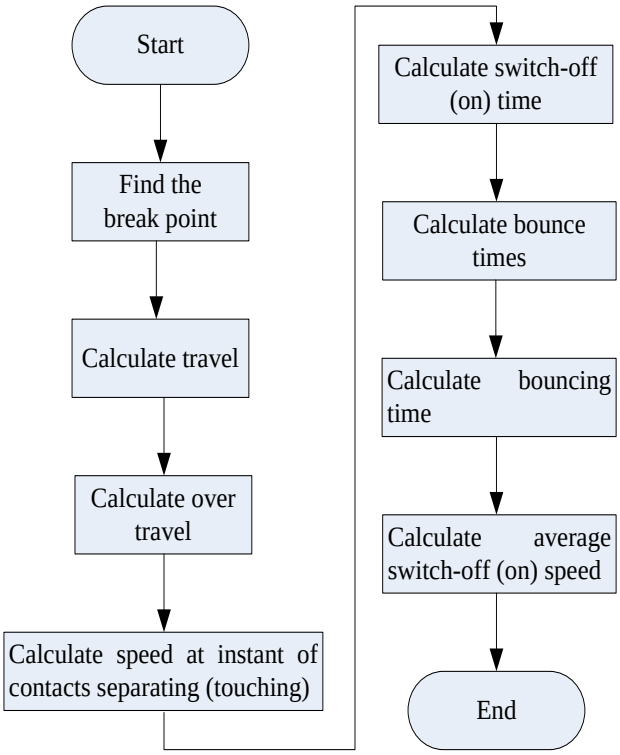

Figure 8. Program Flow Chart of Data Processing Module

6. Experimental Results

6.1. Field Results

We did the design and simulation according to the requirements of hardware and software design, and performed joint debugging on the hardware system, the results of dozens of tests showed that under the current experimental conditions and based on the data fluctuation, the error was less than 3% which was estimated, indicating the design basically met the requirements and achieved the expected objective. The output interface is shown in Figure 9.

(a)Switch-on action (b)Switch-off action

Figure 9. Field Output Results

6.2. Remote Output Results

Remote online real-time monitoring of the mechanical characteristics of circuit breaker is possible if the design requirements are met. The remote monitoring interface is shown in Figure 10.

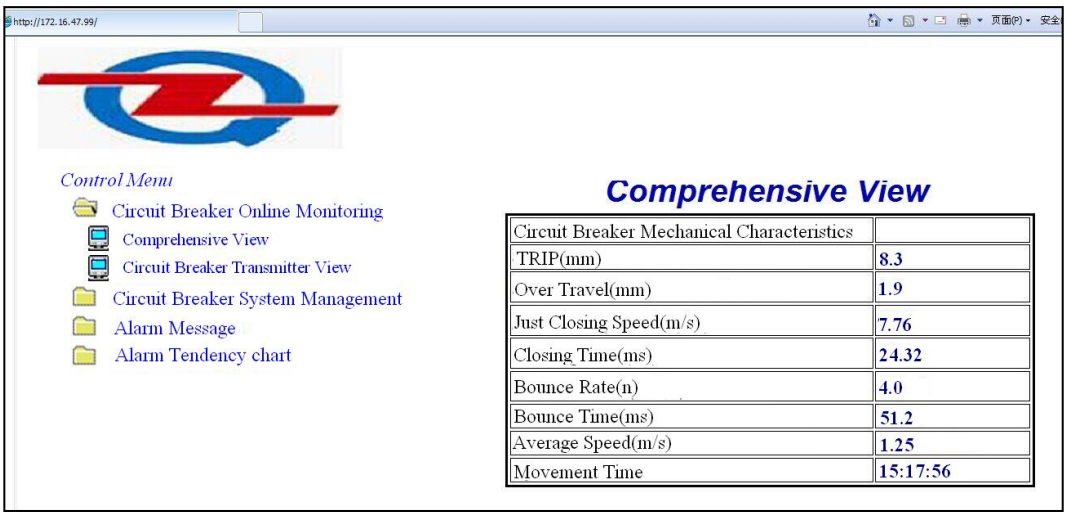

Figure 10. Remote Output Results

7. Conclusion

This paper made an overall design of the online monitoring system for the mechanical characteristics of circuit breaker in smart cabinet, and conducted theoretical analysis of the system identification of mechanical characteristics and the fusion of mechanical characteristics with multi-sensors. From the experimental results, the proposed online monitoring system is capable for online monitoring of the travel, over travel, speed at instant of contacts separating, switch-off time, bounce times, bouncing time, average speed and movement time, and the application of data fusion method improved the precision of test as the system error was turned out to be less than the estimated 3%. The further study will be mainly in the area of system interference resistance and data stability.

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