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Application of IED to Condition Based Maintenance of Medium Voltage GCB/VCB

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***Abstract*—**Time base maintenance (TBM) is conventionally applied by the power utilities to maintain circuit breakers (CBs), transformers, bus bars and cables, which may result in under maintenance or over maintenance. As information and communication technology (ICT) industry develops, the maintenance policies of many power utilities have gradually changed from TBM to condition base maintenance (CBM) to improve system operating efficiency, operation cost and power supply reliability. This paper discusses the feasibility of using intelligent electronic devices (IEDs) to construct a CB CBM management platform. CBs in power substations can be monitored using IEDs with additional logic configuration and wire connections. The CB monitoring data can be sent through intranet to a control center and be analyzed and integrated by the Elipse Power Studio software. Finally, a human-machine interface (HMI) of supervisory control and data acquisition (SCADA) system can be designed to construct a CBM management platform to provide maintenance decision information for the maintenance personnel, management personnel and CB manufacturers.

***Keywords*—**Circuit breaker, Condition base maintenance, Intelligent electronic device, Time base maintenance, SCADA.

I. Introduction

TIME base maintenance (TBM) is conventionally applied by the power utilities to maintain power equipment. Because the actual operating conditions of equipment is not taken into consideration by TBM, unnecessary maintenance for some devices may result in waste of human and material resources and inadequate maintenance for some devices may result in greater risk of poor power quality for both the customers and the utility. Therefore many utilities have changed their maintenance policies by replacing TBM with condition base maintenance (CBM). In CBM, a monitoring system is built to monitor the operating conditions of power equipment in real time, and the early warning function of the CBM management platform will determine if maintenance is needed depending on the equipment's electrical characteristics, the accumulated analog quantities and the trend of status changes. Thus the equipment maintenance is more rational and effective in CBM than in TBM. A circuit breakers (CBs) CBM management platform is constructed in this study and intelligent electronic devices (IEDs) are used to collect the needed electrical information of various CB components. When a CB component enters its early stage of deterioration, an alarm will be issued to the maintenance personnel so that the CB may be maintained before it fails to prevent power supply interruption, casualties and property losses. This study focuses on how to integrate the maintenance scheduling of important CB components into the CBM management platform using IEDs, on the reduction of the operating cost in a cost-effective way and on the improvement of the power supply reliability [1]-[11].

Because there are differences, such as communication protocol and firmware version, among IEDs from different manufacturers, a monitoring system which can integrate all different types of IEDs is needed to acquire all the CBs information [12]-[15]. The Elipse Power Studio software is used in this study to integrate IEDs from different manufacturers, and a human-machine interface (HMI) of supervisory control and data acquisition (SCADA) system is designed to meet the user's requirements [16].

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II. Application of IED on CB CBM

The CB supervision data includes the main contact wear, tripping loop health, spring energy storage status, operating time and SF6 gas pressure. Such data are collected by the IED and serve as the basis of CB CBM decision making [12]-[15].

A. CB Main Contact Wear Supervision

Arc forms at the CB main contact when normal load current is cut off or when fault current is interrupted. Arc results in melting, damage and carbon deposit on main contact surface, increases the resistance and temperature of the main contact, and causes the insulating material of the arc extinguish chamber to deteriorate. CB main contact wear can be determined from the accumulated interrupting current and the contact life curve provided by the CB manufacture. The IED will issue an alarm if the CB main contact wear exceeds the threshold setting.

B. CB Tripping Loop Health Supervision

Keeping the CB tripping loop in healthy condition is vital to power supply reliability. The indicator on the cabinet panel is conventionally used to determine the health of the CB tripping loop by the maintenance personnel. In order to monitor the status of the CB tripping loop more accurately, the monitoring points of the tripping loop are wired to the IED and the delay time is set. An alarm will be issued to alert the maintenance personnel when the duration of operating time is greater than the delay time or when the voltages of the contact points are abnormal.

C. CB Spring Energy Storage Status Supervision

Energy is stored in a spring through a chain by a motor and is released to operate the CB main contact when the CB closes or trips. The status of spring energy storage is an important indication of whether the CB can operate normally. In order to monitor the status of the CB spring energy storage more accurately, the internal logics of the IED are programmed. An alarm will be issued to alert the maintenance personnel when the operating time of the energy storing motor is greater than the setting time.

D. CB Operating Time Supervision

When the CB operating time is longer than the setting time, fault current may not be interrupted in time, which may result in incorrect trip and larger outage area. In order to monitor the CB operating time more accurately, the internal logics of the IED are programmed and the open/close signals of the CB auxiliary contacts 52a and 52b are connected to a timer. An alarm will be issued to alert the maintenance personnel when the CB closing or tripping time is greater than the setting time.

E. CB SF6 Gas Pressure Supervision

SF_6 gas at specific pressure is used in gas-insulated switchgears (GISs) as insulating and arc extinguishing medium. The density of the SF_6 gas must be monitored closely and a dry contact output signal indicates that the SF_6 gas pressure in the gas chamber is too low. The dry contact is connected to the IED and a delay time is preset. An alarm will be issued to alert the maintenance personnel when the SF_6 gas pressure is abnormal.

III. Programming CBM Functions into IED SEL-351A [15]

Field tests are performed at the Miaoli Chunan substation, Taichung Lilin substation and Tainan Baoan substation of Taiwan Power Company (Taipower) in this study. IED SEL-351A in the Baoan substation is taken as an example to illustrate how to set up the additional logic configuration and wire connection in order to apply CBM to the Nissin-Allis Electric gas circuit breaker (GCB).

A. CB Main Contact Wear Supervision Function

1) Parameters Settings

SEL-351A uses the accumulated rate of wear as the primary index and the accumulated number of interruptions and accumulated interrupting current as the secondary indices to estimate the CB main contact wear. The user can set the parameters according to the contact life curve provided by the CB manufacturer. The IED calculates and accumulates the interrupting current and rate of wear each time the CB trips. The IED will issues an alarm on the panel or through the digital output port or the communication port when the accumulated rate of wear reaches 100% to inform the maintenance personnel to perform CB internal inspection. The accumulated rate of wear is reset and the process is restarted after the CB maintenance is completed.

The following four steps are required to activate the CB main contact wear supervision function: CB monitor setting, CB monitor initiation, CB monitor data, and CB alarm setting and resetting.

2) Physical Connections

The analog inputs (I_a, I_b and I_c) of the IED are connected to the three phase currents (A, B and C) of the power lines.

B. CB Tripping Loop Health Supervision Function

1) Parameters Settings

The logic configuration of the CB tripping loop health supervision function is shown in Fig. 1. The parameters settings are as follow.

OUT105 : SV3T
SV3 : !IN105*52A
SV3PU :60

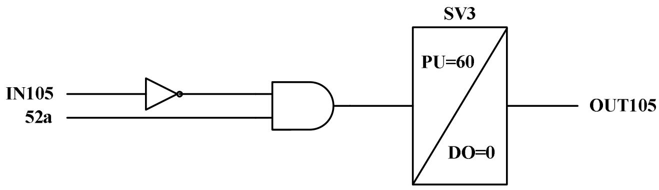

Fig. 1 The logic configuration of the CB tripping loop health supervision function

2) Physical Connections

The physical connections of the CB tripping loop health supervision function are shown in Fig. 2 The DI/IN105 (DI: digital input) of the IED is connected to the 1P and 1T of the CB.

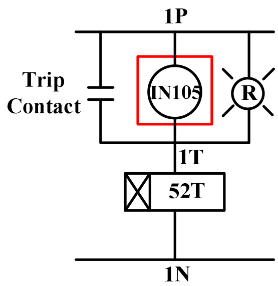

Fig. 2 The physical connections of the CB tripping loop health supervision function

C. CB spring Energy Storage Status Supervision Function

1) Parameters Settings

The logic configuration of the CB spring energy storage status supervision function is shown in Fig. 3. The parameters settings are as follow.

SET9 :/IN106
RST9 :\IN106
SV7 :52A+LT9
SV7PU :600
SET5 :SV7T*IN106
RST5 :!IN106
OUT106 :LT5

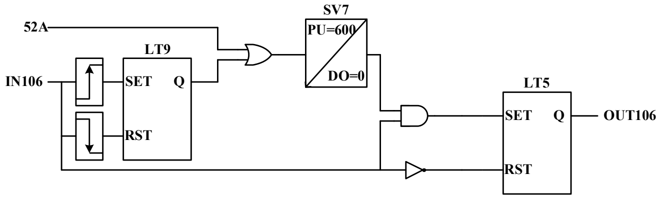

Fig. 3 The logic configuration of the CB spring energy storage status supervision function

2) Physical Connections

The physical connections of the CB spring energy storage status supervision function are shown in Fig. 4. The DI/IN106 of the IED is connected to the 1P of the CB and one contact of the limit switch LS2, and the other contact of the LS2 is connected to the 1N of the CB.

Note: The limit switch LS1 is preferred in the series connection. However, because LS1 does not have a spare contact and LS1 is interlinked with LS2, LS2 is used instead of LS1 without compromising the supervision function.

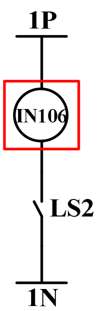

Fig. 4 The physical connections of the CB spring energy storage status supervision function

D.CB Operating Time Supervision Function

1) Parameters Settings

The logic configuration of the CB operating time supervision function is shown in Fig. 5. The parameters settings are as follow.

SET7 :/IN103
RST7 :/52A
SET8 :\IN105*52A
RST8 :\52A
SV4 :LT7+LT8
SV4PU :5
SV4DO :9
OUT104 :SV4T

2) Physical Connections

The physical connections of the CB closing time supervision function are shown in Fig. 6. The DI/IN103 of the IED is connected to the 1C and 1N of the CB. The physical connections of the CB tripping time supervision function are the same as the CB tripping loop health supervision function shown in Fig. 2.

The summaries of IED digital input/output usage and programmed alarms are listed in Table I.

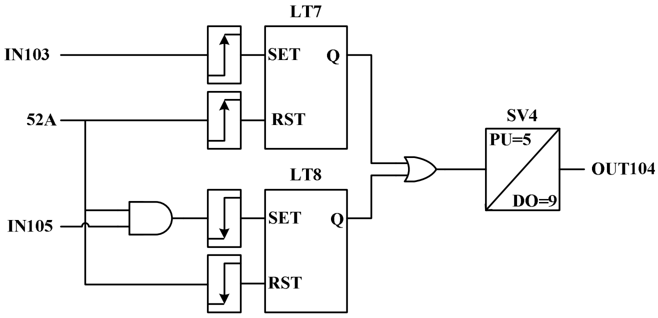

Fig. 5 The logic configuration of the CB operating time supervision function

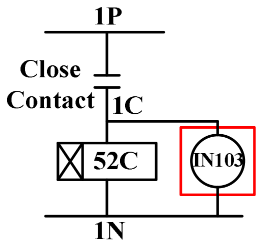

Fig. 6 The physical connections of the CB closing time supervision function

IV. CB CBM Management Platform Framework

The framework of the CB CBM management platform constructed in this study is shown in Fig. 7. A CBM monitoring system mainframe is established with a SCADA system built by using the Elipse Power Studio software. An Ethernet and fiber optic network is used as communication media between the control center and substations [16].

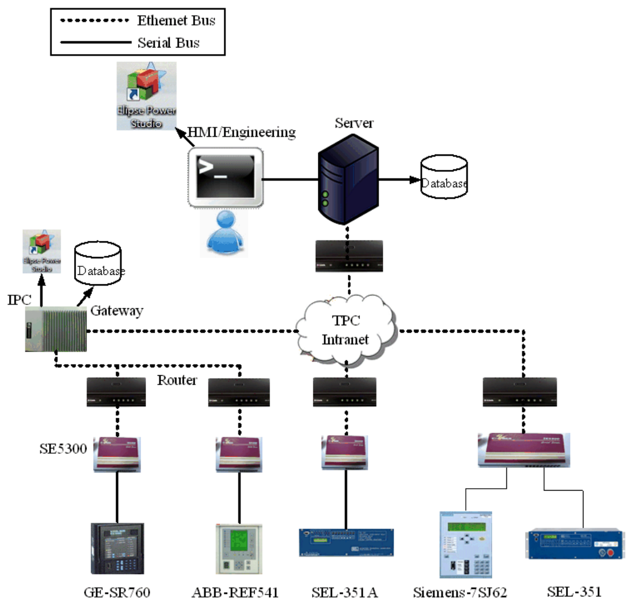

Fig. 7 The framework of the CB CBM management platform

A. The Elipse Power Studio Software

The Elipse Power Studio software is developed by the Elipse software company and is used in this study to develop drivers for various communication protocols, to design customized HMI of SCADA system, and to support a conventional general-purpose database as well as communication platforms such as Access, SQL Server, OPC Server, etc.

The substation CBs maintenance data from all IEDs are collected and integrated by the Elipse Power Studio software, while information such as the electrical parameters, alarms and event recorders of each CB can be displayed through the HMI and can be conveniently viewed by remote management personnel using IE browsers.

B. IEDs in the TPC Baoan Distribution System

Dedicated drivers are needed for logic configuration and parameters setting for different IEDs. RS-232 ports are generally used for communication except for ABB_REF541 which has its own type of communication port. Jumper wires are needed for SEL_351A and Siemens_7SJ62 to connect to the configuration computer. The communication protocols and drivers of the IEDs are listed in Table II.

C. Field Test Environment

Field tests are performed at the Miaoli Chunan substation, Taichung Lilin substation and Tainan Baoan substation of Taipower.

The Siemens-7SJ62 IED, which is connected to the CB of the substation power supply transformer (SSTR) for overcurrent protection in the Chunan substation, is linked to the serial device server via a RS-485 line, and the LAN Port of the serial device server is connected to the switch via a RJ-45 line so that a remote server can access the CB CBM data through Taipower Intranet.

The GE-SR760 and ABB-REF541 IED, which are connected to the CBs of two shunt compensation capacitor banks (SCCBs) for overcurrent protection in the Lilin substation, are linked via RS-485 lines to the serial device server which is linked to an industrial personal computer (IPC) with the Elipse Power Studio software installed to processed and integrate the on-site data detected and collected by the IEDs. There is no need for remote data processing because each IPC has its own database of local substation IED data. The CB CBM information can be displayed on a remote server through HMI by linking the server with the IPCs.

The SEL-351A IED, which is connected to the CB of a SCCB for overcurrent protection in the Baoan substation, is linked to the serial device server via a RS-422 line. As in the Chunan substation case, a remote server can access the CB CBM data through Taipower Intranet.

D. CB CBM Management Platform

After the communication network and the HMI of SCADA system are constructed, data collected by the IEDs are sent to the CBM management platform to build a database. The layout of substations and the CB CBM platform is shown in Fig. 8.

The operations of a CB can be shown dynamically by the alarms of the HMI of SCADA system and the historic events recorded in the database. During normal condition, the electrical parameters of power lines and the operations of CBs can be observed through HMI, and the measured analog data and status may be stored periodically in the event log. During CB malfunction condition, the equipment fault condition can be detected by IEDs, the fault location can be determined from the status of the faulted line and equipment through HMI, an alarm can be issued to the maintenance personnel to clear the fault, and the fault alarm is recorded in the alarm historic log for future reference by the maintenance personnel.

The display of SEL-351A parameters measurement result is shown in Fig. 9, where parameters such as the phase currents, line voltages, active power, reactive power and frequency are included. The display of CB maintenance status information and analog monitoring data is shown in Fig. 10. The CB status information shows CB real time operating condition as well as main contact wear upper limit alarm, spring energy storage time alarm and operating time alarm. The analog monitoring data includes the accumulated rate of wear, contact wear per phase, CB spring energy storage time, upper and lower limits of CB spring energy storage time, CB closing time and tripping time, the degree of deterioration, total times of use and other maintenance information. Maintenance can be scheduled easily by comparing the accumulated quantities with the setting values provided by the manufacturer. The real-time as well as historic alarms can be displayed on the alarm event log monitoring window as shown in Fig. 11.

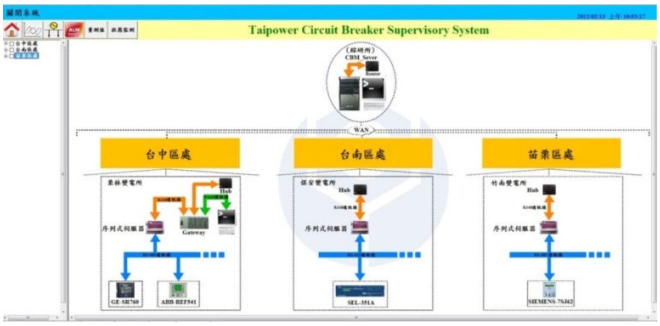

Fig. 8 The layout of substations and the CB CBM platform

Fig. 9 The display of SEL-351A parameters measurement result

Fig. 10 The display of CB analog monitoring data and maintenance status information

V. Conclusion

IEDs are used to monitor and acquire CB electrical and mechanical parameters in this study. The collected data may be used for real-time analysis and diagnosis, to schedule CB maintenance, to reduce CB maintenance cost and to minimize loss caused by CB failures.

Monitoring software is used to integrate the maintenance information of CBs of all substations and a CB CBM maintenance management platform is constructed. Utility Intranet is used by the CBM maintenance management platform as communication media to reduce the communication facility investment. HMI in the forms of web pages are designed to provide users with unified and free browsing interface and different access rights are authorized to different levels of users for data security and protection.

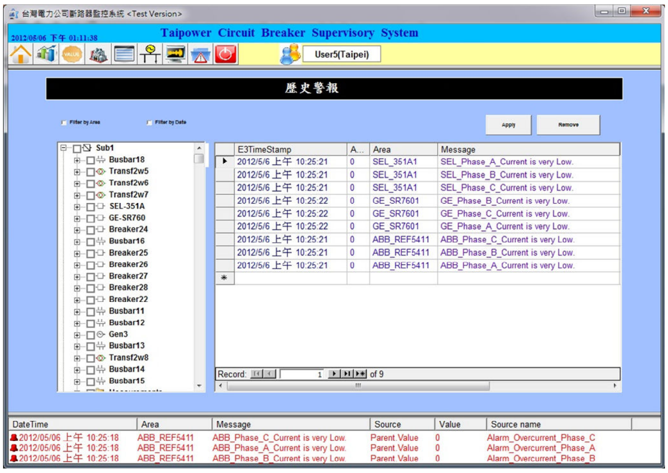

Fig. 11 The alarm event log monitoring window

TABLE I
SUMMARIES OF IED DIGITAL INPUT/OUTPUT USAGE AND PROGRAMMED ALARMS*

Unused contacts		
IN101	OUT101	OUT102 / OUT103
Contacts used		
IED contacts	**Programmed CB supervision function**	**To contacts**
IN102	Operating/maintenance switching	1P and 1N (CB)
IN103	CB operating time	1C and 1N (closing coil of CB)
IN104	SF_6 gas pressure	AN1 (CB) and F4 (fault indicator block)
IN105	Tripping loop health, operating time	1P and 1T (CB)
IN106	Spring energy storage status	1P and LS2 (CB)
Programmed alarms		
	BCW (OUT107)	Main contact wear alarm
	SV3T (OUT105)	Tripping loop health alarm
	LT5 (OUT106)	Spring energy storage status alarm
	SV4T (OUT104)	Operating time alarm

*Configured during the field test in this study and may be changed according to situations

TABLE II
THE COMMUNICATION PROTOCOLS AND DRIVERS OF THE IEDS

IED	Communication Protocol	Driver Version
SEL_351A	SEL Protocol	AcSELerator QuickSetR version 4.17.2.0
Siemens_7SJ62	Modbus	DIGSI 4 version 4.83.11
ABB_REF541	SPABUS	CAP505 version 2.4.0
GE_SR760	Modbus	EnerVista 750/760 version 7.30

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