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New Supervisory Control and Data Acquisition (SCADA) Based Fault Isolation System for Low Voltage Distribution Systems

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Abstract**—**This paper proposes a new supervisory control and data acquisition (SCADA) based fault isolation system on the low voltage (415/240 V) distribution system. It presents a customized distribution automation system (DAS) for automatic operation and secure fault isolation tested in the Malaysian utility distribution system; Tenaga Nasional Berhad (TNB) distribution system. It presents the first research work on customer side automation for operating and controlling between the consumer and the substation in an automated manner. The paper focuses on the development of very secure automated fault isolation work tested to TNB distribution operating principles as the fault is detected, identified, isolated and cleared in few seconds by just clicking the mouse of laptop or desktop connected to the system. Supervisory Control and Data Acquisition (SCADA) technique has been developed and utilized to build Human Machine Interface (HMI) that provides a Graphical User Interface (GUI) functions for the engineers and technicians to monitor and control the system. Microprocessor based Remote Monitoring Devices have been used for customized software integrated to the hardware. Power Line Carrier (PLC) has been used as communication media between the consumer and the substation. As a result, complete DAS and fault isolation system has been developed for remote automated operation, cost reduction, maintenance time saving and less human intervention during faults conditions.

Keywords**-Distribution Automation System (DAS); Low Voltage Distribution System; HMI& GUI SCADA; and PLC**

I. INTRODUCTION

This paper presents a Distribution automation system as an integrated system for the digital automation of distribution sub-station, customers and user functions (engineers & technicians). Faults caused by over-current, earth leakage current and other disturbances create interruptions of electricity supply to the customers. The engineers and technicians have to manually locate the fault point and spend a plenty of time and this tedious work may last for extended periods of time. After the introduction of fault management, the fault is detected by energizing section by section of distribution line until the protective relay trips the feeding circuit breaker of the fault zone. These operations are mostly based on manual and automatic operations.

The advent of microprocessor and the introduction of numerical relays have improved the function of fault management system. Now it is possible to record the fault currents at the feeding distribution substations and the restoration process is also done automatically and is accelerated faster.

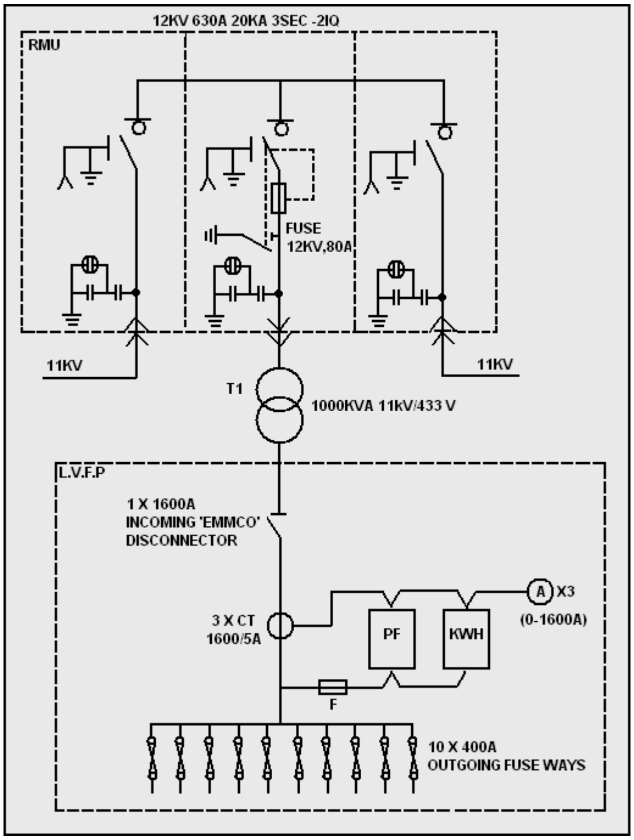

Figure1. Typical Substation

In this paper, a fault management system for low distribution automation system that is included fault detection, fault location, fault isolation and electricity supply restoration is presented. The algorithm is based on ladder logic diagram. The simulation results are compared with the laboratory results.

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II. SERVICE SUBSTATION PANEL

Fig. 1 shows a typical compact substation which is also referred as Ring Main Unit (RMU). 12KV, 630A, 20KVA RMU is the substation that supplies power to Low Voltage Feeder Panel. A three-phase, 1000KVA, 11/0.433 kV transformer is used to step down 11kV to 433V before supplying to Low Voltage Feeder Panel (LVFP).

The outgoing loads are protected by fuses which have to be replaced if fault occurs. In this research project, fuses have been replaced by circuit breakers which can be manually or automatically controlled for switching operation and are not frequently replaced as shown in Fig. 1. The typical panel shown in Fig.1 uses power factor meter, kilowatt hour meter and three ammeters to provide reading of power factor, kilowatt hour and three phase current values. Instead of using different types of meters to provide the reading, a single power analyzer is used in this research to provide the same reading and is also able to send the data to the controller using mod-bus protocol. In this research, the service substation panel consists of four feeder points and each feeder is connected to the customer service substation panel as shown in Fig.2. A relay which is the combination of over-current and earth leakage relay. The 630A, 50kVA, 415V MCCB is used as the main MCCB. The MCCBs are switched on or off by using customized solenoids by replacing the traditional fuses used by TNB.

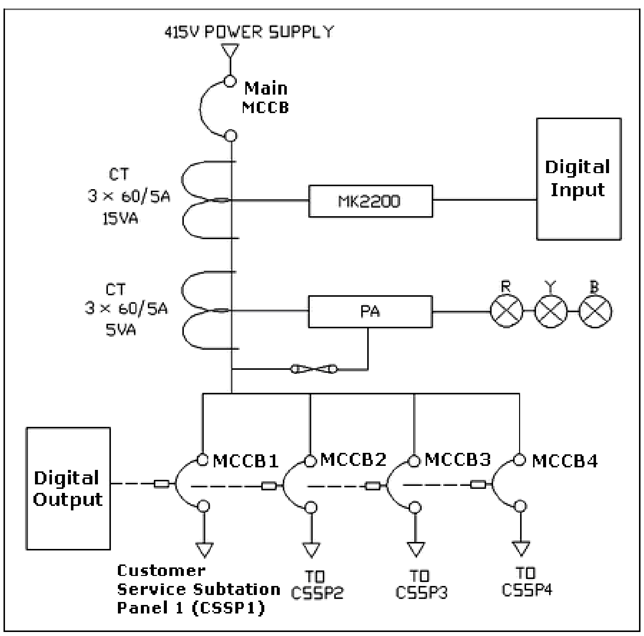


Figure 2. Schematic Diagram of Service Substation

III. EXPERIMENTAL SETUP: LEAKAGE AND OVER-CURRENT RELAY

This Relay which is combined over-current and Earth Fault (EF) relay is a digital microprocessor based relay. R1 contact of the relay is the dedicated trip contact and cannot be programmed. Either earth fault (EF) or over-current will activate this contact. The relay output remains in the on state until the relay is reset either manually or electrically. Generally, the relay output is fed to the shunt trip of a protective device such as CB which isolates the faulted circuit. The relay must be accompanied by a Circuit Breaker (CB) or a fuse.

IV. EXPERIMENTAL SETUP: FAULT ISOLATION METHOD

This research is based on open loop distribution system which means that the loads are connected to two feeders and any section of the feeder can be isolated without interruption. Thus, the average outage time is reduced to the time required to locate the fault and do the necessary switching to restore the service. In this research, the switching can be performed either automatically or manually.

The logic programming is based on this flowchart and C language programming is used. The flow chart is shown in Fig. 3. By using a flowchart, the sequences of operations were determined with the visibility of all the automated equipment and their parameters. Based on the flowchart and the related programming, there are five major actions which are the status of 'power input', mode state, the status of 'reset program', execute 'Operation of Logic Up-Counter (OLUC)' and execute 'Operation of Logic Down-Counter (OLDC)'.

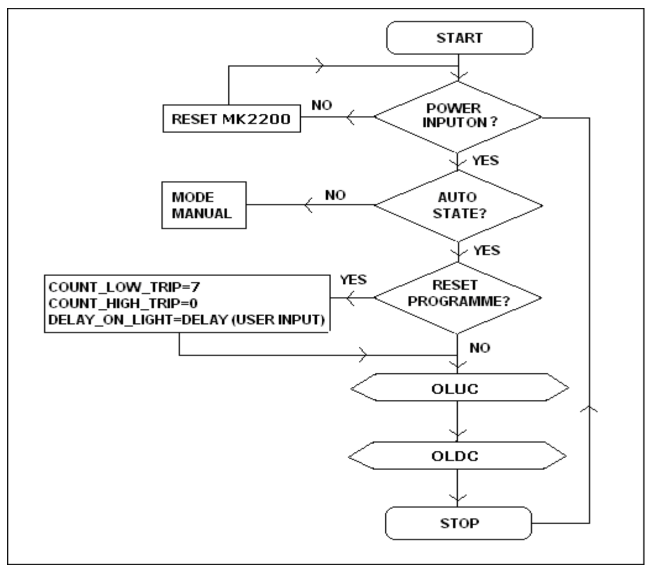


Figure 3. General Flow Chart

First step is to check the power input whether it is turned on or turned off. The power input is referred to digital relay output.

If no fault condition is detected by the relay, the power input is turned on (Normally Close (NC)). When the relay detects the fault condition, power input is turned off (Normally Open (NO)). In this case, the relay is resetted by using a delay timer and power input is turned on automatically.

There are two modes of operations in the developed systems which are manual mode and automatic mode. If automatic mode is selected, when fault occurs, the fault point is isolated automatically by activating the 'start low check' and 'start high check'.

'OLUC' and 'OLDC' are executed only when the fault point is isolated and the unaffected points are operated as normal condition. Once the fault point is operated as normal, the 'reset program' button is pressed. This button resets back the counter to initial value and executes the 'start low check' and 'start high check' again.

'OLUC' checks the logic of up-counter which is from left to right while 'OLDC' checks the logic of down-counter which is from right to left. This is described in Fig. 4. If the manual mode is switched on, when fault occurs, the checking is done manually by the operator. The developed Graphical User Interface (GUI) provides buttons to control the switching of the loads.

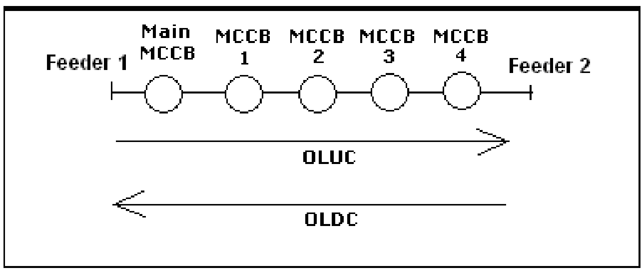


Figure 4. OLUC and OLDC Descriptions

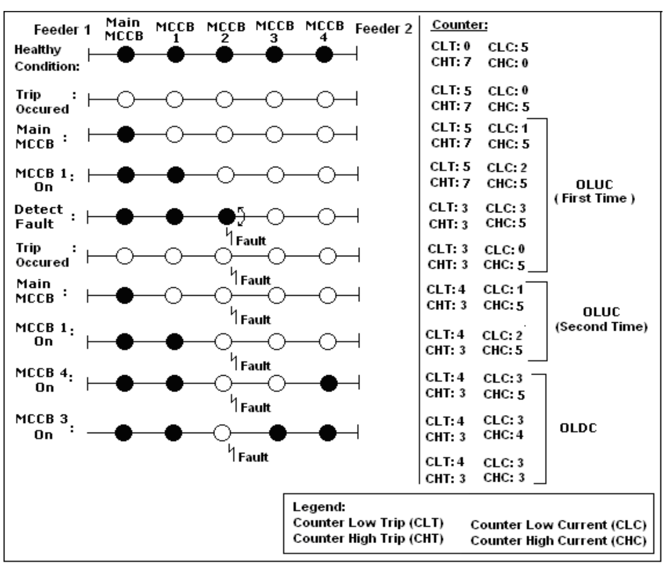


Figure 5. Fault Isolation Method

Fig. 5 illustrates the method used in this project. During no fault condition, all MCCBs are practically switched on.

Two counters are used during OLUC which are the Counter Low Trip (CLT) and Counter Low Current (CLC). The CLT is the counter to store the zone which is under fault condition. The CLC will be increased by one on each time zone. Another two counters are used for OLDC which are the Counter High Trip (CHT) and Counter High Current (CHC). When fault occurs, all MCCBs are switched off. OLUC will start to turn on each zone in sequence until it reaches to the fault zone. Once the fault zone is reached, a trip occurs and all MCCBs are switched off once again. This time, CLC is assigned to CLT to indicate which zones are the fault zones. From the value of CLT, CHT is calculated. The OLUC will start to turn on the Main MCCB and MCCB1 but this time MCCB 2 will remain off. The OLDC will start to turn on MCCB 4 and MCCB 3. Fig. 6 and Fig. 7 show the flowchart of the counter method used in this research project.

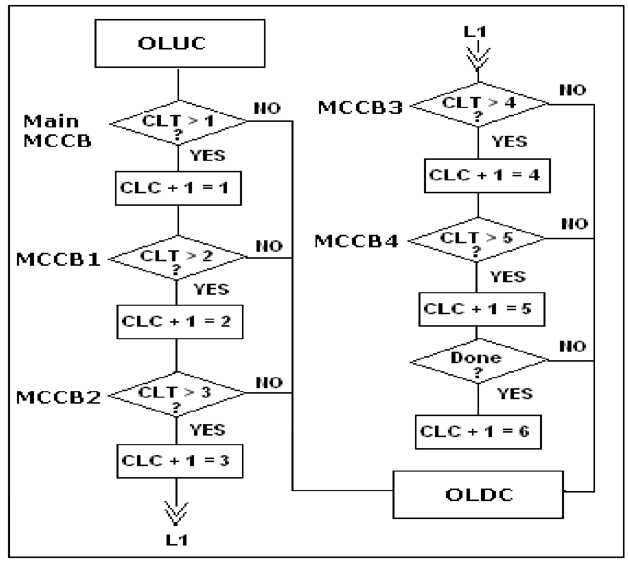


Figure 6. OLUC Flow Chart

TABLE 1. EXPERIMENTAL RESULTS (AUTOMATIC MODE)

Service Substation Panel		Result				
		■ On □ Off				
		MCCB				
No	Action	Main	1	2	3	4
1	Reset system	■	■	■	■	■
2	Main MCCB fault	□	□	□	□	□
3	Reset system	■	■	■	■	■
4	MCCB1 fault	■	□	■	■	■
5	Reset system	■	■	■	■	■
6	MCCB2 fault	■	■	□	■	■
7	Reset system	■	■	■	■	■
8	MCCB3 fault	■	■	■	□	■
9	Reset system	■	■	■	■	■
10	MCCB4 fault	■	■	■	■	□
11	Reset system	■	■	■	■	■

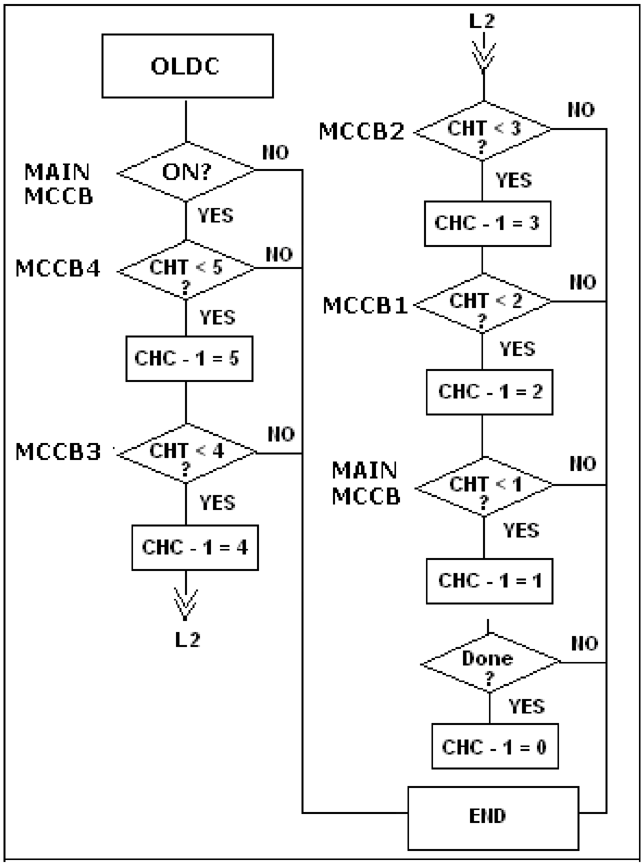


Figure 7. OLDC Flow Chart

V. RESULTS

The experimental results are shown in Table I. By conducting the actual experiments, the appropriate delay timer for controlling the solenoid operation is obtained and operated. By conducting the experiments, the phase current waveforms are obtained as shown in Fig.8 and Fig.9.

A. Laboratory Results

The digital relays are fitted with test and reset buttons in order to conduct testing and commissioning of the relays. By using this test button, trip can be manually triggered.

Reset system is to restore electricity supply to all the MCCB. When the main MCCB is at fault, the experiment results show that all the MCCBs will not be turned on. The system is restored back to normal operation. The MCCB 1 is forced to trip. The system will turn on the main MCCB, MCCB2, MCCB3 and MCCB4 but MCCB1 is remained off. This experiment is repeated as shown in Table III.

B. Phase Current Waveforms

By conducting the actual experiments, the appropriate delay timer for controlling the solenoid operation in the service substation is obtained.

Table II shows the total restoration time for the service substation panel. In the service substation panel, if the delay timer is set too fast, the solenoid will not be able to switch on or off the MCCB. The minimum delay timer needs to be set to five seconds for proper switching operation of the MCCBs by the solenoids. This delay timer is only tested for the type of MCCBs used in this research. Different types of MCCBs may give different results.

TABLE II. TOTAL MINIMUM RESTORATION TIME

Duration 1 (Second)	**Duration 2 (Second)**	**Total Time (Second)**
25	25	50

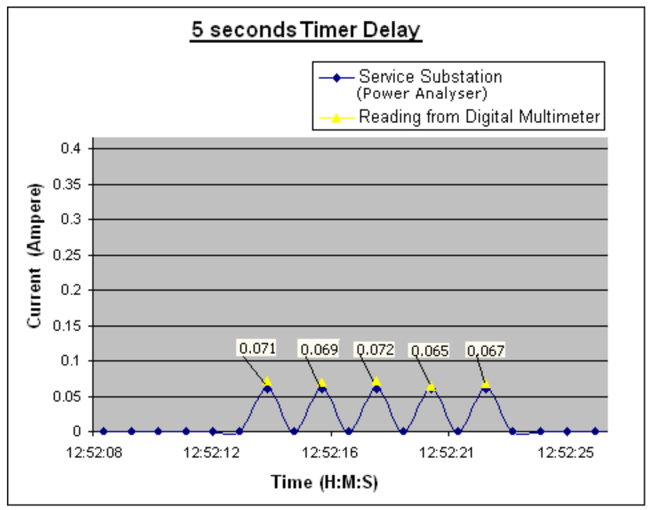


Figure 8. Phase Current Waveform

Fig.8 shows graphs built using from experiment to show the changes of phase current for the service substation panel that is not connected to the customer service substation. The first phase current wave is to turn on the main MCCB. The following phase current waves are to turn on MCCB1, MCCB2, MCCB3 and MCCB4. In Fig. 8, the reading from the power analyzer is compared with the reading measured by digital multi-meter. In this experiment, the delay timer in the service substation panel is set to five seconds. In Table 3, the reading from the power analyzer is lower compared to the reading from the digital multi-meter

TABLE III. COMPARISON OF PHASE CURRENT READING BETWEEN POWER ANALYZER AND DIGITAL MULTI-METER

Description	**Power Analyzer Phase Current (Ampere)**	**Digital Multi-meter Phase Current (Ampere)**
Main MCCB On	16	16
MCCB 1 On	16	16

MCCB 2 On	16	16
MCCB 3 On	16	16
MCCB 4 On	16	16

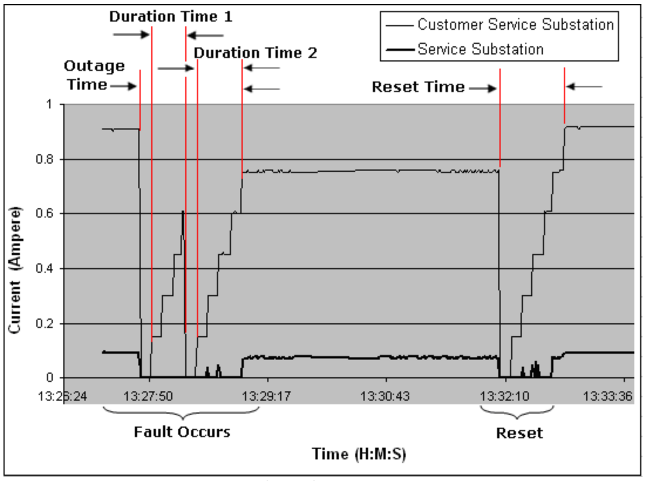


Figure 9. Phase Current Waveform for Customer Service Substation Panel and Service Substation Panel

Fig. 9 shows the phase current waveform where service substation panel is connected to one customer service substation panel. 40 watt bulbs are used as the loads at customer side. In Fig. 9, the phase current waveform for the service substation panel has changed by comparing with the phase current waveform in Fig.8.

The duration time 1 is the time period that is needed by the system to identify which load is in fault load. Duration time 2 is the time period that is needed by the system to isolate the faulted load and restore electricity supply to the rest of the healthy loads. Outage time is the duration of time that the customer experienced electricity supply disruption. Reset time is the total time needed to restore electricity supply to all the loads including the faulted load that has already been repaired.

C. SCADA Results

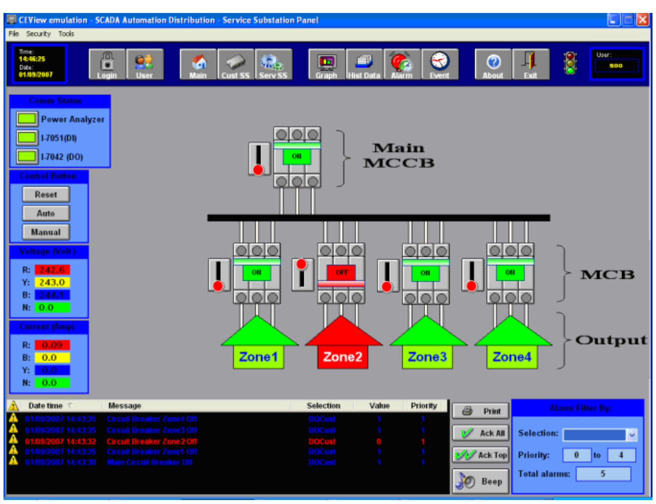


Figure 10. HMI and SCADA Applications for Service Substation Panel

Fig. 10 shows the HMI and SCADA applications for service substation panel developed by using the proprietary software. The operator can operate manually the MCCBs by pressing the Manual Button.

Fig.11 shows the status of the Main MCCB, other MCBs and the outputs. If fault occurs, the MCB and the outputs will change to red colors pattern showing that the MCB is off status. In this case, alarms will be triggered and displayed on the screen. Fig. 12 shows the alarm messages. In the alarm list, the blue color text indicates that the output has changed to healthy status and the red color text indicates that the output is still remained unhealthy. Once the fault points have been checked and repaired, the "Reset" button from the control button in Fig. 13 is pressed to restore the power supply to all the outputs.

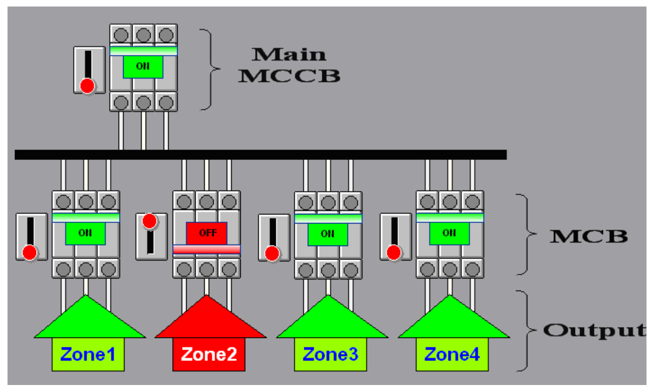
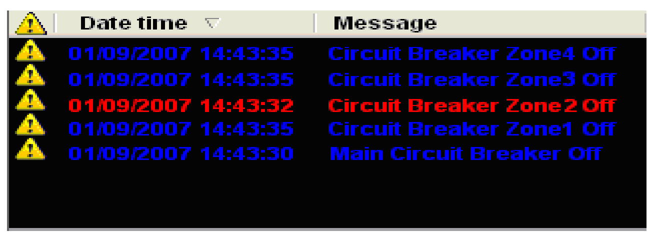


Figure 11. MCCBs - Service Substation



Fiure 12. Alarm Messages

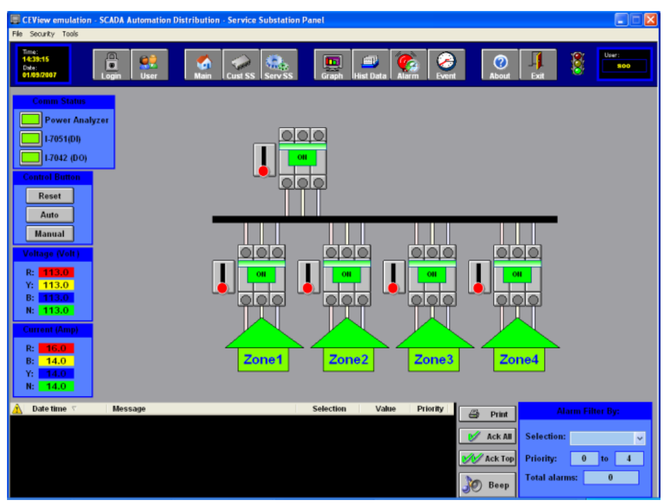


Figure 12. Healthy Condition at Service Substation Panel

V. CONCLUSIONS

The contribution of this research includes developing a complete fault isolation algorithm based on an open loop distribution system as TNB distribution is an open loop distribution type.

In an open loop distribution system, two feeders are used to provide electricity supply to the loads. During fault conditions, any section of the feeder can be isolated without interruption. The algorithm is developed to check the fault point starting from the one of the section feeders or OLUC algorithm and repeated with another section feeders or OLDC algorithm. At the beginning, this algorithm needs to clarify with which point is the fault point by supplying the power to each load after the fault is detected by the relay. When the fault point is being activated, the MK2200 detects the fault and trip mechanism is operated. The algorithm will find the false point and reset the relay to restore the power supply to the loads. This time, only the un-faulted point will be restored.

VI. ACKNOWLEDGMENT

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