

**DEVELOPMENT OF HUMAN MACHINE INTERFACE (HMI) WITH CUSTOMIZED  
SCADA SYSTEM FOR LOW VOLTAGE DISTRIBUTION AUTOMATION SYSTEM**

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Paper Presented at the International Conference on Engineering and ICT (ICEI 2007), 27 -28 Nov 2007, Hotel Equatorial Melaka.

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# Development of Human Machine Interface (HMI) with Customized SCADA System for Low Voltage Distribution Automation System

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**Abstract--** This paper presents the development of Human Machine Interface (HMI) for customized Supervisory Control and Data Acquisition (SCADA) at customer side distribution automation system (DAS). It is operate and control the low voltage (LV) down stream of 415/240V by using the Tenaga Nasional Berhad (TNB) distribution system. SCADA based Remote Terminal Unit (RTU) along with power line communication (PLC) system are used for DAS development that practically simulates the LV distribution system functions in an automated manner. It is the first DAS research work done on customer side substation for operating and controlling between the consumer side system and the substation. Most of the work is focused on building HMI that provides a graphical operator interface function to monitor the system. The HMI of SCADA system is developed using customized software and an RTU microprocessor and its software implements for LV operation and control purposes.

**Index Terms--** HMI, SCADA Software, Graphical User Interface (GUI), Alarm, Event, Trending and Security System.

## I. INTRODUCTION

The SCADA software and service elements may include operator interface software, historical databases, report generators and systems documentation and training [1].

SCADA software can be divided into two types, proprietary or open [2]. Open Software is gaining more popularity because of its ability to mix different manufacturer's equipment on the same system compared to the proprietary software which was developed by the company to communicate to their own hardware. Citect and WonderWare are just two of the open software packages available on the market for SCADA systems [3].

Compania Nacional de Fuerza y Luz (CNFL) which is the main power distribution company in Costa Rica is among the utility company that is currently using wonderware solution to develop their automation system. [4]

International Standards Organization (ISO) has developed open systems interconnection (OSI) model in objective to provide a framework for the coordination of standards

development within that common framework. The software problems of communication between equipment from any

manufacturer can be accomplished by following this standard. [5]

In 1988, the International Electro-technical Commission (IEC) began publishing a standard framework entitled 'IEC 870 Tele-control equipment and systems'. This was developed in stages from 1900 to 1995 to completely define an open protocol for SCADA communications. During the same period, which IEC 870 was progressively released, the DNP3 protocol was developed and released in North America. DNP3 was designed specifically for SCADA applications. [6]

Center operator interface hardware mostly often consists of standard PC computers and LCD monitors with appropriate desks and consoles. Medium and larger systems are normally built with redundant display capability with seating for two or more operator personal. Reports and sometimes alarm systems are also furnished. UPS hardware is normally provided to protect against power outages until backup generation can be placed on-line.

## II. OPERATOR INTERFACE SOFTWARE

An important aspect of every SCADA system is the computer software used within the system. When software is well defined, designed, written, checked, and tested, a successful SCADA system will likely be produced. Many SCADA systems employ commercial propriety software upon which the SCADA system is developed. A SCADA software used in this research is chosen based on the flexibility to interface with different types of software and hardware and provides friendly features in developing a user interface.

Configurable operator interface software provides a graphical operator interface (GUI) function to monitor processes. The monitoring task is a challenging task for user especially when the substation panel contains so many different parts. The user not only needs to monitor the equipment and status of the equipment, but they also need to understand how the equipment and the devices are integrated to one another. This requires a balance of understanding what information is pertinent to display and what information would cause information overload.

Operator interface software includes a library of standard graphical symbols, many of which would however not be applicable to the type of applications encountered in distribution system. The SCADA software in this research does not provide symbols used in distribution system but

This research was supported by Universiti Teknikal Malaysia (UTeM). W.L. Soo is with the Department of Electrical Engineering, UTeM, Malaysia. M.M. Ahmed is with the Department of Electrical Engineering, UTeM, Malaysia (e-mail: musse@UTeM.edu.my).

these symbols can be easily created. All such these symbols have been created for the distribution system in this research.

Standard windows editing facilities are provided such as zooming, re-sizing and scrolling. On-line configuration and customization of the MMI is possible for the users with the appropriate privileges. Links can be created between display pages to navigate from one view to another. Users are allocated to groups, which have the definition of read/write access privileges to the process parameters in the system and this feature is necessary so that the system should not be available to the ordinary operator to do any changes on the process parameters.

### III. HARDWARE INTERGRATION AND INTERFACING

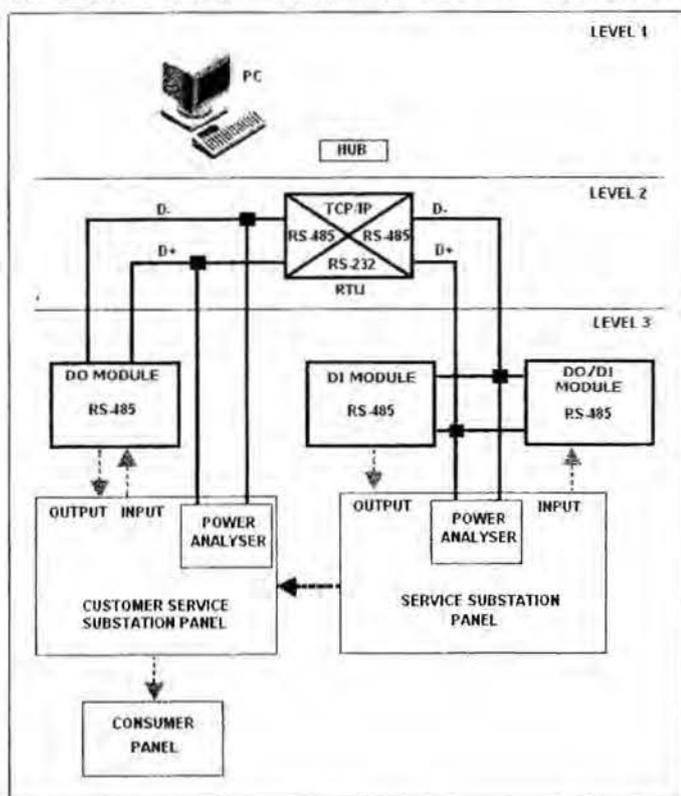


Fig. 1. System Architecture

The system architecture for this research is divided into three levels as shown in Fig. 1. Level 1 consists of SCADA equipment or Human Machine Interface (HMI). Personal computer is equipped with graphical user interface (GUI) that runs under the Microsoft Windows XP platform using a SCADA software. The GUI provides monitoring for service substation and customer service substation, real-time data, data trending, data archiving, display and recoding alarm messages, show communication status of the system and control execution. Systems operations personnel use this equipment to control and monitor the input and output remotely.

Level 2 consists of embedded Ethernet RTU. RTU communicate using a master-slave technique. In this

technique, the master device will initiate transactions while the slave devices will respond by supplying the requested data to the master, or by taking the action requested in the query. The control program is downloaded into the RTU. The logic programming is configured by using RTU software manufactured by vendor. RTU is responsible for communicating with the supervisory system using TCP/IP protocol. RTU also acts as converter to link the SCADA equipment to the digital input (DI) module, digital output (DO) module and DI/DO module using RS485 protocol. The RTU also receives data from power analyzer by using RS-485 port using modbus protocol. RTU can handle control functions without the PC in real time.

Level 3 consists of I/O modules and three panels. Three types of I/O modules are used which are the DI module, DO module and combination of DI/DO module. DI/DO module receives signal from ELCB in the customer service substation panel. It then converts the signal into RS485 standard signal and transfers to RS485 network. This signal is received by RTU. DI/DO module receives signal from the RTU to trigger certain actions to the relays as output devices. DI module and DO module are responsible to receive and send signals to input and output of service panel. Power analyzer is a power measurement metering device that displays volts, amps, watt, vars and etc. It sends data directly to the controllers to be displayed at the monitor.

In actual practice, service substation panel is connected to more than one customer service substation panel. In this research, service substation panel is only connected to one customer service substation panel. Customer service substation panel is connected to the consumer panel. In this case, the consumer panel consists of lights as the control loads. Fig. 2 describes the wiring diagram based on the system architecture.

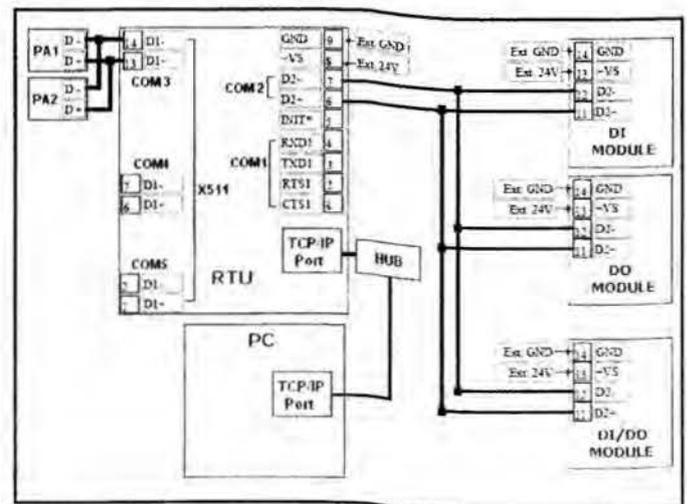


Fig. 2. Communication Wiring Diagram

TABLE 1  
COMMUNICATION DEVICE SETTING

Device	Set ID	Com Port	Baud rate	IP Address
DO MODULE	0x01	2	9600	-
DI MODULE	0x02	2	9600	-
DO/DI MODULE	0x03	2	9600	-
Power Analyzer, PA1	0x01	3	9600	-
Power Analyzer, PA2	0x02	3	9600	-
RTU	0x01	TCP/IP	-	192.168.255.1
PC	-	TCP/IP	-	-

In this research, RTU communicate using a master-slave technique. The modbus protocol provides for one master and up to 246 slaves. Only the master initiates a transaction to provide a real time data to the HMI. All slaves need to have their own address or set ID. This is shown in TABLE 1. The master which is the RTU can initiate a broadcast message to all slaves. Slaves return a message called a 'response' to queries that are addressed to them individually. The Modbus protocol provides frames for the transmission of messages between master and slaves. The information in the message is the address of the intended receiver, what the receiver must do, the data needed to perform the action and a means of checking errors.

#### IV. SCADA SOFTWARE DEVELOPMENT ENVIRONMENT

This SCADA application consists of animated operator interface screens, communication drivers, tags databases and additional modules such as alarm monitors, logic, trend charts, recipes, schedulers and security systems. This SCADA application interfaces with industrial I/O systems and other Windows applications in the run-time environment using Open Database Connectivity (ODBC), Dynamic Data Exchange (DDE), Network Dynamic Data Exchange (NetDDE), OpenGL Performance Characterization (OPC), or TCP/IP protocols. The user can also operate the application through a standard Web browser such as Internet Explorer and Netscape.

The workspace window is a user-friendly interface that enables the user to find any application components such as tag, screens, and worksheets quickly and easily. The workspace contains four tabs which are database, graphics, tasks and comm (refer to communication). Database provides access to all databases tags and security-system components configured for the current application. Graphics provide access to all screens and symbols in the application. Tasks provide access to all task worksheets in the application. Comm provides access to all drivers configured to establish communications with another devices or software programs using available protocols.

#### V. LAYOUT SCREENS ON PC BASED SOFTWARE

User Interfaces are designed to facilitate both general process awareness and specific tasks that are described in Fig. 3.

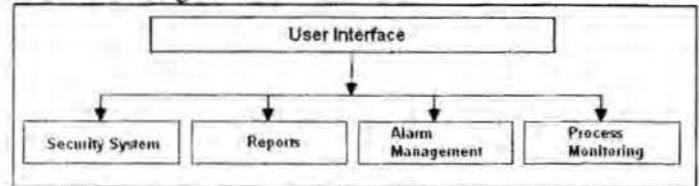


Fig. 3. User Interface

##### A. Process Monitoring

The states of equipment or single process are represented by graphical representation. It gives a quick overview about the condition of a single process or equipment. Value is display by text representation. The designing of the display can only be achieved by following few steps described in Fig. 4.

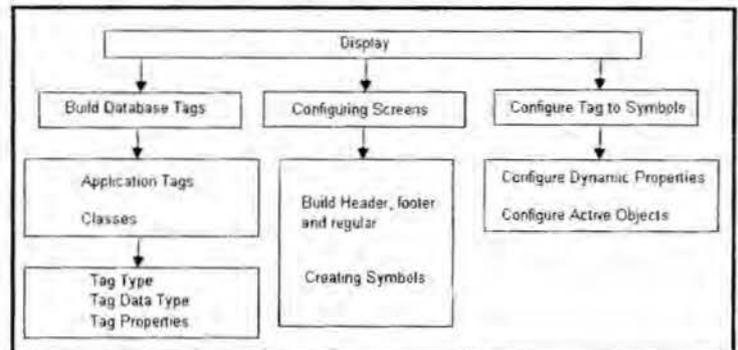


Fig. 4. Display Configuration

Tags are variables that are designed to receive results from expressions specified in screens and worksheets. In designing the tag, this SCADA software allows user to create a basic tags, array tags, class tags and indirect tags. Another consideration when designing a tag is what types of data the tag will receive. Most of the tags are assigned with boolean or digital variables that represent 0 or 1. This data type is suitable to use for turning objects 'OFF' and 'ON' or for closing and opening objects. Tag properties are attributes that are inherent to a database tag such as minimum and maximum values, size, description and so forth.

Application tags contain tags created during application development such as screen tags or tags that read from or write to field equipment. Class contains compound tags, called class tags, created to associate a set of values rather than a single value with an object. Fig. 5 describes class CTank. CTank contains class member which are temperature, pressure and level.

Class: CTank			
	Name	Type	Description
1	temperature	Real	Tank temperature
2	pressure	Real	Tank pressure
3	level	Real	Tank level
4			
5			

Fig. 5. Sample C Tank Worksheet

This SCADA application screen consists of three basic areas which are header, footer and regular. Header is an object located at the top screen to provide standard information such as date and time. Footer is an object located at the bottom of screen such as an alarm object showing the last alarm. Regular is an area between the header and footer to provide information about processes, alarm screens, trends, and so forth. This SCADA software allows building a symbol that represents certain equipment in the substation panel. Symbols can be built by grouping objects such as rectangular, line, polygon, and circle. Fig. 6 shows static objects toolbar that provides buttons to create these objects.



Fig. 6. Static Object Toolbar

Dynamic properties are to apply dynamics to objects or a group of objects. Dynamics enable to modify object properties during runtime according to tag values and to execute commands or insert values to the tags. For example, an object assigned with dynamic properties such as position will turn to green color in true state and red color if in false state. Using dynamic properties, variable's data can be presented through color for the user to identify abnormality of the equipment that needs immediate attention when a problem arises. Refer to Fig. 7.

Command, position and text I/O are dynamic properties that commonly used. Command enables to click on the object or press a pre-defined key to execute the command at runtime. Position is used to specify when and where to display an object, using the specified tag values. Text I/O is to add the dynamic input or output text property to a selected text object. Text I/O allows user to insert and display tag values in real time.

Active objects shown in Fig. 8 provide user to create dynamic objects. Alarm/event control object is to add an alarm/event control object to the application screen. Trend button is to exhibit trend curves of tag data. Other active objects are list box, combo box, smart messages text, push button, grid and alarm to display alarm messages.

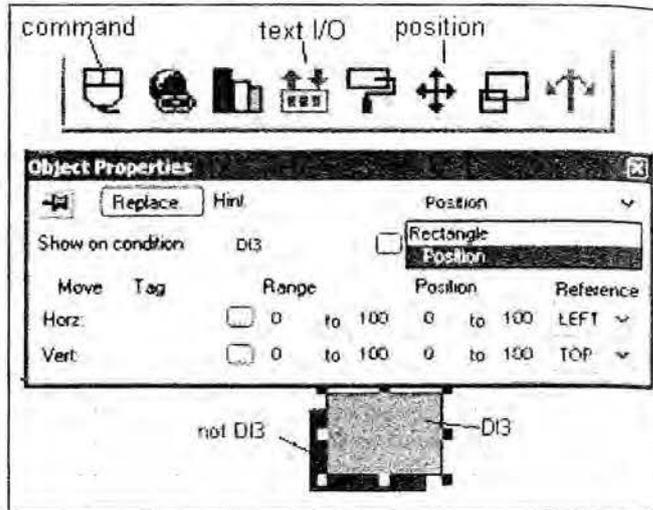


Fig. 7. Dynamic Properties Toolbar

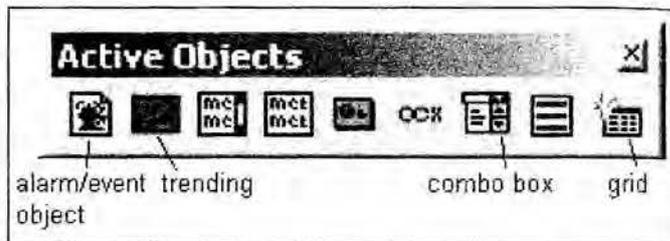


Fig. 8. Active Objects Toolbar

**B. Alarm Management**

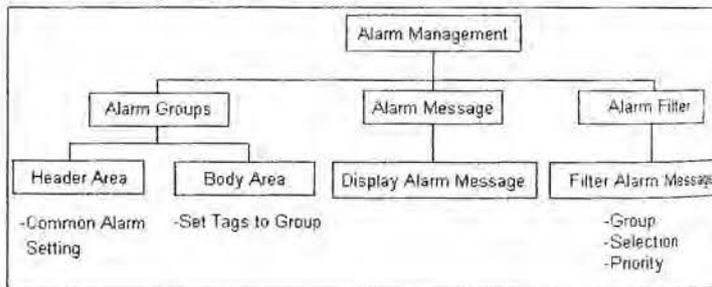


Fig. 9. Structure of Alarm Management

Alarm management is to notify user of monitored alarms, allow acknowledgement of those alarms, provides a record of alarm related events, and display summaries and histories of alarms. Active objects toolbar provide alarm button or alarm/event control button to configure alarm group, filtering alarm messages and displaying the alarm messages. Fig. 9 describes the structure of alarm management.

Alarm message is displayed to inform user of any problems or changes of state during process so that user can take corrective action. Two types of alarm message can be displayed which are on-line alarm messages or history alarm messages. The format of alarm messages can be defined whether to include date, times, names, tags, and messages. The alarm message contains a list of all alarms that are currently active and unacknowledged, active and

acknowledged and cleared and unacknowledged.

Alarm filter is another feature that allows specifying filters for alarm messages. It contains some important field to define the filtering of alarm messages. Group field is to select and display alarm messages based on alarm groups which are digital or analog. Selection field is to display alarm messages that matched the character string specified by user in selection column. Priority range field is to specify a range of alarm priority to be display as alarm messages. For example, priority range field is assigned from 0 to 4. An object represents digital input is set to alarm priority 5. If object changed state and alarm is generated, it will not display alarm priority 5. Ack Tag field is to specify a tag name to filter and acknowledge the active alarm. Ack All Tag field is to specify a tag name to acknowledge all filtered active alarm. All tag will be assigned to certain alarm group. Alarm group is created in alarm worksheet. The alarm worksheet is divided into two areas. First area is header area which contains information for the whole group. Second area is body area where each tag in the group is defined with their alarm condition and messages. Header area contains common alarm setting which is described in Table 2.

TABLE 2  
COMMON ALARM SETTING OF HEADER AREA

Field	Description
Group Name	Type a name to distinguish the alarm groups
Description	Type a description of the alarm group for documentation purposes
Disable	Type a tag to enable/disable all alarms in the group
Remote Ack	When the value of the tag in this field changes, the whole group will be acknowledged
Total Alarms	Enter an integer tag to receive a value denoting the total number of active alarms and unacknowledged normalized alarms.
Total UnAck	Enter an interger tag to receive a value denoting the total number of unacknowledged alarms, regardless of the alarm state
Display/ Save area	Specify the following parameters show in Table 2.

TABLE 3  
DISPLAY/SAVE AREA PARAMETERS

Parameter	Description
Summary check-box	When selected, sends alarm messages to an alarm object on the screen
Ack check-box	Demands the acknowledgment of the alarm messages.
Beep check-box	Sounds the beep until the alarm is acknowledged
To Printer check-	Sends each alarm message of this

box	group to the printer
Save to Disk check - box	Sends the alarm messages of this group to a file on the hard disk
Generate Ack Messages check-box	Generates messages whenever the alarms of this group are acknowledges
Generate Norm Message check-box	Generates messages whenever the alarms of this group return to their normal state
Colors area	Specify parameters to define colors of the alarm summaries for the alarm object

Table 4 shows how the SCADA software for Alarms module counts alarm event messages for the Total Alarms and Total UnAck field total. Body area contains alarm setting is describe in Table 5. Alarm states are defined as in Table 6.

TABLE 4  
COUNTS ALARM EVENT MESSAGES

Alarm State	Acknowledgement State	Counted for Total Alarms Tag?	Counted for Total UnAck Tag?
Active	Unacknowledged	Yes	Yes
	Acknowledged	Yes	No
Normalized	Unacknowledged	Yes	Yes
	Acknowledged	No	No

TABLE 5  
COMMON ALARM SETTING OF BODY AREA

Field	Description
Tag Name	Type a tag to be monitored by the alarm group
Type drop-down list	To select one of the following alarm types: HiHi: Alarm limit is too high Hi: Alarm limit is high Lo: Alarm limit is low LoLo: Alarm limit is too low
Limit	Type a value to limit the alarm generation
Message	Type an alarm message to display
Priority	Type an integer number between 0 to 255 to indicate the priority within a group
Selection	Type a string to filter in the alarm summary objects
Alarm Summary	When the alarm history file is enabled for a group, IWS saves the file as ALyymmdd.ALH in the application's \app\ALARM directory. yymmdd refers to year, month, and day the file was created.

TABLE 6  
ALARM STATES

Alarm State	Description
Normal	No alarm condition exists
Active Acknowledged	Alarm is and has been acknowledged by the operator
Active Unacknowledged	Alarm is active but not acknowledged by the operator
Cleared Unacknowledged	Alarm condition has returned to normal state without operator acknowledgement.

C. Report

Reports features designed to select and display or print written summaries of historical data. Alarm/event object contains alarm filter that allows user to filter the data based on requirement such as filter by selection, filter by priority or filter by date.

D. Password-Based Security System

Security system is to configure their access privileges to tools and applications. User interfaces must be designed to control user access. Access level assigned to an individual will dictate which workstations, interfaces, and displays a user has access to, and which operations the user can perform. Records of operator actions should include the operator's identity, as confirmed by user account login information.

User groups are defined to group users under specific groups. Security level defines the security level for a group (0 to 255). Every object used for data input on a screen has a security level field. New users are created and associated these users to the group accounts created for them. By check the User which is blocked checked-box, the user is not able to access the application.

In the system user entry module, user can enter the system's user name, password and permissions. The system usage permissions can be divided into two categories which are general operator and system administrator. As general system operator, one can only use data query module, and graphics display module etc. As system administrator, the user can use all modules available.

In Fig. 10, the user interface starts with login screen. The default user name is "Guest". The user needs to login before being able to use the toolbar described in Fig. 11. The current user name will be displayed at the top right of the screen.

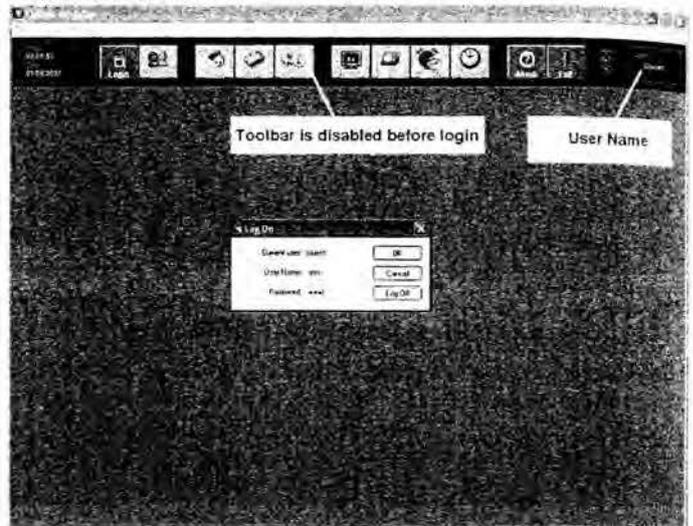


Fig. 11. Log on Dialog Box

In Fig. 10, the control screen consists of main screen, customer service substation screen and service substation screen. These screens give flexibility on the operation personnel and also to assign authorization so that only the authorized personnel are being able to view the screen. The control screen can be divided into three sections which are the footer, header and body section. This is shown in Fig. 11.

The header section consists of toolbar and date and time display. Basically the toolbar provides navigation buttons to open other screens and also to exit the whole application. On the left side, the date and time display that provides the current date and time. The traffic light symbol on the top right indicates that the interface is communicating with the controller.

The body section consists of symbols of input and output, control button, communication status, values of voltages and currents.

The footer section consists of alarm display that is located at the bottom of the screen. Besides that the alarm display button is selected for filtering the alarm. Selection field is to filter alarm messages by the selection text which is defined by the user. Priority field is to filter alarm messages based on priority level. Total alarms will indicate the total alarm displayed. By pressing "Ack Top" button, the alarm on top of the alarm list will be acknowledged. Operation personnel can acknowledge all alarms by pressing on "Ack All". All the alarms displayed will be printed out once the print button is pressed. Operation personnel can press the "beep" button to disable the alarm's sound.

VI. HMI SCREEN ARCHITECTURE

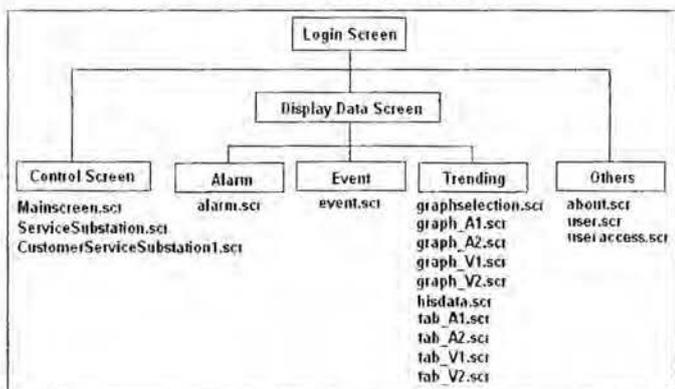


Fig. 10. Screen Architecture

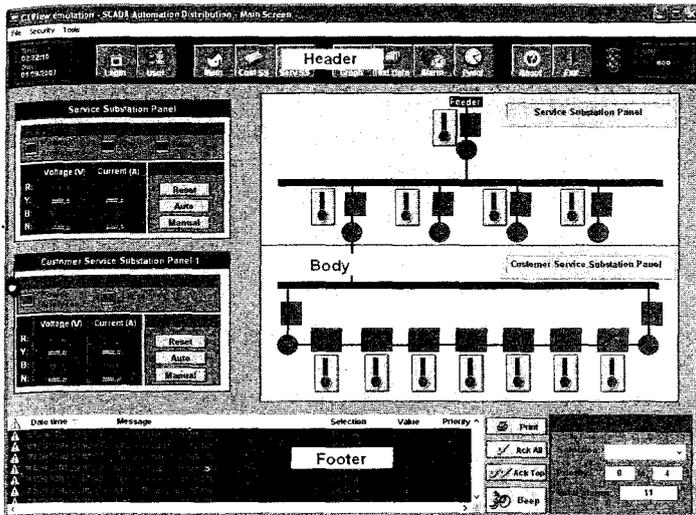


Fig. 12. The Main Screen

Fig. 12 shows the main screen. Main screen displays both panels which are service substation panel and customer service substation panel. Each symbol created is assigned to a tag that is already issued to certain network address that linked to the variable in SCADA hardware application.

The symbols changed to red color to indicate false status and green color to indicate true status. Appendix B.2 shows the service substation panel and customer service substation panel.

The displayed data on the screen consists of alarm screen, event screen, graph screen and table screen. Fig. 13 shows the alarm screen. History alarms display alarm messages from the history database while online alarms display current alarm messages.

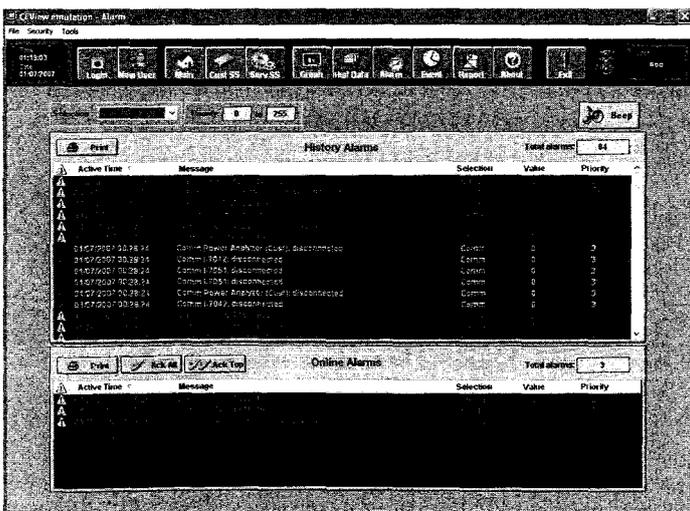


Fig. 13. Alarm Screen

Each tag is configured to the alarm parameters such as group, priority, selection, message, type and limit. Group is refers to the type of group and whether it is digital or analog. Priority is to indicate the priority within the

alarm group. Tags with a higher priority must have a higher priority value. Selection is used to filter in the alarm summary objects. Message is to message the associated alarm that will be displayed on the Alarm/Event Control object. The type is refers to the type of alarm such as “Hi”, “Lo”, “HiHi” and “LoLo”. Limit is the limit value associated to the alarm.

Event screen displays the list of event triggered by the operation personnel. For example, the event of pressing the reset button will be captured and displayed in event screen. Operation personnel can set specific date of event to be displayed or clicked on “today” button to display event that happened today. Fig. 14 shows the event screen and Table 7 listed the captured events.

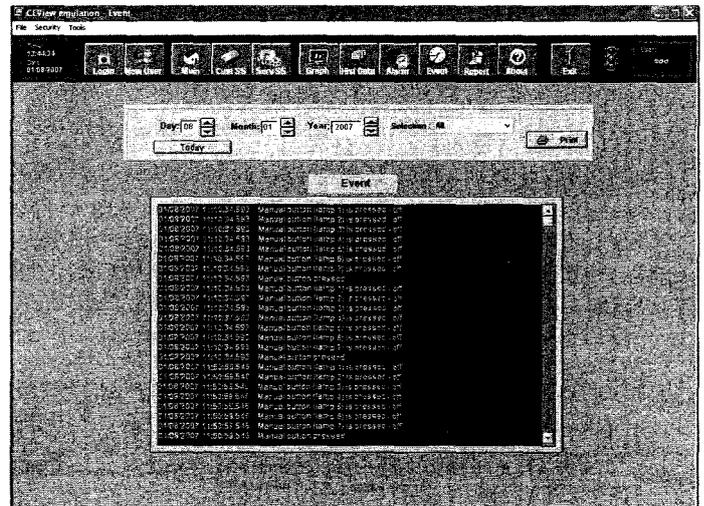


Fig. 14. Event Screen

TABLE 7  
LIST OF CAPTURED EVENTS

Date	Time	Event
01/08/2007	11.10.34.593	Manual button (lamp1) is pressed -off
01/08/2007	11.10.34.593	Manual button (lamp2) is pressed -off
01/08/2007	11.10.34.593	Manual button (lamp3) is pressed -off
01/08/2007	11.10.34.593	Manual button (lamp4) is pressed -off
01/08/2007	11.10.34.593	Manual button (lamp5) is pressed -off
01/08/2007	11.10.34.593	Manual button (lamp6) is pressed -off
01/08/2007	11.10.34.593	Manual button (lamp7) is pressed -off
01/08/2007	11.10.34.593	Manual button pressed

The graph will provide on-line data of voltage and current from the power analyzer. “Cursor” a button at the top of the graph can be dragged to know the value along a certain position of the graph. X-axis and Y-axis can be set to the user preferences. A combo box on the left side of the graph is to change the x-axis. Start Date, Start Time and

duration are to set the y-axis. Fig. 15 describes the trending screen for service substation panel to display current values.



Fig. 15. Graph Current for Service Substation Panel

By clicking on the “Show Tabular” button, screen shown in Fig. 16 will be displayed. This screen is to display the graph data in a table form. The value is archived from the graph shown in the trending screen. “Reload” button is to update the table based on the graph.

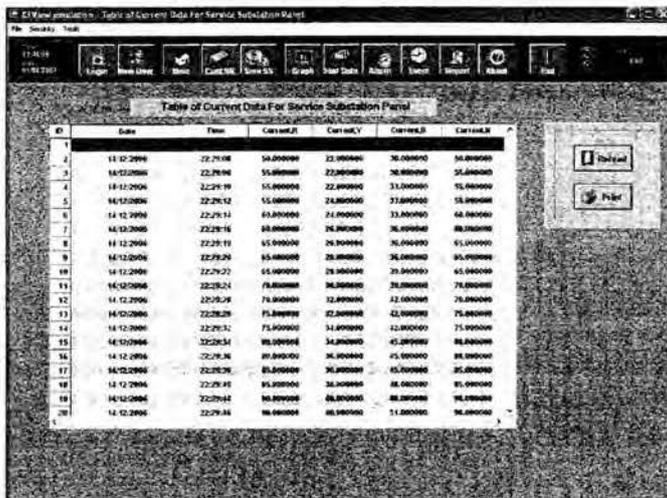


Fig. 16. Table of Current Data for Service Substation Panel

User dialog box is to create new user, delete user, block and unblock user. Fig. 17 shows the user dialog box.

When “New User/Delete User” button is pressed, the screen shown in Fig. 18 will be displayed. User can be blocked from accessing the application by clicking on “Block User” button. “Unblock User” button will undo the block user action. User can be removed by clicking on “Remove User”. “User Access” is to set which screens that are allowed to be accessed under certain user group. Fig. 21 illustrates the user access dialog box.

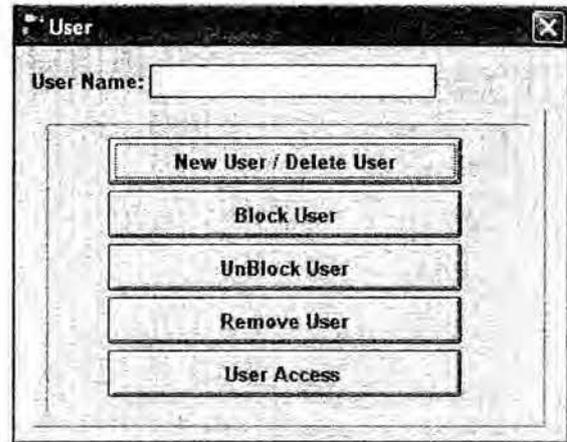


Fig. 17. User Dialog Box

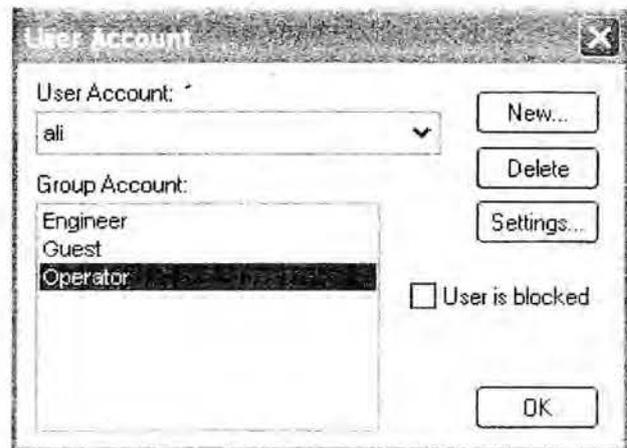


Fig. 18. User Account Dialog Box

“New” button is to create new user and a dialog box as shown in Fig. 19 and will be displayed. “Delete” button is to delete user. A confirmation message box will be displayed to confirm the deleted action. “Setting” button is to change the password of the selected user as shown in Fig. 20. User can also be blocked by checking the check box which indicates that this “user is blocked”.

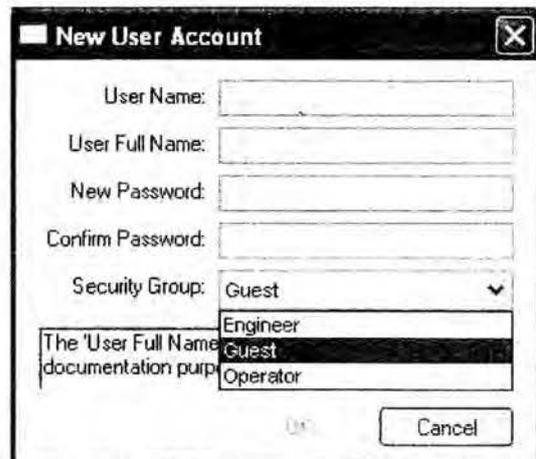


Fig. 19. New User Account Dialog Box



Fig. 20. Setting Dialog Box

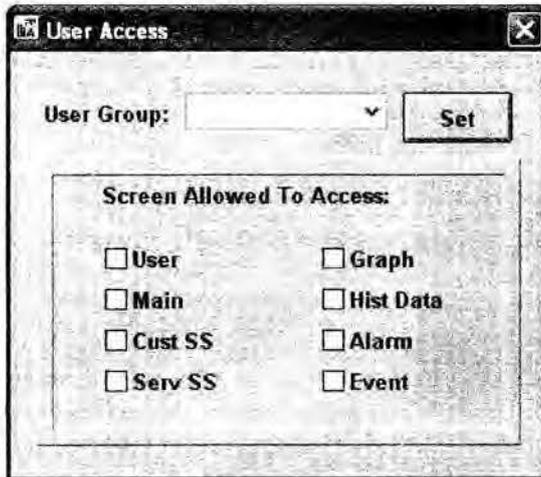


Fig. 21. User Access Dialog Box

### VII. SYSTEM OPERATION

After success login to the system, control screen to be displayed is chosen from the toolbar. An example is shown in Fig. 22, when “Serv SS” button is pressed, the service substation screen will be displayed. Currently all outputs are in healthy conditions. The communication status shows no communication error with the modules as well as the power analyzer.

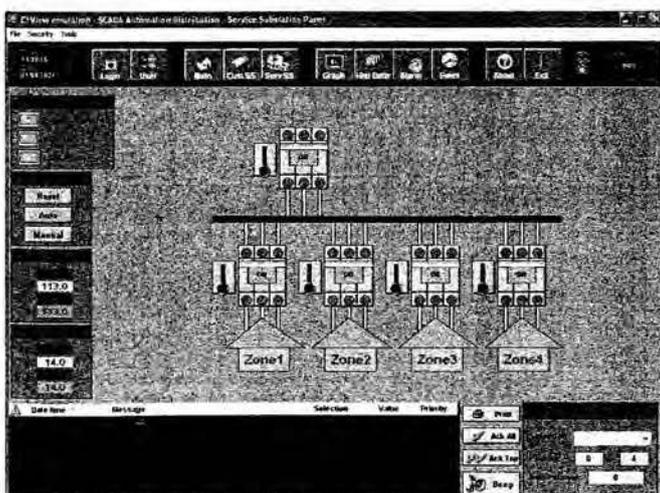


Fig. 22. Healthy Condition at Service Substation Panel

If fault occurs, all symbols that represented the outputs will change to red colors pattern showing that all the circuit breakers are turned off. This is shown in Fig. 23 Alarms will be triggered and displayed on the screen.

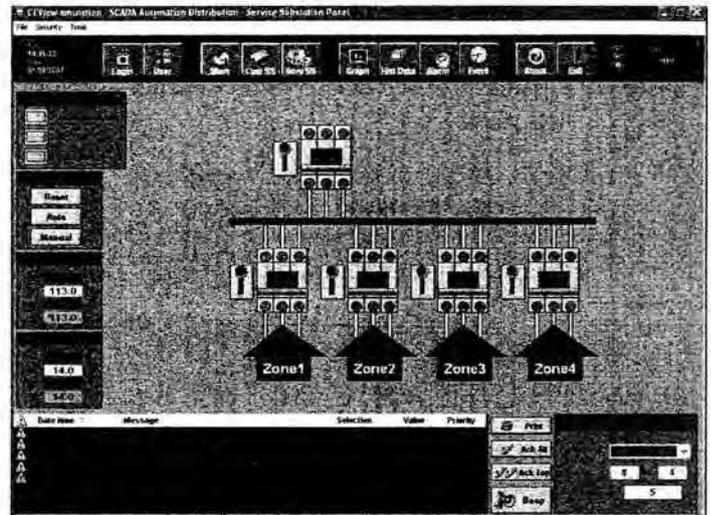


Fig. 23. Unhealthy Condition at Service Substation Panel

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 is pressed to reset the counter and logic programme.

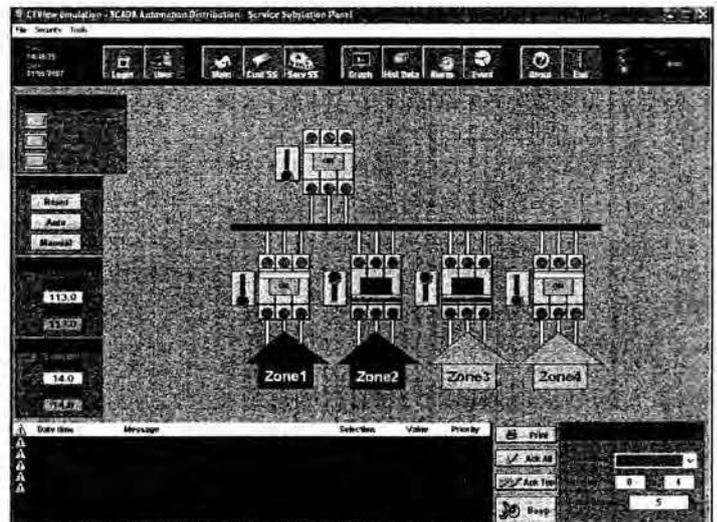


Fig. 24. Fault Isolation at Service Substation Panel

### VIII. CONCLUSIONS

The main contribution of the work in this research project is to develop and design a distribution automation system aimed at the low voltage (LV) distribution system. It is to develop a customized SCADA system which operated and controls the LV system in an automated manner. The SCADA system provides graphical user interface, alarm, data logging and report management facilities for the

operator to interact with the equipment in service substation and customer service substation. Much of the manual verification can now be done at the click of a mouse. This research helps to optimize staff efficiency by deploying staff to on-site location only when necessary. The usage of RTU allows for future expansion. The customized SCADA system is capable of improving the ability to monitor and control equipment at the service substation and customer service substation.

#### IX. FUTURE SUGGESTION

This research project is a step towards developing customized SCADA for low voltage (LV) distribution system and much more work lies ahead in evaluating new SCADA technology and in developing new SCADA applications. However, the outcome of this research as first effort has been very encouraging and bringing beneficial to the distribution system in SCADA research development in the future. Here are few suggestions that will lead a new research projects in the future:

- a) Using web base application as GUI supported by IP-based computer networks and internet connectivity as communication network to remote sites.
- b) An automated solutions to the distribution system comprising automation-ready building blocks such as a synthesis of state-of-the-art individual components (distribution switchgear, fault passage indication, RTU, local power supplies, and communications interfaces), integrated to form complete functional devices. These devices are assembled into a system to solve the complete control or automation needs of each distribution network.
- c) Data collection of not only the status of circuit breakers and relays but also status of each component in the panels. This will help to reduce black-out due to equipment malfunctions.

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