A Distribution Automation System Simulator for Training and Research

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Abstract - This paper presents the design and development of a scaled down physical model for power Distribution Automation (DA) system simulation. The developed DA system simulator is useful in providing hands-on experience to utility engineers / managers to familiarize with the DA system and gain confidence in managing the power distribution system from the computer aided distribution control center. The distribution automation system simulator can be effectively used to carry out further research work in this area. This also helps the undergraduate and graduate students to understandz the power distribution automation technology in the laboratory environment. The developed DA simulator has become an integral part of a distribution automation lab in the Electrical Engineering Department at Indian Institute of Technology Kanpur in India.

Keywords: Distribution automation, training simulator, scaled down model, distribution control center, lab model

1. Introduction

Power Distribution Automation (DA) system is being increasingly installed by the electric utilities to increase the operational efficiency and reduce the losses in the distribution network. Distribution automation is an integrated technology, which enables an electric utility to monitor, co-ordinate and control the distribution components from a remote location, generally called as Distribution Control Center (DCC) [1-6]. Once a distribution system is automated, it needs trained operator at the DCC to extract the desired benefits from automation. To achieve this objective, it is preferred to conduct the operators' training on a simulator instead on an actual automated distribution system in order to prevent the undesired switching operations during the training.

Power distribution automation is a comparatively new subject in the area of power systems [1]. Researchers, very often, realize a difficulty to validate their research concept in the area of distribution automation because testing of a research concept, which has to be carried out several times directly in the utility automated distribution system, may cause undesirable power interruption during testing.

Further, it is important to create interest and motivation among undergraduate and graduate students in academic institutions towards this emerging distribution automation technology [7]. At present, there is a provision of technical tour to accomplish the above objective. But, frequent technical visits are not possible because of the time constraints during academic calendar.

The possible solution is to build a distribution automation lab to impart necessary training to utility operators, which also provides a platform to validate the research concepts and for familiarizing the undergraduate and graduate students with the computer aided monitoring and control of distribution systems, through lab demonstration and experimental set up.

Research work on preprocessing data at the RTU level using Fuzzy Logic and Fuzzy-Genetic algorithm has already earned recognition [8, 9]. The significance of the laboratory is highlighted by the developments in substation automation, which is revolutionizing the automation scenario in power systems [10]. One of the unique features of the distribution automation laboratory, that makes it the only one of its kind, is the use of a distributed processing system, which supports a global database. The use of such a system was favored against that of personal computers with data acquisition add-on cards [11-13], in order to acquaint students with the standard industrial practices. Earlier reports on SCADA (Supervisory Control and Data Acquisition) systems are limited to the description of a Greek EMS-SCADA implementation and application of ATM based networks [14, 15]. It is to be noted that the computer based decision making feature of the distribution automation distinguishes it from the normal SCADA system. In the conventional SCADA system, control decision is supervisory, i.e., the control decision is taken manually on the basis of experience and the available real time data [7]. It is then executed through the man machine interface. On the other hand, computer based control decisions are taken in the distribution automation system and these control decisions are executed in either automatic

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mode or in semi-automatic mode through human intervention. Therefore, it is important to give know-how about power distribution automation system with computer based control decisions and their remote execution to the students and researchers in educational lab environment. Also, it is important to give a physical look and feeling of the distribution network components and its operation during training and study.

In view of the above, it is desirable to perform the task of training and performance studies on a physical simulator that would give more realistic visualization of the automated operation of a distribution system. This paper reports the design and development of a scaled down physical model of power distribution automation system. This is one of the few attempts made over the world to build such a physical simulator to carry out training and research work on power distribution automation system. This work is a part of a mission mode project on Power Distribution Automation at Indian Institute of Technology Kanpur in India.

2. Conceptualization of Distribution Automation Simulator

An automated distribution system consists of mainly power circuit, distribution automation equipments, and control decision software. Power circuit equipments include transformers, feeders, circuit breakers etc. Distribution automation equipments are used to monitor and control the distribution system power equipments. These equipments may include transducers, sensors, actuators, remote terminal units, data communication terminal devices, computers and printers. The control decision software is installed in the computer to provide possible control decision. These are mainly distribution system reconfiguration and load management software.

A distribution automation system simulator, as shown in Fig. 1, has been conceptualized as a scaled down model of an actual automated 10 MVA distribution network of an academic institution township. The township distribution system of Indian Institute of Technology Kanpur consists of one 33/11 kV substation and 5 numbers of 11/0.415 kV substations. The 33/11 kV substation includes one 33 kV incoming feeder from the state electric utility, two units of 33/11 kV 5 MVA transformers, four 11 kV outgoing feeders, necessary switch-gears, control and relay panels. Each 11/0.415 kV substation includes one or more 11/0.415 kV distribution transformers of different ratings, ranging from 250 kVA to 2 MVA, and single or multiple incoming 11 kV feeders. The 415 V feeders coming out from these distribution transformers run to different locations in the township including residences, academic buildings, laboratories, workshops, hostels, commercial establishments, air conditioning plant etc.

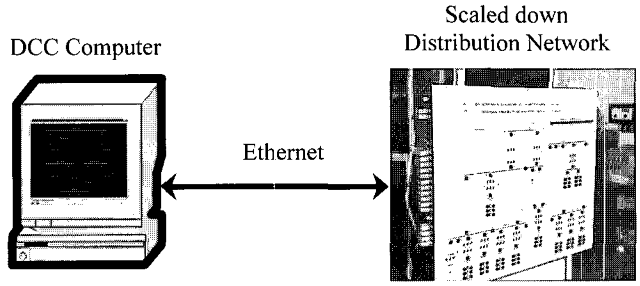

Fig. 1 A conceptual distribution automation system simulator

The necessary scaled down transducers and actuators were selected and connected with the power circuit components in the DA simulator for their monitoring and control. A composite RTU has been designed, developed and connected with the scaled down distribution network to retrieve the network data and to send the control command to the appropriate switching element. The RTU is connected to a computer over Ethernet to exchange the data. For training and lab demonstration purpose, the computer, which is representing the Distribution Control Center (DCC), is used for monitoring and control of the scaled down distribution network through the Graphical User Interface (GUI). The computer receives the scaled down electrical quantities from the simulator. Then, these quantities are displayed on GUI as the actual values in the distribution network. Two application packages are designed, developed and installed in the DCC computer to provide control decisions. These are (i) system reconfiguration software for power loss reduction and (ii) load control software to flatten the daily load curve.

The voltages, currents, line resistances, transformers ratings, and loads of the township distribution system have been suitably scaled down while designing and developing the power circuit of the physical simulator.

3. Design and Development of Simulator Power Circuit

A suitable scale factors both for voltage and current have been derived. 33 kV three-phase voltage level at the input of the 33/11 kV substation of the township distribution network has been scaled down to 415 V three-phase for the simulator, as this supply is easily available in the laboratory. Hence, the voltage-scaling factor used can be derived as

$$K_i = \frac{V_s}{V_a} = \frac{415}{33000} = 126 \times 10^{-4} \qquad (1)$$

Where, V_s is the voltage level used in the simulator and V_a is the corresponding voltage level in the actual network.

Further, a 60 VA transformer in the simulator represents a 5 MVA substation transformer in the township distribution network. Hence, the current scaling factor is given by

$$K_i = \frac{I_s}{I_a} = \frac{\dfrac{60}{\sqrt{3}\times 415}}{\dfrac{5000000}{\sqrt{3}\times 33000}} = 954\times 10^{-6} \quad (2)$$

From the above, the impedance scaling factor can be calculated as

$$K_z = K_v / K_i = 13.2 \quad (3)$$

The simulator power circuit has been designed and fabricated using the voltage and current scaling factors as calculated above. The simulator power circuit consists of mainly scaled down substation transformers, distribution transformers, distribution lines, load on distribution transformer and topology same as the township distribution system. The various components of the power circuit are appropriately connected with a single line mimic diagram representation on the front panel of the simulator. This panel has been mounted on a rigid stand, which has strong trays to hold the scaled down transformers. The front panel mimic diagram of the simulator is shown in Fig. 2. Circuit breakers are represented by miniature illuminated pushbutton switches on the front panel (mounted as shown in the figure) in combination with 4 pole electromagnetic controllable relays placed on DIN rails at the back side of the simulator. Loads are represented by a combination of resistances placed inside the panel. All connections to and from the front panel box to the other parts of the simulator have been made through the removable connectors to assist in easy maintainability of the components. The components of the simulator power circuit has been designed and fabricated in a modular fashion for up-gradation and maintenance in future. These modules are briefly discussed as following.

The specifications of substation and distribution transformers in the township distribution system have been scaled down using the voltage and current scaling factor to determine the specifications of these transformers used in the simulator. Table 1 shows the actual and scaled down specifications of some of the transformers. Three-phase simulator transformers have been designed and fabricated to satisfy the scaled down specifications given above. Fig. 3 shows a three-phase unit of a scaled down distribution transformer connected on the back of the simulator panel.

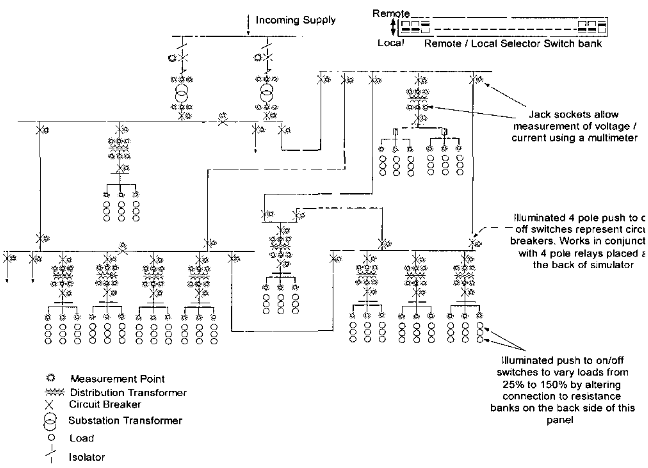

Fig. 2 Schematic showing front mimic panel of simulator

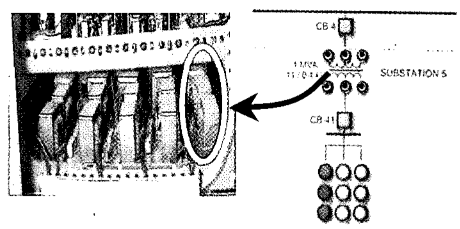

Fig. 3 Scaled down module of a transformer

Distribution lines have been simulated by equivalent scaled down resistance values. The three-phase scaled down distribution line has been designed and fabricated using wire wound resistors as shown in Fig. 4. These have been connected appropriately with other components on the back of the mimic panel.

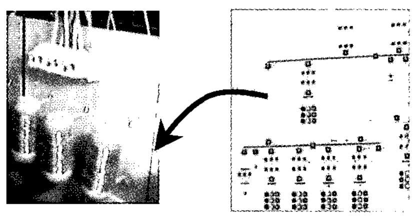

Fig. 4 Scaled down module of a distribution line

Remotely operable switching elements, such as circuit breakers and load break switches, have been represented by four-pole controllable relays with a provision to select remote / local operation. This is depicted in Fig. 5.

Table 1 Transformer Specifications

	Actual specifications	Scaled down specifications
Main substation transformers		
Voltage ratings	33/11 kV	415/140 V
Power ratings	5 MVA	60 VA
Distribution transformer (one typical)		
Voltage ratings	11/0.415 kV	140/5.5 V
Power ratings	500 kVA	6 VA

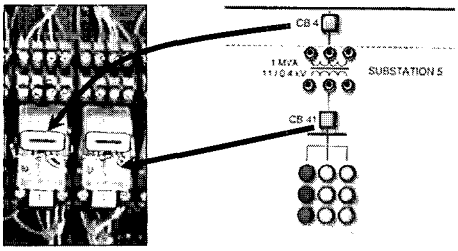

Fig. 5 Scaled down module of remotely operable switching elements

Loads on the transformers in township distribution network have also been appropriately scaled down to represent them in the simulator. Three-phase loads have been designed and fabricated using high wattage resistors, whose values can be varied in the range of 0-150 % in steps of 25%, required to simulate the over, under and normal load conditions. The illuminated push to on/off switches have been used on the front panel mimic diagram to vary the loads. Variable loads are modeled using resistance banks on the back side of the panel as shown in Fig. 6.

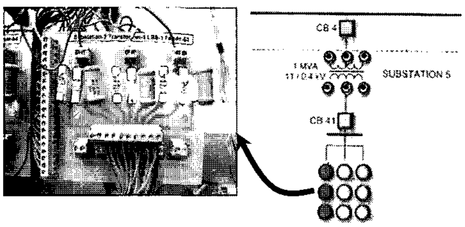

Fig. 6 Scaled down module of a three-phase load

4. Switch Control Circuit

In a typical automated distribution system, the remotely operable switches such as Circuit Breakers (CB) and/or Load Break Switches (LBS) are operated manually using a local Trip-Neutral-Close (TNC) switch or remotely through the computer. The remote or local operation of a power circuit on/off switch is permitted through a remote/local selection switch.

The power circuit on/off switch and its close / open operation through the TNC switch have been represented by a four-pole electromagnetic controllable relay in combination with miniature illuminated pushbutton on the front mimic panel of the DA Simulator. A provision to select remote or local operation of a relay switch has been provided on the front panel of the simulator through a remote/local selection switch.

The control circuit has been designed and developed as per schematic shown in Fig. 7. In the DA Simulator, three out of four poles of an electromagnetic relay are used for switching the three-phase main power circuit while the fourth pole is used to derive the switch close / open status signal. The switch close/open status signal is fed to the RTU. Also a two-pole Remote /Local (R/L) selection switch is associated with each power circuit switch and it is mounted on the front panel of the simulator. Once, R/L selection switch is in local mode, the status of power circuit switch can be altered using the illuminated push button (realized through push to on/off switch) on the front panel. This is equivalent to switching operation in local mode through TNC in actual practice. On the other hand, R/L selection switch can be put in remote position to receive the switch control command from the RTU. The RTU receives the control command when an operator submits the same through the computer at the control center. The control signal interface between RTU and simulator has been conceptualized in terms of potential free contacts (PFC), realized generally through the relays. Also, the other pole of R/L selection switch has been utilized to derive the R/L status signal, which is fed to RTU This signal provides information to the operator at the control center regarding the mode of operation of the switch, i.e., whether a power circuit switch is selected for operation in the remote or the local position. A 12 V DC supply has been utilized as the control supply in the simulator as depicted in Fig. 7.

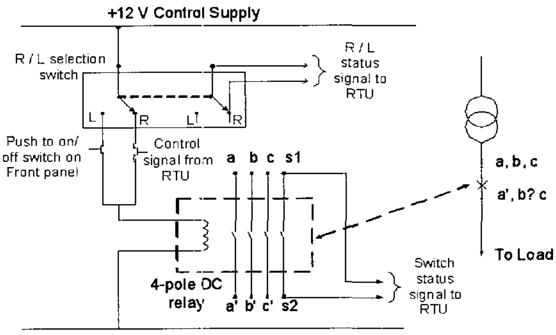

Fig. 7 Simulator control circuit

5. Analog Signal Measurement and Instrumentation

The analog quantities chosen for the acquisition from the simulator are mainly voltages and currents. The voltages at some selected points in the simulator are taken through instrument Potential Transformer (PT). The instrument PT along with necessary terminal interfaces is termed as three-phase instrument PT module. The output of the instrument PT is connected to the RTU. The input of the instrument PT is directly connected to the simulator power network. The instrument PT provides output voltage signal compatible with the RTU. This arrangement is shown in

Fig. 8. The instrument PT is designed and developed for linear operation in the range 0-150% of its nominal value. The PT ratio at different voltage levels is given in Table 2.

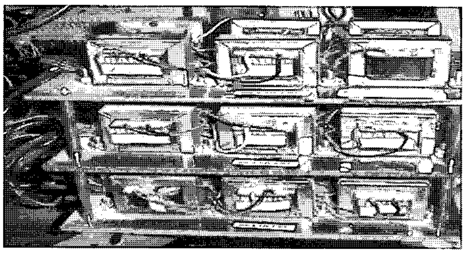

Fig. 8 Three-phase instrument PT modules

Table 2 Specifications of Instrument PT

Actual voltage (kV)	Scaled down voltage (V)	PT voltage ratio (V, phase)
33	415	240/6.5
11	140	80/6.5
0.415	5.5	3/1.5

A Hall effect Current Transformer (CT) installed in the simulator converts the scaled down feeder current in the range of 0-5 A to a value in the range of 0-25 mA as shown in Fig. 9. The current signal is then converted into equivalent voltage signal in the range of 0-5.5 V with the help of an appropriate shunt precision resistance of 220 ohm. These voltage signals, corresponding to the actual current in the simulator are fed to the RTU. The Hall effect CT, along with precision resistance and terminal interfaces, may be termed as three-phase Hall CT module. The Hall CT module is designed and developed for linear operation in the range of 0-150% of its nominal value. The specification of the Hall effect CT is given in Table 3.

Table 3 Specifications of Hall Effect CT

Primary rated amp. Turns	25 At
Number of turns in primary	5
Primary nominal current	5 A
Secondary nominal current	25 mA
CT ratio	0-5 A / 0-25 mA
Measuring resistance	220 Ohm

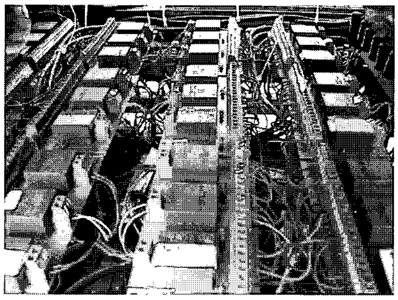

Fig. 9 Three-phase Hall CT modules

6. Composite Remote Terminal Unit

A Remote Terminal Unit (RTU) retrieves the operating point data from scaled down power components of the simulator, does the necessary data processing and calculation, makes a data packet and sends them to a control center either upon receiving a request or by exception. The other major task of RTU is to receive the control command data packet invoked by the operator at the control center, to interpret it, to send the appropriate control signal to actuate the control action at switch level and then to send back the acknowledgement to the operator at the control center.

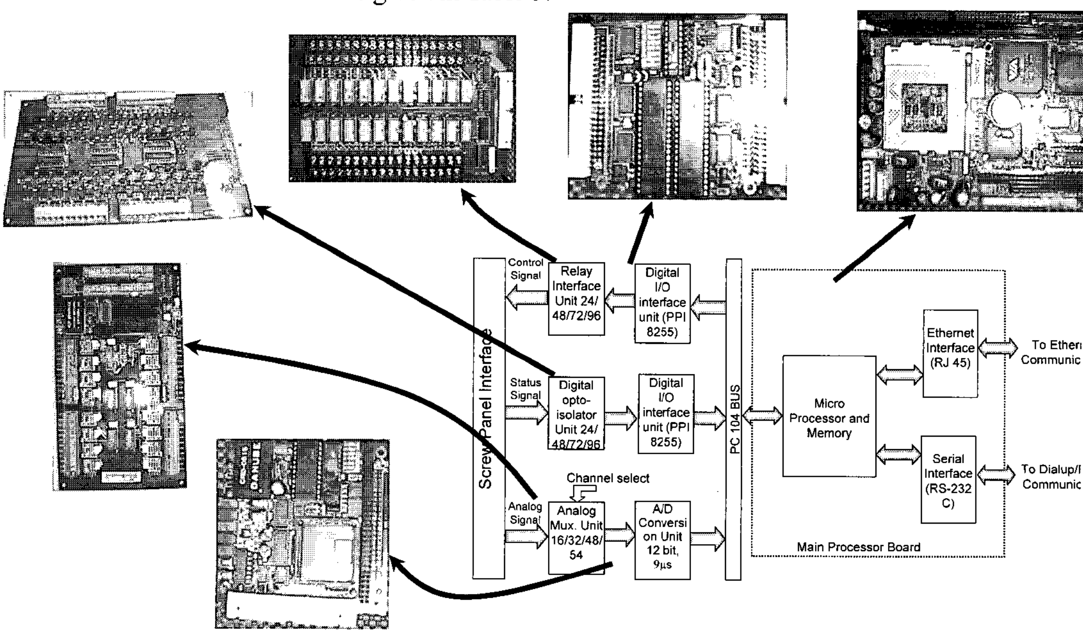

Fig. 10 Block diagram of the Remote Terminal Unit (RTU)

A microprocessor based RTU has been designed and fabricated using standard off-the-shelf PC-104 cards. The basic block diagram of the RTU is demonstrated in Fig. 10. The RTU has mainly three interfaces – (1) analog interface (2) digital input interface (3) digital output interface. RTU receives voltage and current signals through the analog interface, which consists of analog multiplexer and 12-bit A/D conversion device with a conversion time of 9 microseconds. Digital input interface of the RTU consists of digital opto-isolator and Programmable Peripheral Interface (PPI) device. RTU receives discrete signals from the simulator such as close/open status of a switch and remote/local status of a switch. Further, the RTU sends the control signal to the appropriate switch in the simulator through its digital output interface, which consists of PPI along with the relay contacts to create potential free signal. The developed RTU is modular and has 24/48/54 analog and 24/48/72/96 digital I/O channels. The RTU supports bi-directional data communication over Ethernet / dialup media. The developed RTU supports Distributed Network Protocol (DNP3.0) to exchange the data with the computer. The DNP3.0 is an industry standard open protocol [16].

7. Data Communication System

The basic task of the communication system is to transport the data packets, containing the system operating point data, from RTUs to the DCC computer and the data packet for switch control command (open / close) from the DCC computer to the RTU. A client-server architecture has been designed and implemented for data communication between the RTU and the DCC computer over Ethernet in the DA simulator. The architecture of the developed software, at the conceptual level, is shown in Fig. 11. Two server programs ('mserver' and 'ctrserver') are running continuously in the developed RTU. A program is also said as a process under run time.

One server process 'mserver' in the RTU is always ready to listen the request for connection from a client process at the DCC in order to poll the data. When a client process requests for the connection to the server process of the RTU with the intention to poll the data, the server process 'mserver' in the RTU allows for the connection to its valid client process. Thus, a connection is established between the server and the client process to exchange the data. Subsequently, the server process sends the data packets, holding the system operating point data, to the client process. The client process then receives these packets and stores them in a database, which is made of sharable memory. The memory resident database holds the system operating point data consisting of analog and the digital status information.

The other server process 'ctrserver' in the RTU provides facility to receive the data packet for switch control command from the client process 'ctrclient' in the DCC computer as shown in the Fig. 11. In fact, when the client process 'ctrclient' receives a switch control command message from the operator at DCC, it requests the server process 'ctrserver' to make the connection. The server process authenticates and permits for a connection to the client. Once, the connection is established, the data packet for switch control command is sent from the control client process in the DCC computer to the control server process in the RTU. The server process, after successfully receiving the data packet for the switch control command, processes the data packet to identify the appropriate switching device. The instruction is, then, issued to the actuator of the appropriate switch through the RTU. The instruction is in the form of digital output signal ('0' to open and '1' to close a switch). The acknowledgement upon execution of the switch control command is sent back to the DCC through the other path via the server process 'mserver' in the RTU.

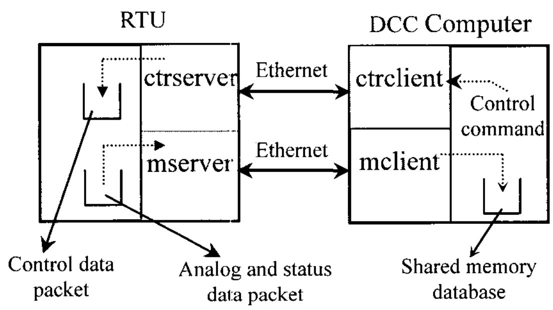

Fig. 11 Data communication between RTU and DCC computer

8. Software Elements

There are two key software elements – Master DA Software and Engineering Analysis Software at the DCC [17]. The master DA software provides the on-line information system. The engineering analysis software uses the system information to provide the appropriate control decisions, which is implemented on the power circuit of the DA simulator again through the master DA software. A Graphical User Interface (GUI) based master DA software has been designed, developed and integrated with the physical simulator. The DA software has been developed using object oriented programming language C++ and the developed software is fully portable from one platform (Linux) to another (Windows). The modules developed for the master DA software are data acquisition & control, data processing and storage, alarm generation, graphical user interface, system operating point data logger, event logger, report generation and self-diagnostic tool. Fig.

12 shows Graphical User Interface in the DCC computer to provide an easy interactive environment for the system monitoring and control. The main features of the developed master DA software are listed below.

- *Network Generation:* Graphical representation, Editing, Validation, Bill board printing
- *Monitoring:* System operating point data, Topological information, Component specification, Customization, Alarm generation (audio / video)
- *Control:* Switch control command, Control interlock
- *Data Logging:* Logging of system operating point, Event log report, Report configuration
- *Status Information:* overloading of equipments, % Unbalance in voltage and current, Component health, Switch close/open status, Remote / Local status
- Graphical User Interface (GUI)
- User's authentication and Cross platform portability
- Self diagnostic and error rectification tool

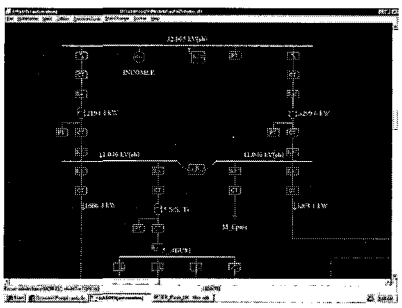

Fig. 12 GUI in DCC computer

The engineering analysis software for feeder reconfiguration and load control functions have been developed separately using programming language "C". The Graphical User Interface (GUI) software enables user to visualize the distribution network in the form of single line diagram on the computer. The engineering analysis software has been integrated with the master DA software in the DCC computer.

The feeder reconfiguration program determines the best possible topology of the distribution network in order to minimize the system loss while meeting the load demands. The reconfiguration programs runs automatically on hourly basis and gives message to the operator if distribution system reconfiguration is required. The operator then submits the required control command through the GUI on the computer to change the network topology and hence to reduce the losses.

The other application software is also developed in "C" language to guide the load manipulation in order to flatten the load curve of feeder and distribution transformer. The software provides information about the loads to be manipulated during different time intervals to improve the system load curve on the basis of predefined priorities of different load types. Loads can then be turned off or on from the DCC computer.

The different hardware/software components of the DA simulator have been designed and developed separately using the modular approach. Thereafter, these components are integrated together to make the simulator fully operational as demonstrated in Fig. 13. The developed DA simulator is mounted in a standard 19-inch rack movable over the wheels. This makes it portable and can be easily shifted to different venue of training.

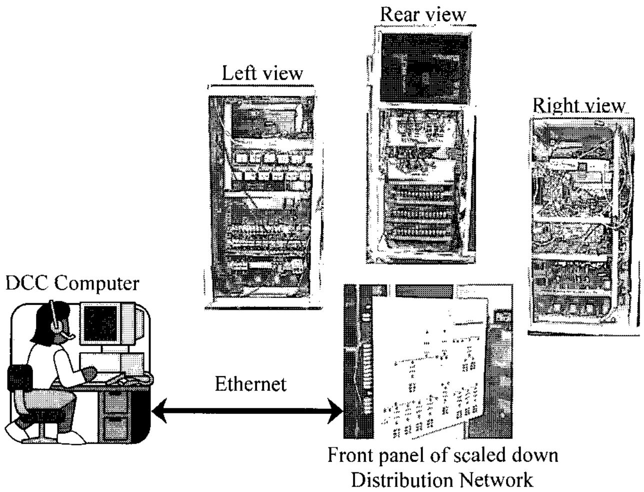

Fig. 13 Developed distribution automation simulator

9. Salient Features of the Simulator

The major features of the developed DA system simulator are as following.

- It represents a distribution network through GUI in the form of its single line diagram, which is easily understood by persons during training. Distribution system components have been represented by standard symbols on the single line diagram, displayed on the computer screen and on the front panel of the simulator.
- Different voltage networks have been represented by different standard colors for better conceptualization of the network.
- The various components of the simulator have been designed and developed in a modular fashion in order to have easy maintainability and scalability.
- The user selected electrical parameters are available on-line for power components such as transformer, feeders etc. on the single line diagram displayed on the computer screen.
- Remote control feature has been implemented for switching on/off of the power circuit.
- The static information, containing specifications of any transformer or feeder, are available on operator's

request on the single line diagram.

- The simulator has an excellent feature to represent variable loads at different buses in the network.
- The simulator provides computer aided control decisions which can be executed from the DCC computer.

10. Simulator Operations and Results

The developed software components have been installed in the DCC computer and can be invoked to perform DA functions. Some of these are briefly described below.

10.1 Data Monitoring

The master DA software allows an user to interact with the computer through an interactive user interface, which is made of several windows. For example, the operating point data of a transformer can be seen by moving the cursor to that transformer on the single line diagram and selecting the "Health" from the drop down menu as shown in Fig. 14. The transformer operating point data includes voltage, current, power factor, real power, reactive power, apparent power, unbalancing in the voltage and the current, etc.

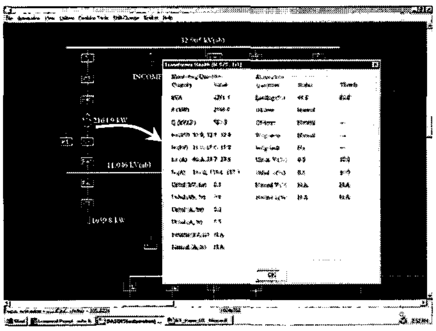

Fig. 14 A typical 'transformer health' window

To check the accuracy of the electrical quantities, a representative list of these quantities is considered. The values of these electrical quantities are taken directly from the simulator power circuits and also from the DCC computer. The directly measured and the monitored values of the few selected electrical quantities, for a 33/11 kV transformer, are shown in Table 4. This table also shows the % error in the values. The maximum error is 0.5 %, which is within the acceptable limit.

10.2 Alarm Generation and Event Logging

The simulator generates audio-visual alarm when a physical quantity exceeds the preset limit value. As an example, consider setting the limits of some of the physical quantities for a specific transformer in order to generate the alarm. This is illustrated in Fig. 15. The cursor is moved to the corresponding transformer on the single line diagram and then the "Alarm" is selected from the drop down menu A window for setting the alarms gets opened. On this window the alarms for overloading, high unbalancing in voltages and currents etc. are enabled / disabled and the value of threshold limits can be set to generate the alarm. This facilitates configuration of the alarm settings for different distribution components separately. Alarms generated under abnormal conditions are logged with time and date in the DCC computer.

Table 4 Test Result for the Accuracy of the Electrical Quantities for a 33/11 kV Transformer

Sl. No.	Electrical quantities	Actual value through direct measurement	Monitored value on the DCC computer	% Error
1	$V_{(hv, ab)}$	32.8 kV	32.9 kV	0.3
2	$V_{(lv, ab)}$	10.95 kV	11.0 kV	0.5
3	$I_{(hv, a)}$	40.1 A	40.0 A	0.2
4	$I_{(lv, a)}$	116.6 A	117.0 A	0.3
5	P	2168.0 kW	2164.9 kW	0.1
6	Q	582.9 kVAR	580.3 kVAR	0.4
7	S	2245.0 kVA	2241.3 kVA	0.2

V: voltage, I: current, P: real power, Q: reactive power, and S: apparent power

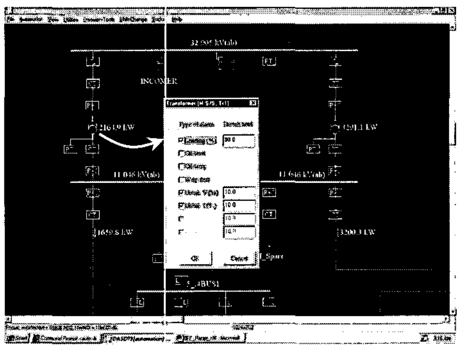

Fig. 15 Alarm setting window of a transformer

To test the alarm generation and event-recording feature of the DA system simulator, the following tests are conducted.

- The loading limit of the transformer "M SS Tr1" in the 33/11 kV sub-station is set to 75% through the window for the alarm setting, whereas the actual loading on the transformer is 80 % of the nominal value.
- The control mode of the switch "M11CB5" is changed from remote to local.
- The switch "M11CB5", which is in the local mode, is closed manually in the field.

It is observed that in all the above situations, both the audio and video alarms are generated along with the appropriate messages:

- Transformer "M SS Tr1" is overloaded.
- The mode of the switch "M11CB5" is changed to local.
- The switch "M11CB5" is closed.
- Further, the above alarm generation was also recorded in the event database together with the date and time stamp as indicated below:
- Fri Mar 09 10:08:28 2004 : rampg : Transformer (M SS Tr1) is overloaded.
- Fri Mar 09 10:15:20 2004 : rampg : Circuit breaker (M11CB5) mode is set to local.
- Fri Mar 09 10:21:10 2004 : rampg : Circuit breaker (M11CB5) is closed.

10.3 Control Command and Interlock

To execute the closing and opening operation of a switch, cursor is moved to corresponding switch on the single line diagram and the "change status" is selected from a drop down menu. A window, then, gets opened to submit the switch close/open command as shown in Fig.16.

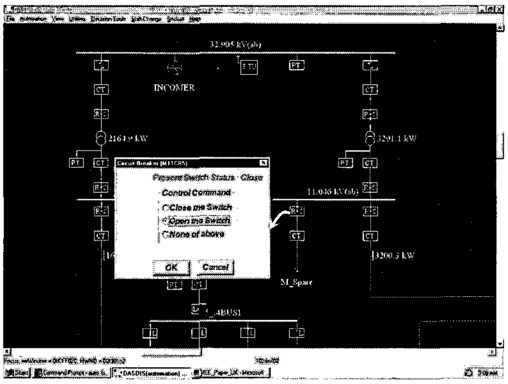

Fig. 16 Switch control command window

To test the functioning of the control command and interlock, a set of remotely operable switches are selected in the simulator. These switches are "M11CB5", "1_11LBS9", "1_.4MCB35" and "1_.4MCB36". The switch "M11CB5" is set to the local mode and the other switches "1_11LBS9", "1_.4MCB35" and "1_.4MCB36" are set to the remote mode at the site. The polling time is set to 10 sec. to poll all the RTUs. Initially all the four switches are kept in closed position. Then, the control command to each of the switches is issued from the DCC as described below.

The opening command to these four switches is submitted from GUI of the DCC computer one by one. It is observed that each of the four switches changes their status from close to open almost without any delay from the initiation of the control command. But, the acknowledgement regarding the change in the switch status is received at the DCC approximately after 10 seconds from the instant of submitting the opening command to the switch.

Further, the closing command is issued one by one to the four switches through the GUI window. It is observed that the control command item is disabled for the switch "M11CB5" as this is in the local mode. Consequently, the closing command to the switch "M11CB5" could not be submitted. Further, it is found that each of the other three switches change their position from open to close almost instantly and the corresponding acknowledgement is received at the DCC after approximately 10 sec.

The above observations regarding the control command, as presented in Table 5, clearly shows that the opening command to the switch can be submitted from the DCC irrespective of whether the switch is in remote or local mode. But, the closing command can only be issued from the DCC to the switch if and only if the switch is set in the remote mode. This is an important aspect of the distribution system operation from safety point of view. The other observation, that the control command immediately reaches the corresponding switch, signifies that the control command is directly going to the corresponding RTU and it does not wait for the routine polling of the RTU. Consequently, the switch open command overrides any polling process. This feature of almost instantaneous opening of the switch is important to ensure safety of the system irrespective of whether the switch is in the remote or local mode. The acknowledgement being received at the DCC after 10 seconds is because of the fact that it comes back from the switch to the DCC through the regular polling mechanism.

Table 5 Test Result for Control Command and Interlock

Sl. No.	Switch	R/L mode	Initial position	Control command option	Response to the 'open' command	Control command option	Response to the 'close' command
1	M11CB5	L	Close	Enable	Open	Disable	-
2	1_11LBS9	R	Close	Enable	Open	Enable	Close
3	1_.4MCB35	R	Close	Enable	Open	Enable	Close
4	1_.4MCB36	R	Close	Enable	Open	Enable	Close

10.4 Network Reconfiguration

Reconfiguration program has been executed on the DCC computer for the base topology of the simulator distribution network as given in Fig. 17. The simulator distribution network represents 11 kV distribution lines emanating from a 33/11 kV substation, computer operated line switches, and loads. The system data, considered in this example distribution network, is given in Appendix-I. Constant power loads, as given in the Appendix-I, are taken for the study. The reconfiguration program has suggested new topology of the network to reduce the power losses while meeting the load demand. The close / open status of the line switches are given in Table 6 both for the base and new network topology suggested by the reconfiguration program. The network topology of the simulator power circuit, then, has been altered through the mouse over the single line diagram on the DCC computer. On-line load flow analysis shows a reduction of the power losses from 10 % to 5.5 % after reconfiguring the network (refer Table 7). This demonstrates the effect of the network reconfiguration on the system power losses.

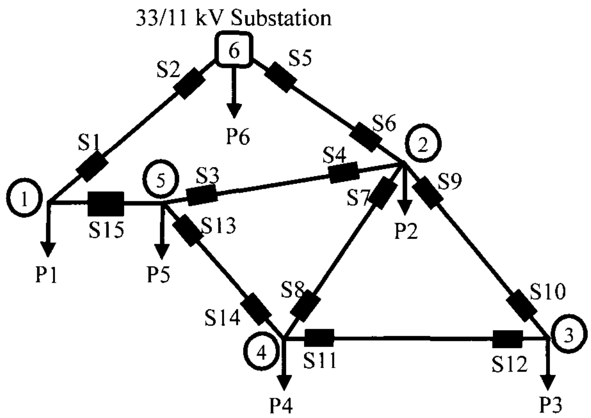

Fig. 17 Simulator distribution network topology Line switches: S1 to S14; Bus coupling switch: S15

Table 6 Status of Line switches (1: close, 0: open)

Switches	Status in base topology	Status in new topology		Switches	Status in base topology	Status in new topology
S1	1	1		S9	**0**	**1**
S2	1	1		S10	**0**	**1**
S3	**1**	**0**		S11	**1**	**0**
S4	**1**	**0**		S12	**1**	**0**
S5	1	1		S13	**1**	**0**
S6	1	1		S14	**1**	**0**
S7	**0**	**1**		S15	**0**	**1**
S8	**0**	**1**				

Table 7 Power Losses in Example Distribution Network

Topology	Total input power (kW)	Total output power (kW)	Power losses (kW)	Power losses (%)
Base topology	8000	7200	800	10.0
New topology	7619	7200	419	5.5

10.5 Load Control

The load control software is invoked in DCC computer in order to flatten the load curve of the simulated 33/11 kV substation. The program has provided information about the simulator loads to be manipulated during different time intervals to improve the system load curve on the basis of predefined priorities of different load types. The schedule of load manipulation achieved from the load control software is, then, submitted in the DCC computer for its automatic execution. Fig. 18 demonstrates the load curve of the simulated 33/11 kV substation before and after execution of the load control function. It is observed that peak load has been reduced from 6 MVA to 5 MVA and load during off peak time is increased from 3 MVA to 4 MVA after automatic execution of the load control function This demonstrates the effect of load control function to flatten the load curve.

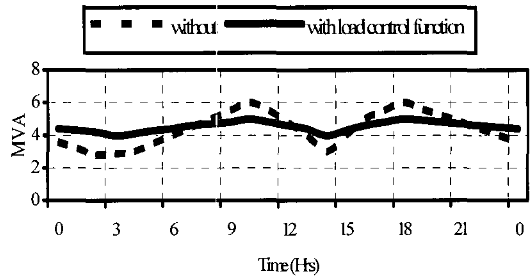

Fig. 18 Simulation of daily load curve without and with load control function

The above developed DA simulator has been extensively used to provide training on Distribution Automation to utility engineers/managers, students, government executives etc. More than 500 people have already taken training on this simulator during workshop, conferences and short term courses. In addition, lab experiments have been set up for the graduate students to test the DA functions, as illustrated in the earlier sections.

11. Conclusion

A scaled down version of academic institution township distribution system has been conceptualized, designed, and developed. The automation components such as DA software, composite RTU and data communication system over Ethernet have been developed separately. Thereafter, these automation components have been successfully interfaced with the scaled down model of the distribution network to build a physical DA system simulator. Subsequently, a set of DA functions and operations such as data monitoring, execution of switching operation from computer console, alarm generation etc., have been successfully achieved. The test result demonstrates reduction in the simulator power losses through the system reconfiguration software. Load control function is successfully executed on the DA simulator in order to flatten the load curve. The DA simulator is being effectively utilized for training, research and education purpose.

Since there is one to one co-relation between single line diagram on the computer and front mimic panel of the simulator, it helps the trainees and students to correlate the computer based operation and visualize its impact directly on the front panel of the DA simulator.

The developed DA simulator has become an integral part of a distribution automation lab in the Electrical Engineering Department at Indian Institute of Technology Kanpur, India. The DA simulator provides an interactive environment to the undergraduate and graduate students to understand the emerging technology of the power distribution automation. In addition to the above, the developed DA simulator provides an on-line platform for researchers to validate their algorithm for distribution system analysis and various automation functions.

Appendix I : System Data

Line Data

Line		Length (Km)	No. of circuits	R (Ω/Km)	X (Ω/Km)
From bus	To bus				
1	6	23.7	2	0.167	0.092
2	6	8.5	2	0.167	0.092
2	5	15.9	1	0.167	0.092
4	5	16.1	1	0.167	0.092
2	4	30.0	1	0.167	0.092
3	4	7.7	1	0.442	0.106
2	3	44.5	1	0.325	0.100

Load Data

Bus No.	Load (kW)
1	1850
2	400
3	600
4	2700
5	850
6	800

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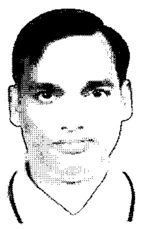

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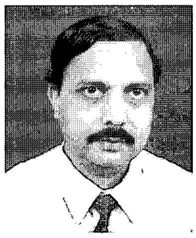

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