TECHNOLOGY DEVELOPMENT AND IMPLEMENTATION FOR POWER DISTRIBUTION AUTOMATION SYSTEM

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Abstract

This paper describes the indigenous development and implementation of a Power Distribution Automation system at pilot level in Indian Institute of Technology (IIT) Kanpur, India. Electric Power Distribution Automation (DA) system is being increasingly adopted by the electric utilities to reduce the operational problems of distribution networks. The DA system not only provides system wide status and health monitoring but also helps in coordinated controls required to enhance quality and reliability of the supply.

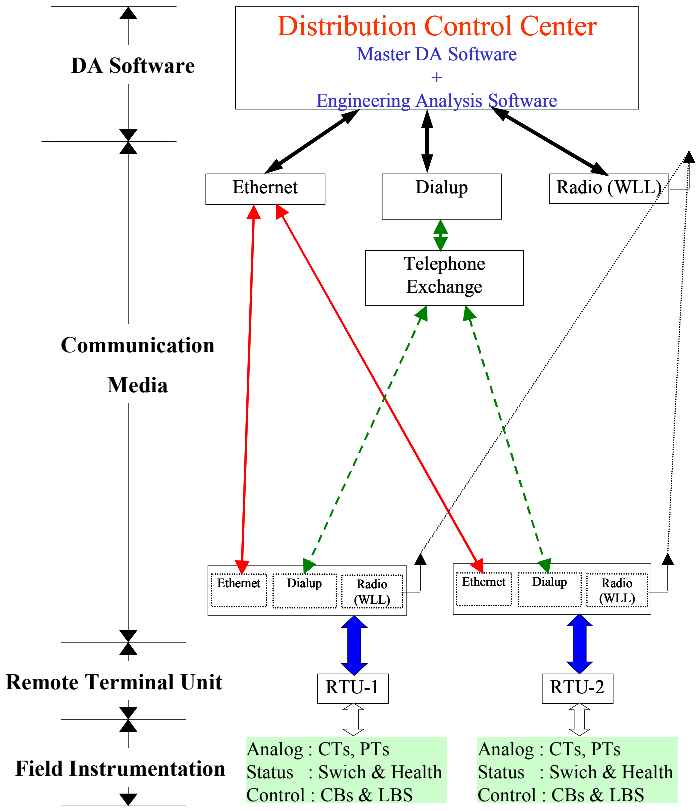

Fig. 1. A typical power distribution automation system

Key Words

Power, Centralized Monitoring and Control, Performance Improvement, and Distribution Automation.

1. Introduction

The economic growth and development of a country depends heavily on the reliability and quality of the electric power supply. Generally, rigorous planning is done for the addition of the generation and expansion of the transmission networks. However, the distribution systems have generally grown in an unplanned manner resulting in high technical and commercial losses in addition to poor quality of power.

Efficient operation and maintenance of distribution system are hampered by non-availability of system topological information, current health information of the distribution components such as distribution transformers and feeders, historical data etc. Other reasons include the lack of efficient tools for operational planning and advanced methodology for quick fault detection, isolation, and service restoration, etc. All these lead to the increased system losses, poor quality and reliability of power supply in addition to the increased peak demand and poor return of revenue.

Keeping the above problems in mind, it becomes necessary to improve the operation of distribution systems and hence the quality of power supply. This can be achieved by use of better methods, proper monitoring and control of the distribution system. In view of the extensive size of the network, this task can be effectively achieved through the intervention of information technology (IT) utilizing the available high-speed computers and communication networks. This system of monitoring and control of electric power distribution networks is also called as the Distribution Automation System. IEEE has defined Distribution Automation (DA) system as a system that enables an electric utility to remotely monitor, coordinate and operate distribution components, in a real-time mode from remote locations [1]. The location, from where control decisions are initiated, is generally called Distribution Control Center (DCC). Distribution

Automation System encompasses data acquisition, telemetry and decision making system. It involves collecting information, transferring it to a DCC, displaying the information and carrying out analysis for control decisions and improvement in system operation [2]. The control action is then initiated either through remotely operable devices or manually. A typical DA system is composed of field instrumentation, remote terminal units, communication systems and distribution automation software. In a typical distribution automation system the above components are integrated as shown in the Fig. 1.

Field instrumentation includes sensors, transducers and actuators, which are directly interfaced to the equipment being monitored and controlled by the DA system. These sensors monitor certain parameters and actuators control certain equipment or feeder in the system. The actuators could be either operable remotely or manually.
Field instrumentation connected to the equipment being monitored and controlled are interfaced to a local unit called Remote Terminal Unit (RTU) that allows data manipulation and help in implementing control action in the field. Another key function of this unit is to gather data from the equipments and transfer it to the DCC.

The Communication System is required to communicate data from DCC to various remote terminal units and vice versa. Essentially, the communication system refers to the communication equipment and interface needed to transfer data between DCC and different remote terminal units. Thus, the point to multi-point communication is an inherent need of DA system. The communication media can either be wired (cable, fiber, telephone) or wireless (Wireless-in-local loop, radio etc.) [3].

There are two key software elements – Master DA Software and Engineering Analysis Software at the DCC. The master DA software acquires the system data (both static and dynamic) and converts it into an information system. The engineering analysis software provides the control decision utilizing the system information, available at the DCC. The decision making feature of the distribution automation distinguishes it from the normal SCADA (Supervisory Control and Data Acquisition) 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. It is then executed through the man machine interface. On the other hand, computer based control decisions are taken in the DA system and these control decisions are executed in either automatic mode or in semi-automatic mode through human intervention.

The benefits of the distribution automation are reduced technical loss, support for commercial loss reduction, improved cash flow, low service restoration time, reduction in equipment damage, availability of system information, better operational planning, remote load control and shedding, and improved power quality and reliability [4]. In Indian utility distribution system, the technical and commercial losses are around 45%. It is envisaged that the technical part of the losses can be brought down to the minimum value with the implementation of DA system. Currently reported transformer failure rate of around 15-20 % in Indian distribution systems is mainly due to non-availability of transformer health parameters and its loading conditions. This can be brought down to around 1% with the help of DA system. Cost/benefit analysis of DA system justifies the capital investment for distribution automation system [5].

Despite the obvious benefits mentioned above, the distribution automation system has not yet gained momentum among the utilities and manufacturers in the developing countries. Utilities have realized a need of indigenous Distribution Automation (DA) system, which could be retrofitted in the existing distribution network to achieve better system operation through remote monitoring and control. This paper reports the outcome of a mission mode project on Power Distribution Automation carried out at Indian Institute of Technology Kanpur, India. This project was aimed at developing indigenous know-how of complete DA system including its implementation at a pilot level on IIT Kanpur distribution network. The aim was also to demonstrate the indigenous DA technology to power distribution utilities. The software and hardware components required for indigenous DA system have been designed and developed at Indian Institute of Technology Kanpur, India under the mission mode project. The indigenous design and development efforts have been focused on the following:

- DA software to enable remote monitoring, alarm generation and remote control
- Remote terminal unit (RTU) specially low cost pole top RTU
- Remotely operable switches for 11kV and 415V feeders
- Communication and networking technology using wired and wireless media
- Data acquisition from Intelligent Electronic Devices (IEDs) such as IED meters and IED relays
- Distribution network simulator (a scaled down model of a real-life distribution network) to provide a

test bed for a comprehensive testing of the developed technology, components and software.

2. Development of DA Components

The developed components for power distribution automation under the technology development mission project are described below.

2.1 Distribution Automation Software

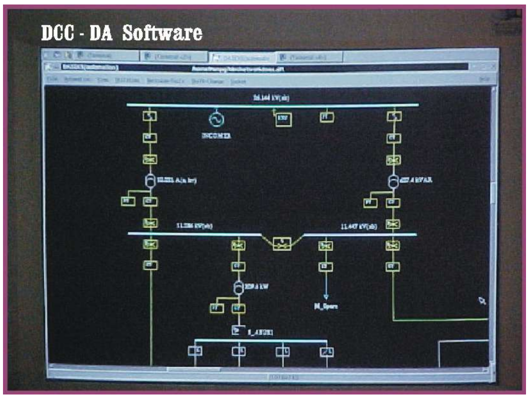

Fig. 2. User interface of DA software at DCC

As described earlier, the master DA software and the engineering analysis software are the two core software elements at DCC. The master DA software provides the system information. The engineering analysis software uses the system information to provide the appropriate control decisions, which is implemented in the field through the master DA software. The main features of the developed master DA software, an example shown in Fig. 2, 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 generation
- System Information: System quantities, % Unbalance in voltage and current, Component health, Circuit Breaker (CB) / Load Break Switch (LBS) / Isolator status, Remote / Local status, Auto trip status
- Graphical User Interface and Cross Platform Portability
- Security for user authentication
- Watchdog diagnostic and rectification tool

The engineering analysis software for network re-configuration, load shedding, volt-var control through capacitor switching, and fault detection and isolation has been developed and integrated with the master DA software.

2.2 Remote Terminal Unit

Fig. 3. Remote terminal unit

Microprocessor based substation and pole-top RTU has been designed and fabricated using standard off-the-shelf cards. The RTU is modular and has 24/48/54 analog and 24/48/96 digital I/O channels, and affords bi-directional data communication as depicted in Fig. 3. The acquired data (voltage and current) are processed for rms and power factor calculations. Some design goals focus at low cost, flexibility and expandability, modularity at signal conditioning level, and communication interface. The developed RTU has a capability to exchange the information with Intelligent Electronic Devices (IEDs) such as IED meter and IED relays.

2.3 Remotely Operable Switches

Air break type Load Break Switch (LBS) for 11kV operation and a Moulded Case Circuit Breaker (MCCB) unit for 415V operation have been designed, developed and tested as per available specifications. The three-pole 11kV LBS (developed for outdoor installation) opens in 90-100 milliseconds at the rated current of 80 A as depicted in Fig. 4. While this switch is primarily meant for breaking load current, it can sustain 16 kA of fault current for one second and can also close on fault. The remote operation is through a three-phase induction motor coupled with gear mechanism. The 415V MCCB unit, on the other hand, has an isolator on the incoming circuit and two MCCBs for two outgoing feeders as given in Fig. 5. Flexibility exists to choose the MCCB of appropriate rating corresponding to the rated feeder current. The remote operation is through solenoid-plunger arrangement.

Fig. 4. Load break switch at 11 kV

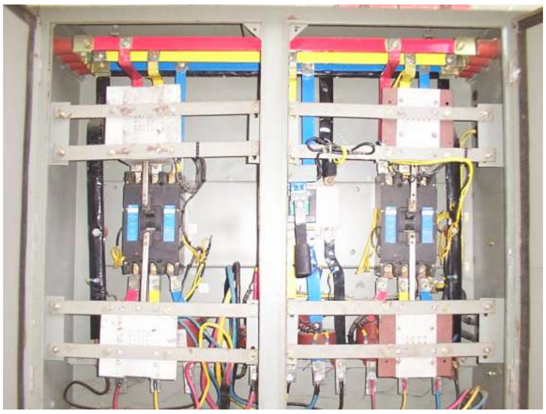

Fig. 5. Remotely operable MCCB Unit at 415 V

2.4 Communication System

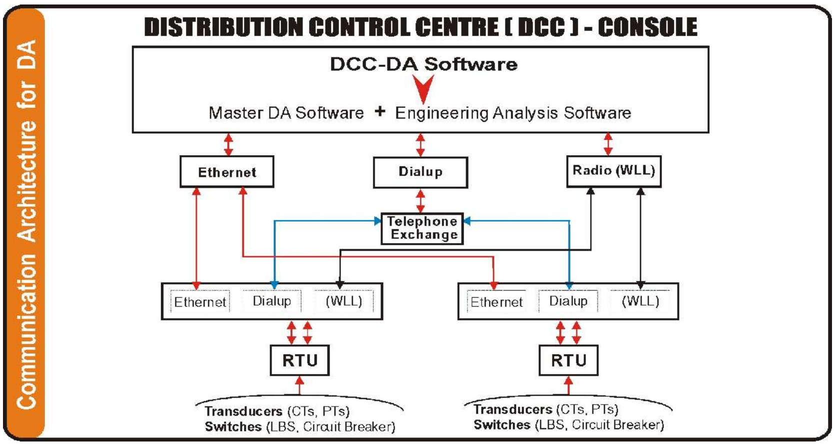

Fig. 6. Data communication system

Communication system enables distributed data acquisition, monitoring and control system functions. Unlike traditional communication solutions, the approach adopted here is to have a core communication controller at the DCC that can support diverse choices of communication media (dial-up, Ethernet, WLL, GSM) as shown in Fig. 6. This open approach facilitates cost effective implementation. The communication controller has cross-platform portability, supports functions for communications network management, and permits LAN, Internet, and Intranet connectivity through Ethernet. All the control command functions are invoked through Graphical User Interface (GUI) of DA software. Data transfer between DCC and RTUs supports Distributed Network Protocol (DNP-3.0), which is the industry standard open protocol.

2.5 Substation IEDs and Protocols

A pole top RTU is required at each distribution transformer and a panel mounted RTU is required at each distribution substation for the purpose of their computer aided monitoring and control. These RTUs need to communicate the data with the Distribution Control Center (DCC) and Intelligent Electronic Devices (IEDs) available at the site. This is demonstrated in Fig. 7. Examples of IEDs are electronic meters and relays with data communication interface. The existing IED meters and relays have been utilized to retrieve the analog and digital information by the RTUs to reduce the instrumentation activities. The other analog quantities and digital information, which are not retrieved directly from the IEDs, are taken through the Input/Output interfaces of the RTU. This requires installing additional instrumentation between RTU and power distribution components such as transformer and feeders. Also, the RTU has provision to send the control command to the actuator of a switching element through the IED relay if available at the site.

The present techniques of data communication among the intelligent devices supplied by different vendors involve adherence to the protocol DNP-3.0 (Distributed Network Protocol) or IEC-60870-5 (International Electro-technical Commission). This protocol is optimized for serial data communication, and assumes master-slave architecture while supporting unsolicited reporting.

The developed communication interfaces and RTU supports the DNP3.0 protocol over the serial link as demonstrated in Fig. 7. The IED meters and relays installed at the substation have been used to retrieve the analog and digital information at the substation level [6]. The existing IED meters support DNP3.0 over serial port in the substation. But, existing IED relays support proprietary protocol. Therefore, these IED relays are connected to a Data Concentrator and protocol converter that collects the data and converts it to DNP3 format. This scheme of data retrieval from IEDs at the substation level is very flexible to the extent that a new IED can be integrated in the substation with a minimal effort in future. A Personal Computer (PC) with DA software is installed and connected in the substation to perform the task of monitoring and remote control.

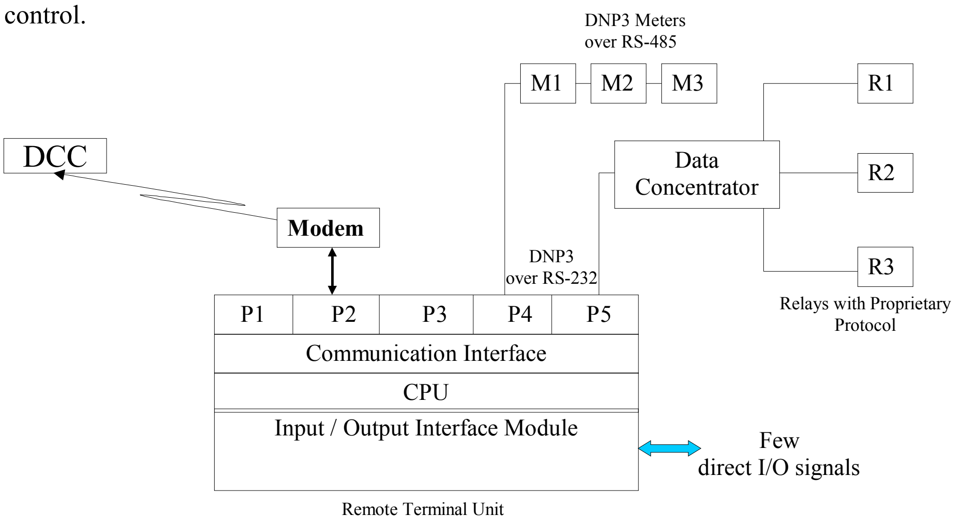

Fig. 7. Substation RTU and IEDs
M1, M2, M3 are IED meters and R1, R2, R3 are IED relays.

Few analog and digital signals, which are not handled by any of the IEDs, are directly connected with the RTU that communicates with DCC.

2.6 Distribution Network Simulator

As a part of DA system development, a simulator has been developed which is a scaled-down model of the actual distribution network. This consists of suitably scaled-down versions of fourteen transformers, thirty 11 kV feeders, forty one circuit breakers represented by four-pole controllable relays (with selection for remote/local operation), LT loads which can be varied from 0-150% in steps of 25%, communication linkage (for Ethernet, dial-up), single generic RTU (96 digital I/O and 54 analog channels) covering all transformers. This is shown in Fig. 8. The simulator applications include testing of various communication systems and protocols, testing of DA software, fine tuning of RTU and LBS control prior to their field installation, and integration and testing of engineering analysis software. As the simulator provides a feel of actual physical system, it can serve as a training tool for operators of the DA system.

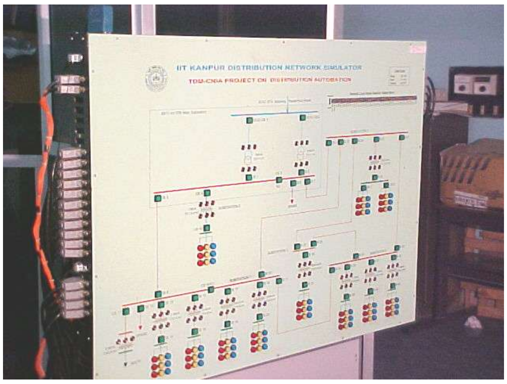

Fig. 8. Distribution network simulator

3. Field Implementation

As a pilot level installation for field reliability evaluation, the developed components and technologies of the DA system has been installed in the real life distribution network for system monitoring and control. The distribution network considered for implementation of DA system is a part of the power distribution system at IIT Kanpur. The single line diagram of this distribution system is shown in Fig. 9. This distribution system is having various distribution components such as substation transformers, distribution transformers, feeders / lines, circuit breakers, buses, bus couplers, isolators, load break switches, loads etc.

The IITK distribution system consists of one 33/11 kV substation and 5 numbers of 11/0.415 kV substations. Further, the 33/11 kV substation includes one incoming 33 kV feeder from the KESCO utility, two units of 33/11 kV, 5 MVA transformers, four outgoing 11 kV feeders and 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 campus including residences, academic buildings, laboratories, workshops, hostels, commercial establishments, air conditioning plant etc.

A part of the above distribution system, as indicated in Fig. 9, (called the sample distribution network) is selected for remote monitoring and control under the field trial of the distribution automation system. The sample distribution network consists of one 33/11 kV substation, three 11/0.415 kV substations, seven 11 kV feeders and several 0.415 kV lines / loads connected to 11/0.415 kV substations. One of the 11/0.415 kV substations has five distribution transformers of different ratings and the other substations have one or two distribution transformers. The major components covered in the scope of the automation are shown in Table 1.

Table 1. Distribution System Components Considered under Distribution Automation

Sl. No.	Voltage Level (kV)	Components	Number
1	33/11	Main Substation	1
2	11/0.415	Remote Substation	3
3	33/11	S/S Transformer	2
4	11/0.415	Distribution Transformer	8
5	33	Feeder	1
6	11	Feeder	7
7	0.415	Feeder	23
8	33	Bus	1
9	11	Bus	5
10	0.415	Bus	8
11	33	Circuit Breaker	2
12	11	Circuit Breaker	17
13	33	Isolator	2
14	0.415	Isolator (Manual Switch)	59
15	11	Load Break Switch	1
16	0.415	Load Break Switch	2

Some of the substations are about 35 years old. In order to extend the DA system in such installations, retrofitting of the equipments were carried out to provide necessary sensors for acquisition of system data and switch status. Public Switch Telephone Network (PSTN) has been used to transfer the data between RTUs and DCC. Pole-top RTU is provided with enclosure of IP-55 protection with locking and cooling arrangements. Integration of the complete DA systems, its testing and commissioning have been carried out. The system is continuously working successfully since year 2000. The IIT Kanpur distribution system has witnessed for improvement in the power factor from the earlier average value of 0.75 (lagging) to 0.95 (lagging) after DA system installation.

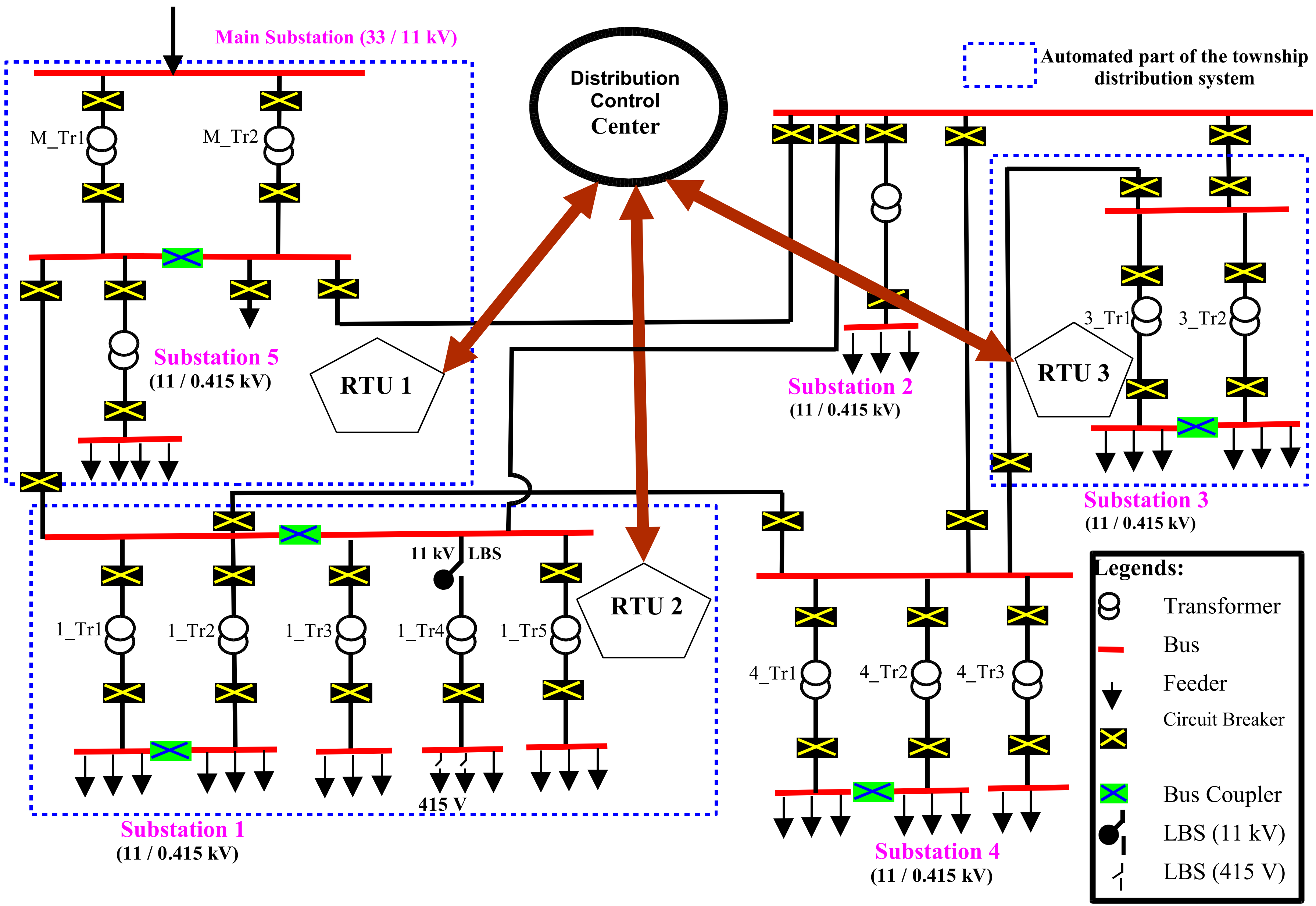

Fig. 9. Single line diagram of the township distribution system

4. Conclusion

Different components of Distribution Automation System have been indigenously designed, developed and successfully implemented at the pilot level under the mission mode project on Power Distribution Automation at Indian Institute of Technology Kanpur, India. The major developments under the project are comprehensive DA software for monitoring and control, microprocessor based RTU, remotely operable load break switches, data communication interfaces, distribution network simulator and necessary field instrumentation. The substation IEDs can be used to retrieve the substation data. Use of IEDs simplifies the DA installation at the substation level. Further, conversion of protocol from proprietary (with existing relays) to DNP3 has been addressed. The capabilities of the developed Distribution Automation System include:

- Monitoring of voltage, current, power factor, real power, reactive power, voltage and current unbalance etc. on in-coming / out-going feeders and transformers
- Monitoring of circuit breaker, manual switch and isolator status and operation history
- Alarm generation under abnormal operating conditions
- Monitoring of local / remote selector switch status
- Monitor transformer health status
- Remote operation of 33kV, 11kV and 415 V breakers and bus couplers
- Detailed engineering tools for data acquisition and automation implementation

The developed indigenous Distribution Automation System has been successfully demonstrated to many power distribution utilities, manufacturers, researchers and Government officials in order to create awareness and indigenous know-how about Distribution Automation System.

5. Acknowledgement

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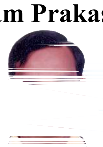
Biographies



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