A

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## CERTIFICATE

I hereby certify that the dissertation work entitled **"DISTRIBUTION AUTOMATION"** is the work done by **Mr. PIKESH JAIN** is submitted in partial fulfillment for the award of Degree of **"BACHELOR OF TECHNOLOGY"** in Electrical Engineering and submitted in the **DEPARTMENT OF ELECTRICAL ENGNEERING** of the **JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE, JAIPUR** is an authentic work under my supervision.

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# Introduction to Distribution Automation Systems

## 1.1 Historical Background

Power system utilities consist of generation, transmission, and distribution functions. Several advances have been made to improve the performance, efficiency, reliability, and security of power systems. The initial design of the electricity industry by Edison in 1881, with AC generation, has changed with several modifications. This design, with its modifications, has led to the development of today's power system utilities. The design of large-scale electric production has produced AC power at high voltage and current levels. The growth of the industry has led to many innovations, including economy of scale from large hydro, fossil fuel and, recently, small independent power producers (IPP), in what is called distributed generation. The designs of distributed generation have been based on criteria to improve its reliability, load management, and system performance in response to various disturbances. Over the last decade, protection schemes to detect abnormalities, control schemes to stabilize the system, and economic principles to ensure optimal allocation and bidding have all been implemented to ensure a network's competitiveness in the electric market.

The generated power is transmitted over long distances from city to city or across country boundaries. The transmission lines can be rated to operate as either DC or AC systems at low, medium, or extra-high voltage levels of 230 kV, 750 kV, or 1130 kV respectively. Efficiency and reliability at an affordable cost is the ultimate aim of the transmission planners and operators. The line must withstand and tolerate dynamic changes in load and contingency without unreasonable impact on the continuity of service. To ensure that the system meets the expected performance, reliability, and quality of supply, some standards are preferred following the occurrence of a contingency. Simulation tools and advanced technology such as load flow, optimal power flow, state estimation, stability estimation, reliability estimation, market stimulation tools, and flexible AC transmission devices (FACTs) have been developed to ensure the reliability and security of the transmission/distribution system. The transferred power is ultimately delivered to residential, commercial, and industrial customers at local but lower voltage levels. The voltage level for industrial customers ranges from 4.0 kV to 34.4 kV. Residential customers are supplied with voltage levels at 120/ 240 V, while the typical voltage level for commercial customers is 440 V. The distribution reliability and the quality of utility services are easily measured by all stakeholders at the customer end. With this in mind, the progressive utility must provide adequate planning and operation, as well as reliability-centered maintenance to the system, to minimize downtime of service from the distribution level up.

## 1.2 Distribution System Topology and Structure

Distribution system topology can take a variety of forms. The topology is typically radial or ring, mesh, or radial mesh, depending on the configuration, quality of service, and cost. The cost of operation and maintenance (or lack of it) is usually huge, so appropriate techniques used in communication technology and automation are desirable in achieving a distribution system of high quality. For example, distribution automation functions have recently been designed to support trouble call analysis, which will reduce repair crew time and ensure timely payment of bills. Distribution automation also enhances integration to system reconfiguration and restoration, thereby minimizing losses and voltage deviation, especially during an emergency. Several optimization and intelligent-system techniques are used in the design of distribution automation schemes.

Prototype work is being carried out using optimization and intelligent- system techniques to address some of the common day-to-day problems that can affect the quality of service. Furthermore, the penetration of electronic devices such as power converters and flexible AC transmission (FACT) devices can be utilized to improve the system power quality. The future distribution network will also incorporate distributed generation, such as photovoltaic (PV), wind power, biomass, and micro turbines. This has improved the capability of distributed systems to meet the ever-changing load demands at a reduced cost for capital equipment.

The transmission and distribution of electrical power is commonly based on single- and three-phase transmission using aluminum conductors from point to point or to many other points. The challenge of routing power within its capacity limits at minimum cost and minimum losses is part of the overall design problem.

Power systems (in an unbalanced state) in the new competitive environment also have to meet some regulatory requirements to ensure safety and security. The important functions and regulatory requirements that must be met are as follows:

1. Generation, transmission, and distribution must be able to meet anticipated demand with sufficient reserve margins, which could be met by demand-side management schemes or storage schemes for the distribution business units.
2. The power system, including distribution subsystems, must be cost effective with the overall goal of meeting technical, economic, environmental, and public-perception constraints.
3. The reliability and quality of power transmission and distribution must be able to meet minimum standards.
4. Appropriate cost-benefit analysis should be done to ensure priority of project execution, which will improve the performance and quality of service.

With this in mind, modern tools must be developed to support the distribution options that have traditionally been tracked as nonrigorous, simple, and error-analysis strategies.

The distribution system's main features are shown in Figure 1.1. The sample diagram in Figure 1.1 consists of fuses, reclosers, relays, a circuit breaker, transformers, regulators (voltage), and dispersed generator/storage.

We describe each of them here briefly:

**Relay**: a device designed to protect against overvoltage, frequency, or current. It relays abnormal voltage or current to the circuit breaker to open (close) a circuit from further deterioration due to fault signals.

**Reclosers**: devices serving as special purpose, light-duty circuit breakers for interrupting overloads but not faults. It allows temporary faults to clear and then restores service quickly, but disconnects a permanent fault.

**Circuit breaker**: a high-current device that automatically disconnects faulted equipment. It facilitates protection of equipment from further damage or people from injury, and it is typically rated in terms of voltage and fault current. Circuit breakers come in different forms due to the arcing phenomena caused during contact (opening/closing) at high voltage. Typical models are air-blast circuit breakers, vacuum circuit breakers, oil circuit breakers, and sulfur hexafluoride circuit breakers, which use SFL gas media for extra-high voltage, which are applications above 345 kV.

**Fuses**: These are devices that melt when overload current passes through it. They come in different forms of low- or high-voltage fuses made from zinc, copper, silver, cadmium, or tin materials. They are rated in terms of BIL, voltage, continuous current, and interrupt-capacity fuse coordination (time it takes for the fuse to blow).

**Sectionalizer**: A device that is used to automatically isolate a fault online segment from a disturbance. It senses any current above its activating current followed by a line and then de-energizes using a recloser.
**Renewable energy/storage**: referred to as IPP, an independent power producer at the customer side. It is called distributed power resulting from a renewable energy source such as photovoltaic, biomass, microturbine, or wind power.

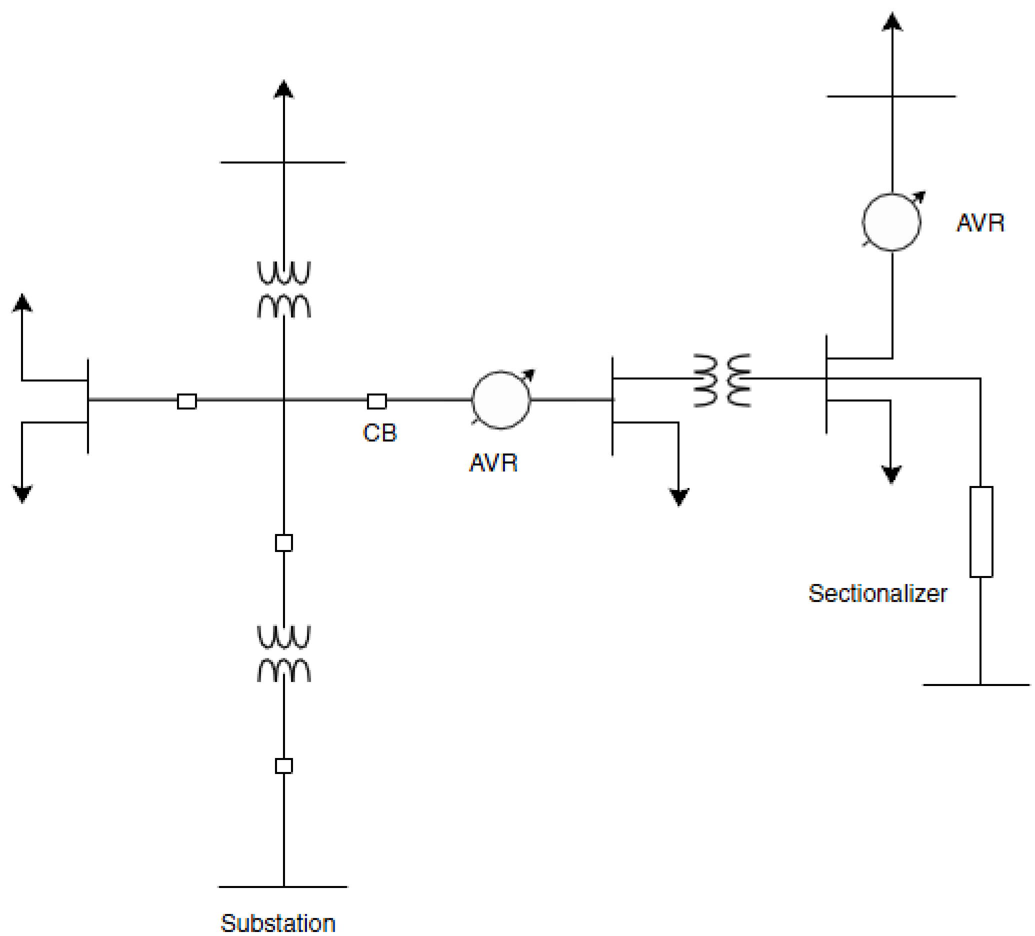


FIGURE 1.1 Distribution system.

## 1.3 Distribution Automation (DA) and Control

The term “distribution automation” is used to define the application of communication, optimization, and intelligent systems to improve the performance and functions of distribution systems during normal and abnormal operation. DA facilitates system efficiency, quality of service, and the security of the power system. These abilities are classified as DA function options as follows:

**Efficiency**: DA function option that controls (minimizes) losses through network reconfiguration and restoration by appropriate relocation of fuses, circuit breakers, and loads for optimum performance during an overload.

**Reliability and quality**: To guarantee that the system is reliable at an acceptable value of risk (given the history of recorded failures and duration), an index to quality-acceptable customer-interruption service preference is proposed. Actions to manage unreliability through maintenance or demand-side management (DSM) are planned using distribution automation. New data-gathering tools such as power management unit (PMU) and frequency recorders are used for reliability assessment.

**Security**: The security of distribution is enhanced using integration of dispersed energy storage, distributed generators (DGs), or FACT devices. The aim here is to reduce voltage sag and eliminate harmonics that could cause low power quality and to dampen instability caused by penetration of DGs.

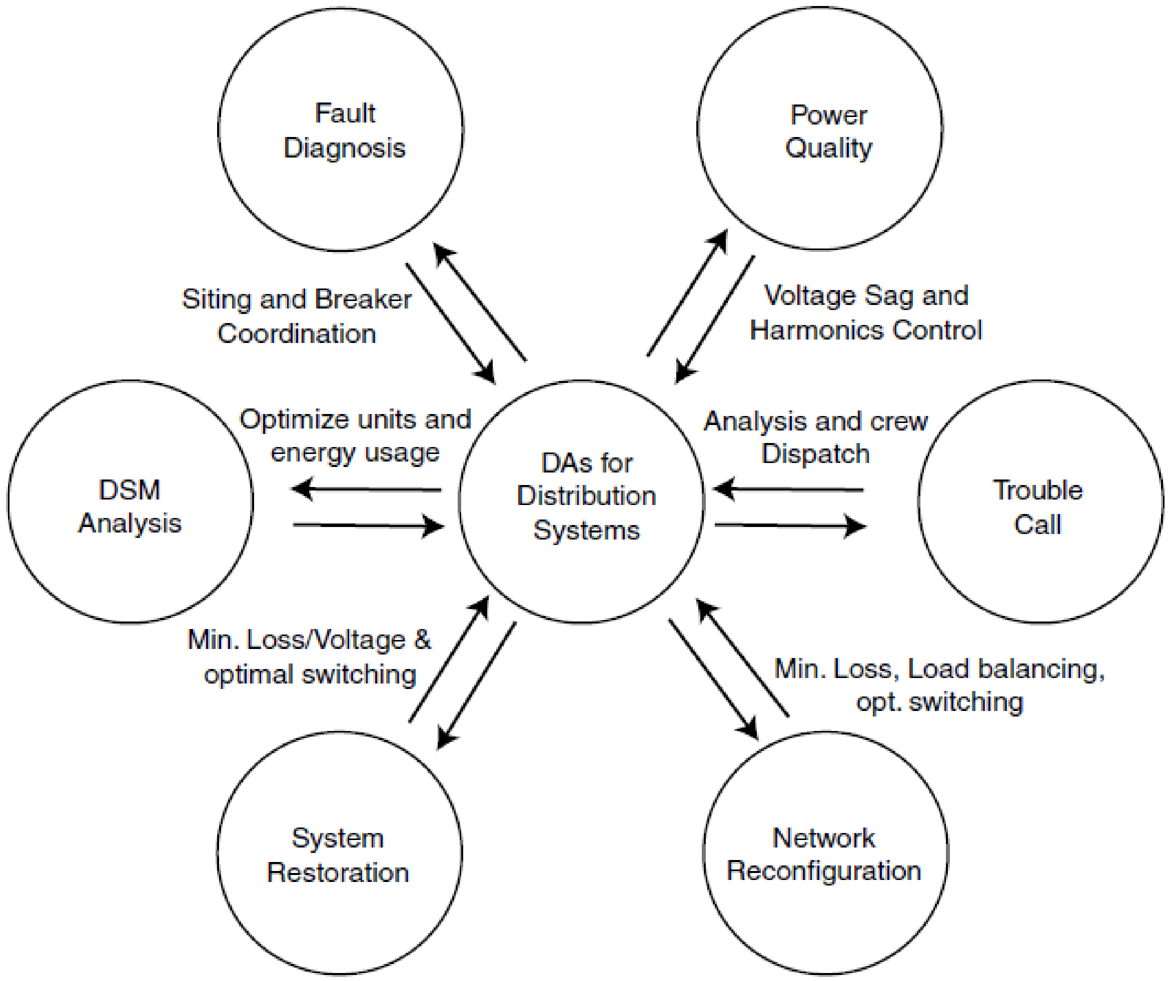


FIGURE 1.2 DA functions and structure.

The integration of these DAs will provide a platform for building a future, highly competitive, and efficient autonomous distribution system that will be able to respond to different situations and be self-aware, self-organizing, and self-reconfigurable.

We present here an overview of DAs for distribution systems. The overall structure indicated in Figure 1.2 utilizes a combination of optimization and intelligent systems to develop effective DA functions. For example, the intelligent system (IS) will be based on fuzzy logic for demand-side management and restoration. Expert systems will be used for classification and ranking of control options, and artificial neural networks (ANN) will be used for fault detection and restoration as well as power quality assessment and control.

Optimization schemes based on linear and mixed integer programming and next-generation optimization techniques, evolutionary programming, adaptive dynamic programming (ADP), Tabu search, and annealing methods will be used to enhance the development of distribution automation functions.

# 2

# Distribution Automation and Control Functions

## 2.1 Introduction

Electric power distribution is important in the delivery of energy to consumers from an electrical power system. The idea of distribution automation was motivated by the evolution of communication and information technology. Automated distribution uses these technologies to improve the operating performance of distributed systems, enhancing efficiency, reliability, and quality of service, as well as better management and control of the power distribution system. The principal objective can be summarized as energy conservation through reduction of losses, peak load, and energy consumption. IEEE defines a distribution automation system as one that enables an electric utility to remotely monitor, coordinate, and operate distribution components in a real-time mode from remote locations.

Distribution automation functions (DAFs) cover the following areas:

1. Demand-side management
2. Voltage regulation/VAr control
3. Real-time pricing
4. Dispersed generation and storage dispatch
5. Fault diagnosis/location
6. Power quality
7. Reconfiguration
8. Restoration

## 2.2 Demand-Side Management

Demand-side management (DSM) options provide an effective means of modifying consumer demand to cut operating expenses from costly generators while deferring capacity addition. DSM options also promote environmental conservation (reduced emission in fuel production) while sustaining industrialization at minimum cost and contributing to the reliability of generation systems. Demand-side management options have been categorized into:

1. Peak shifting
2. Valley filling
3. Peak clipping
4. Storage conservation

These options have an overall impact on the utility load curve. For DAFs, demand-side management is classified into three main categories:

1. **Direct control of load**: This uses a communication system such as power line carrier/radio to transmit control from the utility side to the customers. The aim is to directly control load, small generators and storage.
2. **Local load control option**: This enables customers to self-adjust load to limit peak demand, e.g., demand-activated breakers, load interlocks, timers, thermostats, occupancy sensors, cogeneration heating, cooling storage, etc.
3. **Distribution load control**: The utility controls the customer loads by sending real-time prices.

The cost benefits of direct-control options are numerous:

1. Reduced peak load/capital investment
2. Integrated least-cost planning
3. Emergency control — system contingencies/overload
4. Automatic control
5. Voltage collapse
6. Long-term stability
7. Operating (spinning) reserve
8. Distribution dispatch (normal conditions)
9. Reduced loading on facilities
10. Cold load pick-up

## 2.3 Voltage/VAr Control

Voltage control within a specified range of limits and capacitor switching are an effective means of minimizing loss and improving voltage profiles and deferred construction and maintenance costs in the end within the reliability and power-quality constraints of the system. Voltage/VAr control considers multiphase unbalanced distribution system operation, dispersed generation, and control equipment in the large system. In distribution automation, functions using voltage/VAr control options must maintain proper communication between planning problems like the decision to install capacitors, and recognizing the cost benefit analysis.

## 2.4 Fault Detection (Distribution Automation Function)

Conventional fault studies are concerned with "what if" scenarios, i.e., on considering what happens after a fault occurs, identifying the location of the fault, and assessing the nature of the damage caused by the fault. In contrast, if potential faults could be identified by an early warning system before a catastrophic fault actually occurs, the chance of an interruption of service would be reduced. The decision-analysis functions use the relevant information from the detection technique to enable appropriate control actions. We summarize the commonly used methods.

2.4.1 Classical Approaches Used for Solving Detection Techniques

**2.4.1.1 Harmonic Sequence Component Technique**
This uses the third and fifth harmonics of a fault current after frequency decomposition of three-phase unbalanced faults. One can detect and classify high-impedance faults by measuring the degree of unbalance and comparing it with a threshold.

**2.4.1.2 Amplitude Ratio Technique**
The harmonic currents are very small in a system under normal conditions. When an arcing fault/high-impedance fault occurs, the harmonic currents increase. The amplitude ratio technique is used to compare the second harmonic to the fundamental current or compare the ratio between even and odd harmonic currents for the first seven harmonic ranges.

**2.4.1.3 Phase Relationship Technique**
The presence of a notch on the leading edge of each half-cycle of a high- impedance current waveform indicates that they must be rich in odd harmonics. This observation is used to develop ratios of the third harmonic with respect to the fundamental frequency current or voltage.

**2.4.2 Modeling of Faults/Classification**

Faults are classified as Single-Line-to-Ground (SLG), Double-Line-to-Ground (DLG), or three-phase (3φ) bolted or unbolted short circuit faults, or open circuit faults occurring on one or more lines.
A high-impedance fault is a short-circuit fault through high impedance to ground. The above formulations and definitions provide the framework for designing different fault detection and location strategies.

1. On-line fault detection indicators are developed as part of decision analysis options.
2. The equipment status and difference network connectivity are available in new modern system engine interfaces but not in distributed systems.
3. A proper historic fault frequency data recorder should be installed at the utility and customer end to gather real-time data for analysis during a given fault event. User interfaces are for online interrogation.

## 2.5 Trouble Calls

The trouble-call distribution-automation option is a distribution management system in support of increased customer-focused service. It is built within the utility system to receive trouble calls from customers by phone, fax, or external communication services. This is a more cost effective method to reporting a fault event, as compared to physically going to the site location of the fault. Answering and logging of trouble calls are handled using advanced communication-support services.

Figure 2.1 shows the sequence of activities leading from reception of a trouble call to the dispatch of a crew. The trouble-call-handling scheme progresses through the following sequence. Local calls made to customer service and crews are immediately dispatched, or trouble-call information is processed via a customer call center to verify the problem type, confirm account activities, and proceed to authorization of a dispatch crew. A toll- free call can also be made directly to customer service to confirm account status and request service per trouble-call placement.

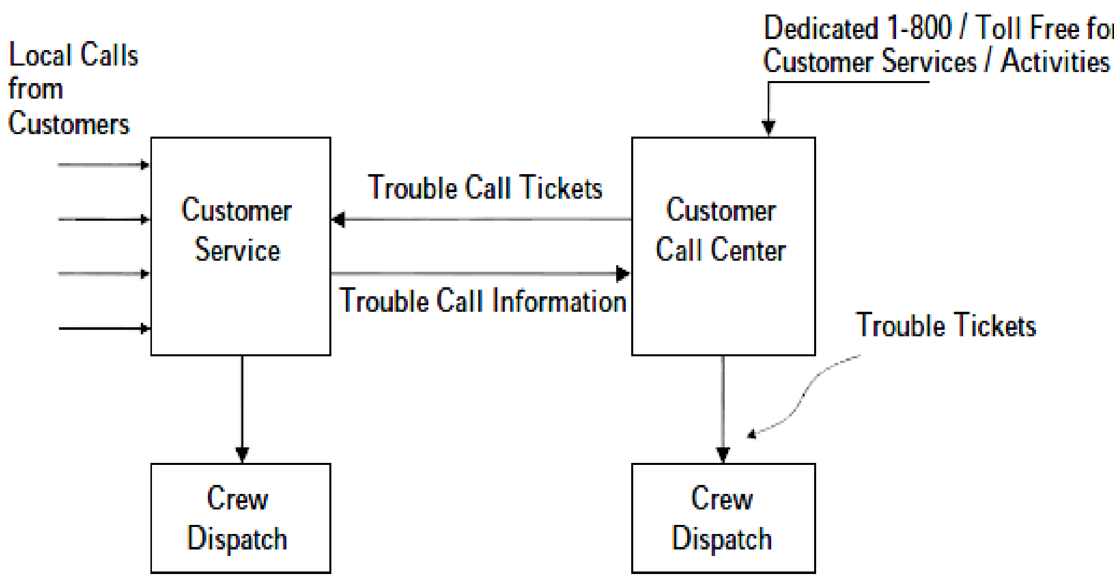


FIGURE 2.1 Trouble-call-handling sequence.

**Trouble-call handling and alarm processing**: New methods of remotely processing trouble (feeder problems, etc.) are done by using alarm processing indicating caller ID, telephone interface, loss-of-voltage indicator, and several other options.

**Trouble-call placement**: Overall system connectivity is checked locally if the network is available via geographic information systems (GIS) technology for network analysis, location of faulted distribution systems, and diagnostics. A repair crew may also be sent to the site for immediate repair or maintenance, depending on the nature of the problem. For instance, a switch gear may require maintenance, a capacitor bank may need to be switched, a pole may need replacement, etc. Feeder balancing and load balancing are other problems to be addressed during reconfiguration and restoration of the system. This aspect of distribution automation is referred to as trouble call management, and performance of other management applications may be necessary, such as receiving calls, diagnosing and locating the fault, identifying all affected customers, and restoring the network in the shortest possible time.

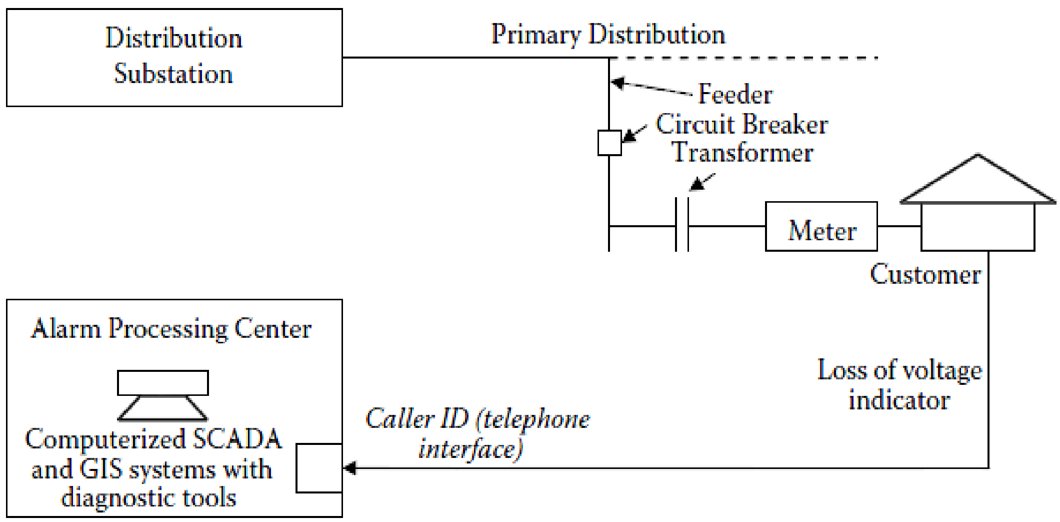


FIGURE 2.2Basic communication schemes in a trouble-call reception system.

The use of supervisory control and data acquisition (SCADA), energy management systems (EMS), customer information systems (CIS), and geographic information systems (GIS) interface is strongly recommended for a reliable and efficient trouble-call management. Future research in trouble- call analysis and alarm management for distribution systems is in development. The basic communication linkage between distribution automation and customer during trouble-call management is shown in Figure 2.2.

Customer-based trouble-call analysis under development includes the fault detection of the distributed generation network with the following problems: loss of voltage (leading to voltage collapse and instability), power factor correction, harmonic etc.

## 2.6 Restoration Functions

Planning a restoration service for a distribution system is a critical task for dispatchers in a power system control center. Restoration provides an ample amount of power to non faulty out-of-service areas for as many customers as possible while guaranteeing the safety and optimum reliability of the distribution systems. Several methods exist to solving restoration problems, ranging from the dispatcher's experience and to the operating values used in intelligent systems. The classical optimization technique is aimed at minimizing the number of unserved customers. (Use of sequential restoration schemes with analytical cold load pick up model to minimize the total restoration time.)

## 2.7 Reconfiguration of Distribution Systems

Distribution networks are generally configured in a radial structure. The configuration can be varied with manual or automatic switching operations so that all the loads are supplied with minimum losses and increased reliability, power quality, and security. The automatic switching sequence is an important subject in distribution automation. Switching operations are performed to ensure that the radiality of the network is maintained while preventing the distribution system from out-of-service conditions, overloads, or unbalanced conditions. The greater the number of switches, the greater are the possibilities for reconfiguration and ease of application.

To evaluate every possible configuration of the network feeders results in too many combinations to select for an optimal or near-optimal solution. Several techniques from heuristics, optimization, and intelligent systems have been proposed. The principal aim of reconfiguration is to satisfy the following objectives:

1. Minimize distribution losses
2. Optimize voltage profile
3. Relieve overload requirements while maintaining the radial structure of the network

2.7.1 Methods Used for Reconfiguration

1. **Loss minimization**. This has been an active research area. It was first developed by Merlin and Black using the branch-and-bound-type optimization method to determine the minimum loss configuration based on a schedule-switching pattern that corresponds to the loss.
2. **Heuristic algorithm**. This is an extension of the previous method that involves introducing an improved load flow and closing all switches, which are then opened one after each other so as to establish an optimum power-flow pattern.
3. Other variants of the first two methods are developed to improve the load estimation, to facilitate effective determination of system configurations, and to enhance modules for computing cost-benefit analyses of the reconfigured structure.

Other noncombinational heuristic search methods, binary integer programming techniques, optimization techniques, and annealing methods have been used to determine minimum energy losses for a given period. Additionally, AI techniques have been proposed for minimum loss using artificial neural networks (ANN), rule-based systems, genetic algorithm (GA), fuzzy logic (FL), and other evolutionary programming algorithms. The schemes for network configuration do not explicitly take into account the radiality aspects due to modeling issues in mathematical programming techniques.

## 2.8 New Approaches of Power Quality

New techniques include wavelet transforms, artificial neural net- works (ANN), and genetic algorithm (GA) methods. New signal-processing techniques such as wavelet transforms are used to improve feature extraction. The wavelet transform has the ability to handle nonstationary harmonic distortions in power distribution systems, and the results obtained by applying wavelet transforms provide a better assessment scheme for power-quality study for broadband signals that may not be periodic — a case for power transients. The ability of waveform transforms to dilate or contract transient signals while varying the frequency allows for the representation of power disturbances in a three-dimensional space.

# 3

# Intelligent Systems in Distribution

JECRC

# Automation

## 3.1 Introduction

Artificial neural networks (ANN) and genetic algorithms (GA), which are used to achieve an efficient and reliable distribution system. This chapter reviews the directions of research in this field and the application of intelligent systems to distribution automation functions. Next, we will identify the common trends and emerging trends in intelligent systems as they cut across several domains of power system automation. Finally, we will outline research themes of significant importance for the future evolution of intelligent systems in distribution automation functions.

The following features frequently characterize these problems:

- Inadequate model of the real world
- Complexity and size of the problems, which prohibit timely computation
- Solution method employed by the human incapable of being expressed in an algorithm or mathematical form; usually involves many rules of thumb
- Operator decision making based on fuzzy linguistics description

These drawbacks have motivated the power system community to seek alternative solutions techniques through the use of artificial intelligence (AI) systems and variants of its applications. In this chapter such techniques including Expert System, Artificial Neural Network, Fuzzy logic and GA are explained.

## 3.2 Distribution Automation Function

The problems of distribution automation functions have been discussed earlier. They include the following:

**Reconfiguration**: principal aim of reconfiguration is to minimize distribution losses, optimize voltage profiles, and relieve overload requirements while maintaining the radial structure of the network.

**Restoration**: provides an ample amount of power to nonfaulty, out-of-service areas for as many customers as possible while guaranteeing the safety and optimum reliability of the distribution systems
**Power quality**: refers to a large number of anomalies related to voltage, current, and frequency deviation that result in failure or abnormal operation of customer/utility equipment
**Fault analysis**: involves considering what happens after a fault occurs, identifying the location of the fault, and assessing the nature of the damage caused by the fault

## 3.3 Artificial Intelligence Methods

AI is a subfield of computer science that investigates how the thought and action of human beings can be modeled or mimicked by machine. The symbolic computation involved in AI is numeric and nonnumeric. The mimicking of intelligence includes not only the ability to make rational decisions, but also to deal with missing data, to adapt to existing situations, and to improve itself over a long time horizon based on accumulated experience. In general, it is conceived as a computer program that possesses an algorithm that attempts to model and emulate, thus automating an engineering task that was previously carried out by a human. In this section we provide an overview of four major families of AI techniques that are applicable to distribution systems, namely:

- Expert system techniques (ES)
- Artificial intelligence neural networks (ANN)
- Fuzzy logic systems (FL)
- Genetic algorithms (GA)

### 3.3.1 Expert system techniques (ES)

An expert system is an artificial intelligence (AI) program incorporating a knowledge-and-inference system. The expert system software includes heuristic rules based on the expert's experience. In such a system, the knowledge takes the form of so-called production rules written in the form of if/then syntax (knowledge base). The system includes facts, data that generally describe the domain and the state of the system contained in the so-called database.

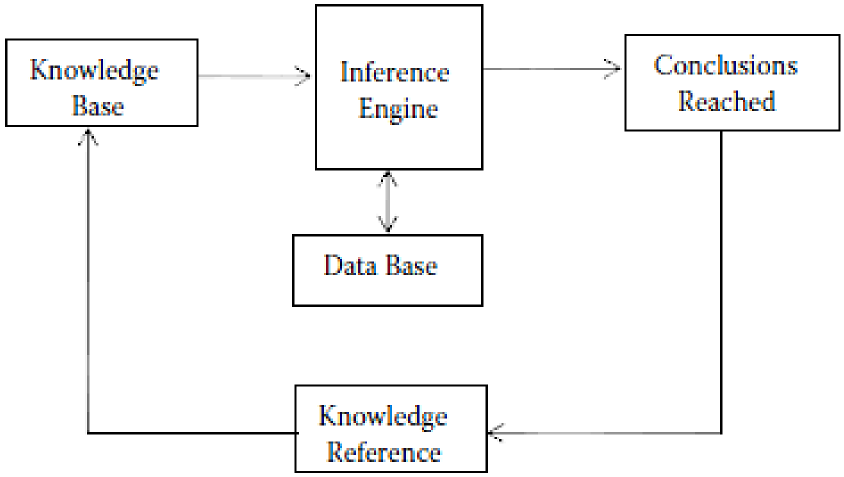


FIGURE 3.1 Architecture of an expert system.

### 3.3.2 Artificial intelligence neural networks (ANN)

The ANNs are very different from expert systems, as they do not need a knowledge base to work. Instead, they have to be trained with numerous actual cases. An ANN consists of interconnected processing elements known as neurons or nodes. It acts as a directed graph in which each node performs a transfer function $f_i$ of the form

$$y_i = f\left(\sum_{j=1}^{n}\left(w_{ij}x_j - \theta_i\right)\right)$$

or for high-order networks of multiple input

$$y_i = f_i\left(\sum_{j=1}^{n}\left(w_{ij}x_j x_m - \theta_i\right)\right)$$

where

$y_i$ is the output of node $i$

$x_j$ is the $j$th input to the node

$w_{ij}$ is the connection weight between nodes $i$ and $j$

$\theta_i$ is the threshold (bias) of the node

Usually $f_i$ is nonlinear, and it is represented as a heavy-side, sigmoid, Gaussian, or exponential function.

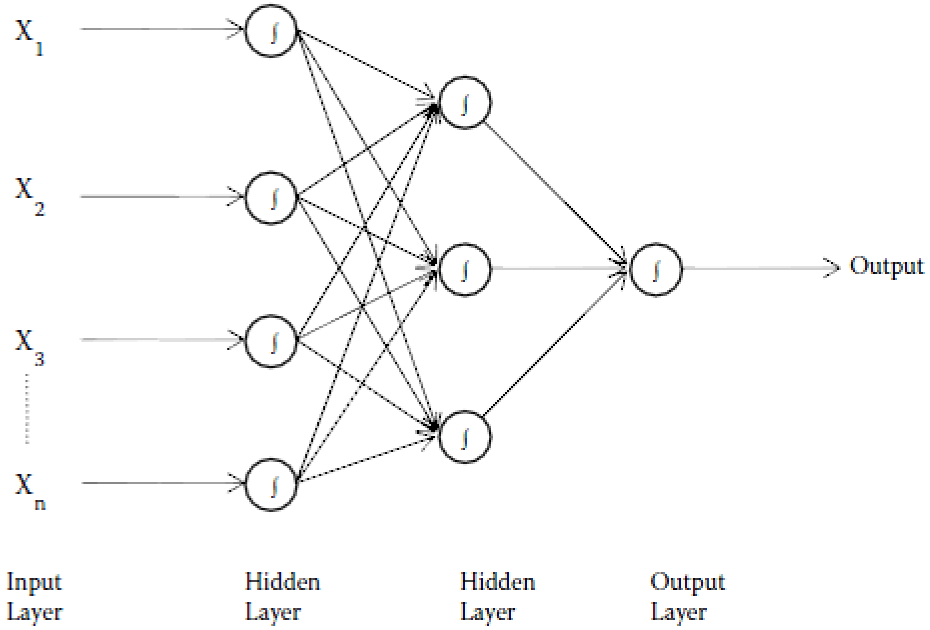


FIGURE 3.2 Architecture of an ANN.

### 3.3.3 Fuzzy Logic

"Fuzzy set" is a term coined by Professor Zadeh to argue that human reason cannot be represented in terms of discrete symbols and numbers but in fuzzy sets. Fuzzy set are functions that map a value that might be a member of the set to a number between zero and one, indicating the actual degree of membership.

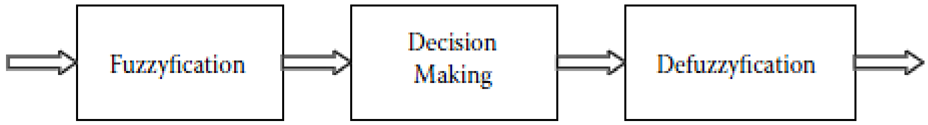


FIGURE 6.3 Simplified block diagram of fuzzy logic approach.

### 3.3.4 Genetic Algorithms (GA)

Genetic algorithms emphasize the use of a gene type that is decoded and evaluated. These gene types are often simple data structures. The chromosomes are bit strings that can be recombined in a simple form of several reproductions and can be mutated by simple bit flips. These algorithms can be described as function optimizers. GA algorithms find competitive solutions, but GA is also useful as a search process rather than strictly as an optimization process. As such, competition of selection of the fittest is the key aspect of a GA search.

Table 3.1

Comparison of Classical AI Techniques

| Features | Artificial Intelligence (AI) Techniques | | | |
|---|---|---|---|---|
| | ES | ANN | FL | GA |
| Knowledge used | expert knowledge in forms of rules | information from training sets | expert knowledge in developing fault criteria | information data search |
| Modify results | inference engine rules can be changed | internal signal cannot be changed | easy to change internal signal | cannot be changed internally |
| Self-learning | possible | natural | possible | natural |
| Robustness | noncritical, easy to ensure | difficult to ensure | not critical, easy to ensure | difficult to ensure |
| Diagnose fault | convenient | large number of simulations required | convenient knowledge and simulation are used | large number of simulation required |
| Computations | extensive | dedicated hardware | moderate | extensive |

The intelligent systems (IS) — ES, ANN, FL, and GA — have their own advantages and limitations. The IS systems have the following features in common for comparison, as seen in Table 3.1: what knowledge is used, how to modify the results, self-learning ability, robustness, fault diagnosis, and computations required. These attributes will be compared for different automation functions, for example fault analysis/diagnosis.

## 3.4 Intelligent Systems in Distribution Automation

### 3.4.1 DSM and AI

There have been successful implementations of ANN, expert systems, another heuristic schemes and generic algorithms in the area of load dispatching, optimal power flow (OPF), and unit commitment, but they have not been fully utilized in the area of load management until recently. It is worth-while to explore the possibility and potential of using intelligent systems in managing loads in distribution systems.

The limitations of existing demand-side management (DSM) are as follows:

1. The chronological load impact of DSM can be taken care of, but often at the cost of ignoring the network aspect. Thus a full AC network that accounts for VAr/MW is necessary.
2. An accurate model of DSM options and characteristics produces a high

computational burden due to the large number of control variables at each element node.
3. The requirement of full AC modulation calls for a highly efficient algorithm.

Based on the above observations, an AI approach could be developed that would provide a compromise between mathematical programming rigor and computational practicality. For example, the following is one way of achieving optimal DSM scheduling using AI:

1. Taking the output of optimal power flows for different hours from the pre dispatch stage to train a neural network to yield a set of power-flow solutions in real time given the real-time data on nodal demand and DSM resource availability

2. Fuzzifying the DSM characteristics and some of the unit-commitment-related constraints, like start-up/back-down constraints and minimum uptime/downtime constraints, to reflect the degree of satisfaction of these constraints

3. Applying a rule base compiled with a fast-decouple load flow to check the constraints of the network solution and analyze DSM impacts

## 3.5 Use of AI Techniques for Fault Analysis

With the progress made in AI, the classical approach used to analyze fault problems has changed. AI schemes are being used to solve the most complex problems such that we can achieve speed, accuracy, and reliability of the results and low cost for the detection schemes. Many AI-based methods have been considered by researchers. Some of the outstanding work needs to address the following:

1. Development of a rule-based technique for classifying different types of faults combined with the use of a fuzzy logic system for appropriate fault location.

2. The use of ANN to classify faults that are hard to model, such as arcing and high-impedance faults

3. A hybrid of ANN and expert systems to combine the special features of diagnosis and location of different faults

# 4

# Distribution Management Systems

## 4.1 Introduction to EMS

An energy management system (EMS) balances the sources of energy and consumption of energy to achieve the lowest cost. The energy sources can be electricity, water, gas, oil, steam, or renewable energy in the form of distributed generators (DG). The consumption of energy can be industrial, commercial, manufacture, or residential.

An EMS generally puts the user in control of energy consumption through monitoring, billing, and cost allocation. The integrated management software consists of power flow, security assessment, system stability, and system reliability. Furthermore, EMS represents a large collaboration of power distribution control products that connect state-of-the-art devices for communication control. It interfaces with communication and intelligent devices such as switchgear and intelligent switching controllers that are connected through an Ethernet network to computer systems equipped with software for collecting and displaying data from the network

### 4.1.1 DMS and EMS

A DMS (distribution management system) and an EMS are similar in many ways:

1. Both collect measurements of the state of the system and its power devices remotely at the data collection terminals equipped with remote terminal units (RTU).
2. Both processes present information to operators through a user inter- face on a video display.
3. Both store information for later retrieval and analysis of historic events.
4. Both contain analytical functions to help operators interpret the information and analyze future situations.

However, there are fundamental differences between distribution and transmission systems; hence there are also differences between DMS and EMS:

- Distribution systems are typically radial; transmission systems are typically network connected.
- Distribution system devices are located along the length of distribution circuits, often on pole tops: transmission system devices are generally located only at substations.
- The number of locations requiring RTUs in a distribution system is at least an order of magnitude greater than the number of locations in the associated transmission system.
- On a distribution system, most field devices are manually operated; on a transmission system, most fields devices can be remotely controlled.

## 4.2 SCADA (Supervisory Control and Data Acquisition)

SCADA is a platform with basic functionality to classify or handle events, alarm processing, monitoring, and the limits of measurable power qualities.

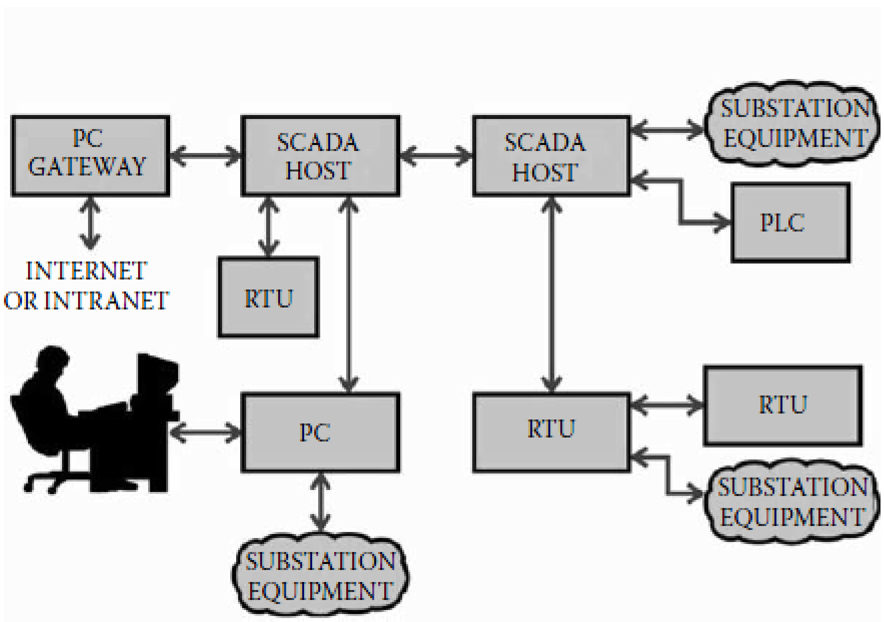


FIGURE 4.1 General SCADA architecture.

It consists of a process database, a man–machine interface (MMI) (a PC with a graphical user interface [GUI]), and application software. The MMI accesses the data from the process database and presents it in the form of single-line-diagram tabular displays and reports. MMI is based on a client- server architecture and the display device, which can be a workstation or a PC with a standard GUI. The general architecture of a SCADA system is shown in Figure 4.1.

The overall SCADA functions include:

- Data acquisition from the transmission system equipment and sub-sequent processing of the data received for further uses
- Provision of state estimation data based on data collected at the substation level
- Control of the transmission system equipment and alarms to notify operators when an abnormal event occurs
- Event and data logging to record all interactions between the operator and the system
- Man–machine interface that provides an interactive channel for the operator
- Voltage control for automatically controlling the voltage of any specific point in the transmission system

## 4.3 RTU (Remote Terminal Units)

RTUs are installed in distribution substations at various feeders and other pieces of equipment to facilitate automation of the distribution network. They are also used as a digital communication interface with computer-based substation control systems. They are designed in modular form for use in pole-top, single-node configurations as well as large multimode configurations in substations.

Distributed architecture is used to connect an RTU to the control node. The control node in turn connects with the DMS master using DNP3.0 protocol. IEC 810-5-101 communication protocol is also possible. Input/ output (I/O) nodes include digital signal processing, which enables AC input from potential and current transformers. This information is used to compute real and reactive power flows; to calculate harmonic contents and other power quality indicators, such as voltage sag and swells; and to detect and collect distributed data, including the sequence of events. RTU also supports the definition and execution of programmable large functions, such as closed-loop voltage control of transformer taps.

The substation RTU communicates with the DMS master over an existing digital microwave link or over leased lines and a time-division multiple- access radio system. RTU communication generally uses 9600K links, and these are polled for data every 2 sec for status changes and every 10 sec for analog changes. The RTU analog points are typically configured with 1% dead band for reporting changes. RTUs are generally equipped to report data as specified in the protocol arrangement.

## 4.4 SCADA System Functions for DMS

Each DMS has full high-performance SCADA functionality. This provides all typical data acquisition, alarming, supervisory control, historical data collection, and other functions expected in a modern control center (Figure4.2). It is characterized by the following attributes:

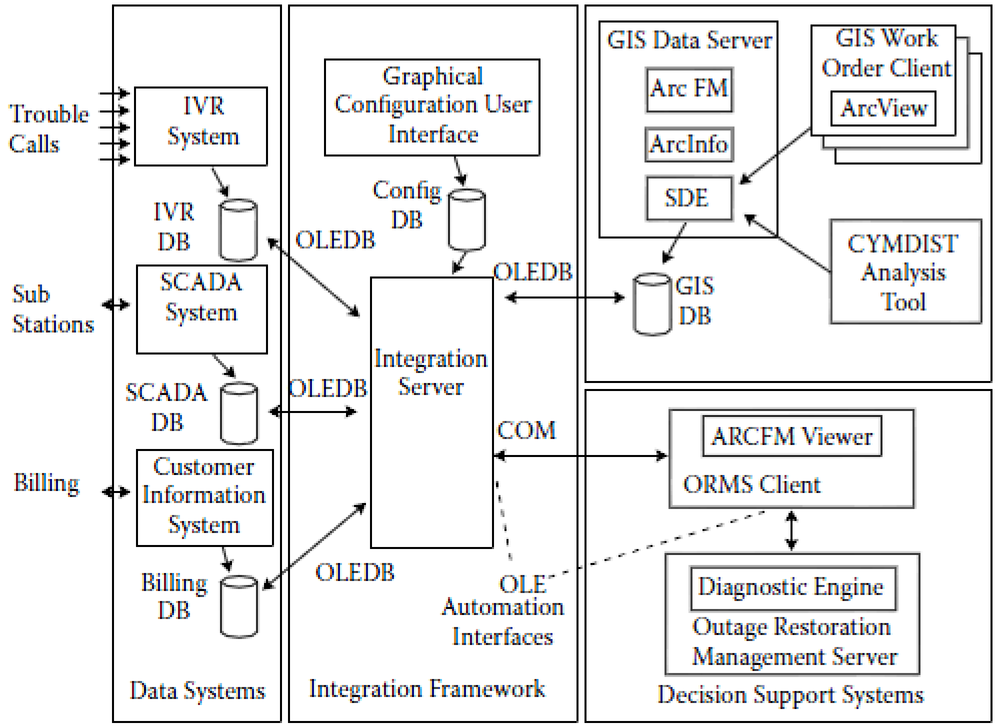


**FIGURE 8.2** Architecture of integrated distribution management system.

- **Flexibility**: The architecture should be capable of providing sealable application and support a diverse set of distribution applications.
- **Expandability**: New functions can be integrated into the existing program easily without affecting other functions.
- **Maintainability/portability**: If changes to the database scheme for a power system model are required, the effect is limited to data-access routines; no application code should be affected.
- **Data integrity**: Data integrity must be easily accomplished and be independent from any application.

## 4.5 DMS Functions

At the heart of the DMS are the application functions that provide network model analysis and capability. The functions of a DMS application system are grouped into layers, as illustrated in Figure 4.3:

1. Substation and feeder SCADA (SFS)
2. Substation automation (SA)
3. Feeder automation (FA)
4. Distribution system analysis (DSA)
5. Application based on geographic information system (GIS), such as automated mapping (AM) and facilities management (FM)
6. Trouble-call analysis management (TCM)
7. Automatic meter reading (AMR) and distribution system analysis

These functions are displayed with selected application areas used in distribution automation functions, as seen in Table 4.1

TABLE 4.1

Distribution Automation Functions

| Substation Automation Functions | Feeder Automation Functions | Customer Interface Automation Functions |
|---|---|---|
| Data acquisition from:<br>· Circuit breakers<br>· Load tap changers<br>· Capacitor banks<br>· Transformers<br>Supervisory control of:<br>· Circuit breakers<br>· Load tap changers<br>Fault location<br>Fault isolation<br>Service restoration<br>Substation reactive power control | Data acquisition from:<br>· Line reclosers<br>· Voltage regulators<br>· Capacitor banks<br>· Sectionalizers<br>· Line switches<br>· Fault indicators<br>Supervisory control of:<br>· Line reclosers<br>· Voltage regulators<br>· Capacitor banks<br>· Sectionalizers<br>· Line switches<br>Fault location<br>Fault isolation<br>Service restoration<br>Feeder reconfiguration<br>Feeder reactive power control | Automated meter reading<br>Remote reprogramming of time-of-use (TOU) meters<br>Remote service connect/disconnect<br>Automated customer claims analysis |

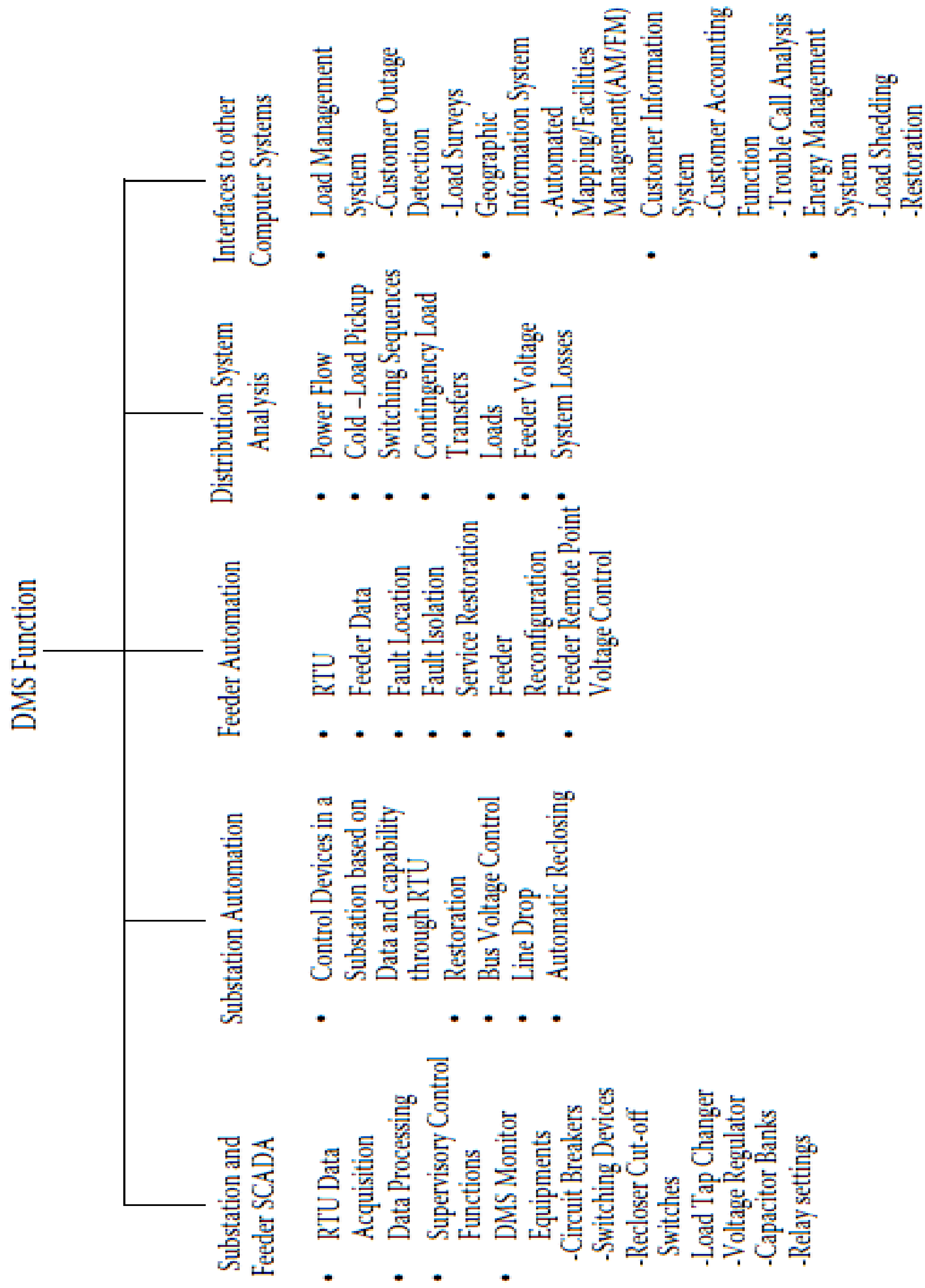


FIGURE 4.3 DMS function layers

### 4.5.1 Substation and Feeder SCADA

A SCADA system coupled with RTUs serves as supporting hardware to the DMS in monitoring: the distribution equipment of substations (circuit breakers and other switching devices); the status of reclosers, cutoff switches, and load tap changers; voltage regulator positions; capacitor banks; bus phase voltages; transformer temperatures; relay settings; real and reactive power flows; harmonics; and voltage sag and swells. DMS monitors equipment located on pole taps and other locations along feeders, including line recloser sections, and other measurable quantities such as capacitor bank status, phase voltages and magnitudes, switchgear status, etc. The SCADA system at the substation provides sequence-of-events recording data collection and event logging, and it generates reports on system stations.

### 4.5.2 Feeder Automation

The DMS system supports feeder automation functions, which include:

- Feeder automatic sectionalizing for fault location, isolation, and restoration (FLIR)
- Service restoration of feeder
- Feeder reconfiguration
- Voltage/VAr control
- Substation reactive power control
- Substation transformer load balancing
- Cold pickup and automatic reclosing

### 4.5.3 Substation Automation (SA)

The substation automation layer includes control devices, and data collected from these devices are processed via RTU or DMS application software that does digital signal processing (DSP). The data information from substation automation are used to perform system restoration based on voltage control, optimal reclosing, and switching.

### 4.5.4 **Distribution System Analysis (DSA)**

The distribution power flow is the key analysis tool in a DMS system. It models system components and is used to determine the steady-state criteria of the system voltage and to compute balanced or unbalanced system conditions. It is also developed to handle radial, loop, or mixed configurations. Distribution power flow is capable of handling single-phase, double-phase, or three-phase systems. Chapter 5 provides computational algorithms for distribution power flow.

Fast analysis techniques for voltage control, distribution losses, cold-load pickup, system restoration, and contingency analysis are available. Off-line stand-alone applications based on telemetered or static-mode data and state estimation techniques can be used to detect erroneous measurements in the distribution system. The distribution power flow, in general, serves the same function as in the EMS counterpart used in the transmission system environment.

### 4.5.4 Load Management System (LMS)

These are special interconnection systems designed for direct load control. They are equipped with a load management system accessible through a communication system. Large load management systems employ power-line communication (PLC) or some other communication technology using the distribution feeder as a communication path. The load management system is used for different automation functions in a distribution management system (DMS). It provides interface automation for automatic meter reading (AMR), direct load control, customer-outage detection, customer and load management, as well as trouble-call analysis for a given distribution system.

### 4.5.5 Geographic Information System (GIS)

The geographic information system (GIS) is an automated mapping/facilities management (AM/FM) system that was developed in the 1980s in the U.S. It links automated digital maps of utility infrastructure to databases containing nonspatial facility-management data. The GIS is easily interfaced with a distribution-automation operator and other customer-based information systems. A GIS database could be used as the source for distribution model data supporting the distribution system analysis formulation. GIS can also provide automatic data transfer on the status of monitored switches and operator entry of manual switches, trouble-call management, and update information to the customer during an outage.

Geographic information systems (GIS) are now developed with Web-supported servers. This enables updating of maps more efficiently and accurately compared with the manual-based GIS services done daily based on field marking from crew workers.

### 4.5.6 Customer Information System (CIS)

The customer information system (CIS) was developed to solve the customer- accounting function and the trouble-call analysis function. The CIS is often used in connection with a trouble call that connects the trouble-shooter to the location of the suspect device. The DMS in the distribution system also provides support to the trouble-call analysis function.

# 5

# Communication Systems for Distribution Automation Systems

## 5.1 Introduction

As the energy enterprises are slowly restructured, utilities and customers are feeling the pressure to reduce costs, improve efficiency, and increase operating flexibility. This is accomplished through the introduction of communication options to support distribution systems. Technical devices associated with distribution automation functions include remote terminal units (RTU) and supervisory control and data acquisition (SCADA). Utilization of these devices provides the framework for the design and development of a distribution system.

### 5.1.1 What is Telecommunication?

Modern communication systems involve the integration of computers and telecommunication technology. Telecommunication is communication from afar using various forms of equipment, computers, networks, and different media over short to long distances. Early forms of communication from afar, including drums, mirrors, flags, and smoke, became extinct following the discovery of electricity by Edison. The value of both electricity and telecommunication has revolutionized our world and continues to penetrate our lives. Much progress has been made in research and development of telecommunication and its applications to power system automation. The telecommunication industry has facilitated several of the distribution automation functions, such as:

- Improved reliability
- Greater cost efficiency through automatic meter reading and billing
- Automatic outage analysis and maintenance

• Acceptance of various architectures and protocols for different data types and controls for efficient management
• Provision and handling of control strategies to improve the configurability, restoration, and quality of supply

## 5.2 Telecommunication in Principle

Telecommunication is generally a transmission from a transmitter, which is a source, to another device (sink) called the receiver. Messages are coded in analog or digital encoder waveform and sent through a communication channel to a decoder or demodulator to an output signal to the message device. This communication line can be from one computer to another computer or from one device to another device with the capability to be configured as:

Simplex (one directional) where information flow can have any orientation, but it all flows in the same direction simultaneously

Half duplex, where information can flow in two directions, but only in one direction at a time

Duplex, also known as full duplex, where information can flow in two directions at the same time

## 5.3 Data Communication in Power System Distribution Network

Telecommunication facilitates the transport of data and information among distribution agents for the purpose of system analysis and for remote use for storing, retrieving, and processing. The resulting enterprise is simply an information system with distribution management system (DMS) software that organizes data to produce information to benefit the distribution automation function. It provides:

• Opportunity to plan future activities and its supportive role
• Information that guides (controls) present activities
• Supportive information that is used to operate the enterprise

The telecommunication setup shown in Figure 5.1 involves data communication between RTU, DMS, and other automated distribution functions, which requires the use of data signals for automation and control.

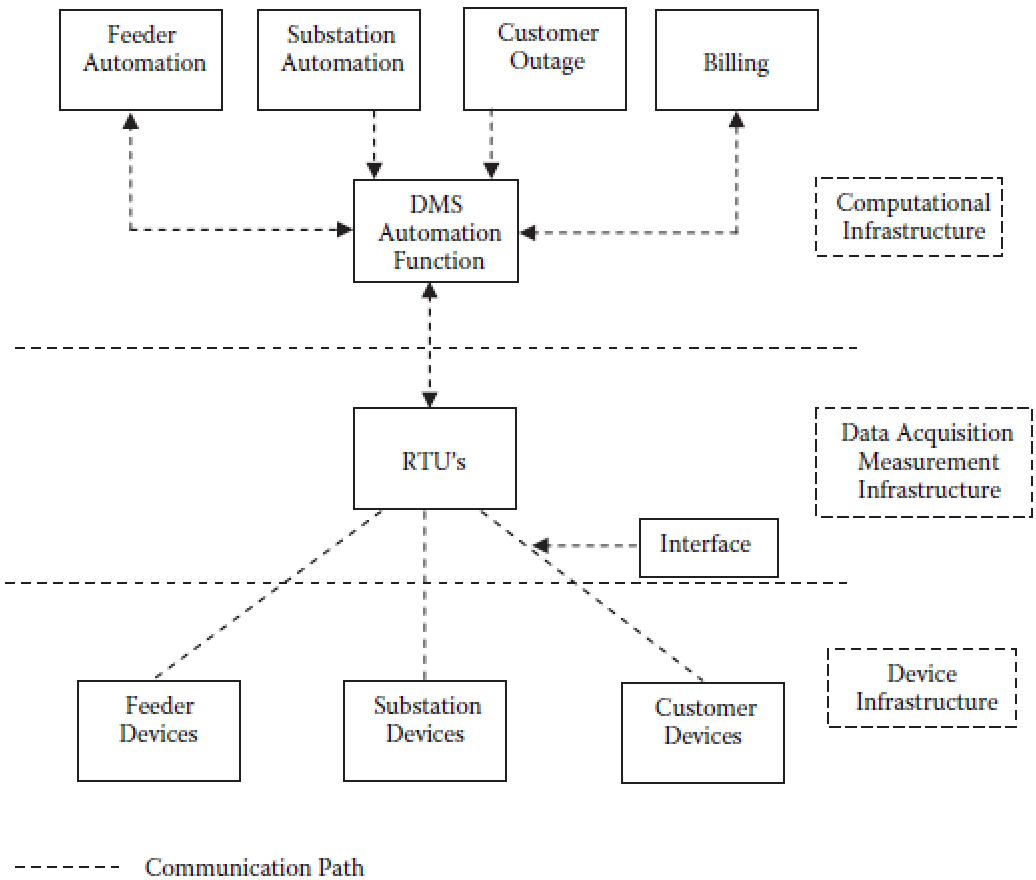


FIGURE 5.1Integrated distribution systems.

## 5.4 Types of Telecommunication Media

In recent years, new technology has been developed to facilitate communication via signal transmission. Such transmission can span long distances, between local phones and from computer to computer, hence providing the backbone for many communication networks. These networks are used in office buildings, industrial plants, and electric utility companies. All communications require a link between those originating the transmission and those receiving it. In electrical digital communications, the conversion of bitstream signals can carry the information over the communication medium.
Those signals are electromagnetic waves that are carried through a medium as radio waves or optical signals. Commonly used media are described in the following subsections.

### 9.4.1 Copper Circuit

The most widely used communications medium is still the copper circuit, consisting of a direct link using parallel conductors, twisted-pair conductors, or coaxial cable. Although copper is the best-known conductor, other metallic materials are used. One particularly interesting communications method available to the power supply industry is power-line carrier (PLC), where the conductors used to carry electric power are also used to carry communications signals using PLC techniques that have been extended from the use of EHV (extremely high voltage) transmission lines to include overhead lines and cable distribution systems and signalling data mains. Propagation along a copper link is governed by the interaction of electrical and magnetic fields in the conductors. This leads to delay, distortion, attenuation**,** and reflection of the signals in the communications circuit, all of which complicate the transfer of information. The propagation speed in copper is about the speed of light (3×10^8 m/sec).

### 5.4.2 Twisted Pair

This is made from insulated copper wire and consists of a large number of pairs of copper wires of varying sizes in a cable. At high frequency, signals are able to leak out in twisted-pair cable. It is unsuitable for high-speed data transfer due to loading coils at the low-pass filter and bridge tap, which does not allow a direct path of electrical signal flows.

### 5.4.3 Coaxial Cable

Coaxial cable consists of a single-stranded iron wire core surrounded by shielding. It has a higher transmission speed than twisted pair.

### 5.4.4 Fiber Optics

A fiber-optics system is similar to a copper wire system. It uses light pulse signals instead of the electrical signals that are used to send information down copper wire systems. We provide here the characteristics of a fiber optic cable.
A light-emitting diode (LED) is used to generate the light pulses, which move down the fiber-optic line. Fiber-optic cable is constructed from a fiberoptic strand or cable clad, which represents the strength of the material and is illustrated in Figure 5.2.
The optical receiver receives the light pulses and converts it to an electrical signal for further information processing. The electrical signal is then transmitted via a coaxial cable to the end user. It has a very wide application in power companies for monitoring and communication systems as well as in office buildings, universities, industries, etc.
The immediate advantage of optical fibers is that they have a high inherent immunity to external interference and do not generate interference. The signal used in this medium is light. Short bursts of light can be used to represent 1, and the absence of light can be used

to represent 0. However, the propagation properties of the optical fibers can lead to delay, distortion, attenuation, and reflection of the transmitted signals.

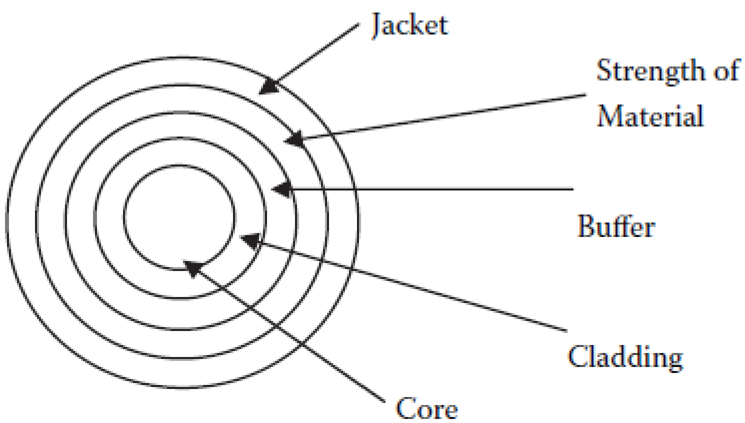


FIGURE 5.2Cut view of a fiber-optic cable.

Because of its wide use, we enumerate both its merits and demerits. Fiber optics does not connect easily with current hardware, and so some amount of retrofitting has to take place. The speed gained is inhibited at the conversion points, and some malfunction can take place at the electronic interface hardware. However the greater bandwidth and speed outperform other media. It is important that a signal regenerator be used to boost the electronic pulse in a copper cable to keep the signal going in the fiber-optic system. An optical repeater is also used to transmit the pulse in a fiber-optic cable.

### 5.4.5 Microwave/Radio

These are transmission media above the Earth and the ionosphere. Microwave relay stations are built for line-of-sight-path communication to either another microwave relay station or a satellite communication site at about 22,000 miles above the Earth. The signals are then processed by another microwave relay station on Earth.

The immediate advantage of radio and microwave communications is that they do not require a physical link between the transmitter and receiver. The dependability of these systems relies on the capabilities of the base stations, since the medium is guaranteed and the range of transmission can be very great. Radio systems offer broadcast facilities by which a transmitted signal is received by several receivers, whereas microwave systems use directional capabilities so that the transmission is concentrated to a single receiver.

Radio and microwave transmissions are susceptible to delay, distortion, attenuation, and reflection. They are also susceptible to and generate interference.

## 5.5 Frame relay in distribution automation

Frame relay is a networking protocol that works at the bottom two levels of the OSI reference model: the physical- and data-link layers. It is an example of packet-switching technology, which enables end stations to dynamically share network resources. Frame-relay devices fall into the following two general categories:

1. Data terminal equipment (DTE), which includes terminals, personal computers, routers, and bridges

2. Data circuit-terminating equipment (DCE), which transmit the data through the network and are often carrier-owned devices (although, increasingly, enterprises are buying their own DCEs and implementing them in their networks)

Figure 5.3 illustrates a typical use of a frame relay in distribution automation.

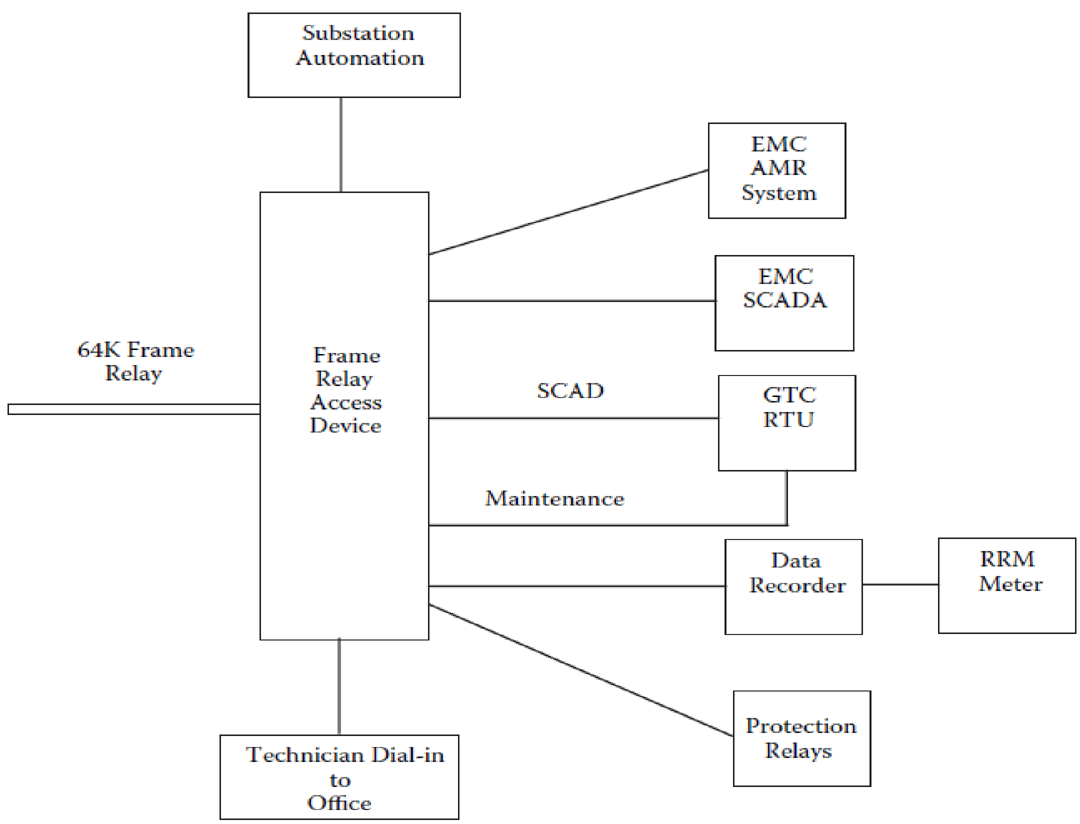


FIGURE 5.3 Typical use of a frame relay in distribution automation

## 5.6 Communication Networking

Information is distributed over a variety of connections:
1. One-to-one connection of one location to another, e.g., telephone
2. One-to-many connection of one location to many other locations, e.g., cable TV
3. Many-to-many connection of many locations to many locations, such as a conference arrangement or the so-called local area network (LAN)

This combination of connection types has led to new configurations, referred to as local area networks (LAN), wide area networks (WAN), and metropolitan area networks (MAN).

## 5.7 Utility Communication Architecture (UCA)

The current utility computing environment consists of major networks of networks, which include business functions, accounting and engineering applications, and EMS functions for real-time applications such as dispatching and operation. For example, computers are connected on LAN or WAN network arrangements. The different operating networks overlap and are specified for special stand-alone operations. In the past, the connections between them were unable to communicate across business, plant operations, and real-time operation of a typical EMS. Now with the advent of distribution automation and control through EMS and DMS, much work is needed to support:

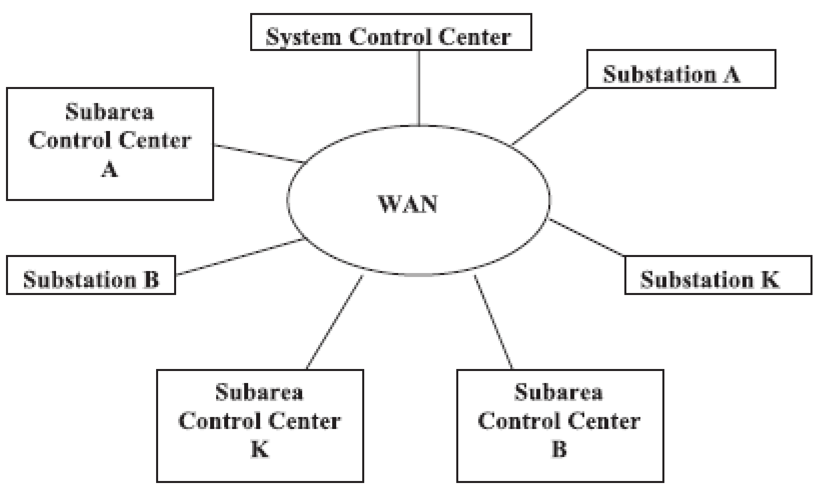


FIGURE 5.4 Integrated utility communications architecture system.

- New data exchange processing
- Different protocols and standards in use in the industry

These new standards are derived from frame relay, and other variations of standards from the professional bodies. The new standard allows for the interchange of information between the control system and business and other application programs.

Figure 5.4 shows the integrated UCA. The following networks are connected through a WAN via communication processor for each of the subnetworks: power plant network, corporate network, distribution automation/DMS network, transmission network, and control centre network.

# 6

# Conclusion

## 6.1 Challenges to Distribution Systems for a Competitive Power Utility Environment

Electrical power system has issues of distribution automation, control, and its various functions with various options, renewable energy, and performance assessment. Government agencies and utility companies have proffered a variety of roadmaps identifying the characteristics and features of future distribution systems, the required technologies, and the scope of coverage for research and educational purposes.

The areas of future work will improve the distribution so that it can become flexible, reliable, and smart. Several government organizations and utility companies have proposed some of the challenges in building the so-called smart-connection technology platforms for distribution systems. Simply stated, smart-connect is an attempt to develop communication and technology controls that enable a distribution system with distributed generation (DG) to be upgraded with smart, reconfigurable, self-healing, restorative, and reliable systems.

In the near term, the research road map using the concepts discussed in the report will increase the capability of future distribution systems. In this chapter, we have classified grand challenges/problems.

## 6.2 Protection

The current protection schemes have limitations in a distributed-generation based distribution system. We need to develop a new generation of protection schemes capable of detecting faults and restoring the system in minimum time for a two-way power flow.

## 6.3 Demand Response

Using voltage sag, frequency, power factors, or harmonics changes, a demand-response strategy is needed to control distribution system contingency impacts.

## 6.4 Communication Advances

Advances in low-cost communication and Ethernet technology can easily be the option for handling the features of distribution management systems. For example, the use of phasor measurement units (PMU) and state estimation could enhance real-time management and control using advances in global positioning systems (GPS) and Internet technology.

## 6.5 Microgrid

Increased penetration of DG units in electrical proximity to the loads for autonomous generation operation from the grid has led to the development of the microgrid concept. These developments of DG units are derived from different renewable options such as wind, solar, geothermal, etc. The ability to control and communicate with the microgrid requires computational tools that are capable of handling system dynamics, uncertainties, and interconnection issues. To this end, advances in wireless communication and robust dynamic optimization schemes, such as adaptive dynamic programming (ADP), will be useful for real-time operation.

## 6.6 Standards and Institutional Barriers

Much work and documentation have been done to establish standards for the interconnection of DG to future distribution to achieve reliability and safety objectives. There is further work to be done in standardization of the software tools needed for distribution automation.

To overcome institutional barriers to the development and deployment of the new features of distribution automation, research products that integrate the demand-side management (DSM) function using communication and intelligent systems need to be available for adaptation by the utility. Finally, plug-and-play technology that will facilitate deployment of control measures with embodied intelligence is needed to achieve a self-healing, safe, reliable, and cost-effective distribution system.

### 6.7 Pricing and Billing

The distribution system is the business endpoint for obtaining a return on investment in a power system. The ability to collect bills on time and guarantee power at an affordable price is one of the overall missions of automating the distribution system. Smart meters and good pricing structures are needed to justify the investment, using cost-benefit analysis tools. Further research is needed to promote enabling technology to achieve accurate and correct billing and competitive pricing for future and current owners of distribution systems.

Finally, an enabling environment for billing and sustaining distribution automation and control for a competitive power market requires the use of innovative tools and dedicated effort. Funded research work and prototype products currently available require further testing and customization by the power industry.

# References

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3.