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Comprehensive Study on Central Control Management of a Power Distribution System

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The purpose of this study is to develop a familiarity with the central control and management functions, the nerve of any power system. The paper considers a distribution system and emphasizes on distribution management system (DMS). DMS uses state estimation to maintain the healthy working condition of the system. It plays a very important role in the control of the distribution system, as the level of control that possible is restricted owing to the specific structure of distribution networks and penetration of real-time monitoring and control facilities. So far, the level of SCADA implementation in distribution networks has controlled around 10% of switching devices and has been limited to circuit breakers at the larger primary substations. The four main functions of the DMS have been discussed focusing mainly on Outage Management.

Keywords: *Central control, Distribution system, DMS, Outage management.*

1.0 INTRODUCTION

The primary concern of any Power System [1,2] is to ensure uninterrupted and secure power flow to the end user. The nerve center of any power system is the central control and management unit, as it is the place where all the operational strategies are carried out. Even if distributed control and operation is implemented, the results of such action must be communicated to the central coordination point.

With the growing complexities in the electricity network worldwide as it enters a period of change, there exists an increasing demand for improved methods of control and management functions.

The two major aspects of this change are as follows:

Consumer-Friendly Network: The moves to privatize, deregulate, and unbundle, which provide consumer an open access to independent power suppliers outside the network companies' service territory, together with the establishment of other legal entities for the trading and supply of energy.

Emphasis on Consumer Satisfaction: The increased awareness, either regulator or public-led, of both business and residential consumers' perception of the utilities' operation, leading to a greater emphasis on quantifying the cost of providing services and improvements on quality, real or perceived.

Hence, it becomes necessary to understand the functioning of the central control and management unit if we focus on healthy working of a power system. This paper is an attempt to do the same.

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It talks about the central control and management in a Distribution Network, (Section-III). Section-IV explains the role of a DMS, and Section-V introduces the four main functions of DMS with an elaboration on a specific function of a DMS, known as Outage Management.

2.0 CONTROL CENTER

2.1 Control Operation

Power System Operation requires the balance to be maintained between security, economy, quality

While delivering electrical energy from the generating source to satisfy the demands of the end user. From a technical point of view, this balance depends on the following factors:

1. The structure of the types and size of the generating plant
2. The structure of the network
3. The condition of delivery network
4. The demand characteristics of the end user. The new business management superimposes a new factor
5. The need to balance the rules of regulation and a free market, where the free market operates at the supply and retail level and the regulation influences the operation of the monopolistic network companies that deliver the power.

Historically, control systems have been implemented on bulk power systems, where all incoming and outgoing points of the network were monitored. Such real-time systems form supervisory control and data acquisition systems: SCADA systems. Advances in computation technology and power system modeling allowed usage of real-time data from SCADA in many fast applications, thereby providing additional decision-making information for the operators. Gradually, these applications allowed increased levels of automation in the decision-making process. The system operation functions required at the control center can be split into 3 groups, corresponding to different time horizons. This classification is shown in Table 1.

TABLE 1

SYSTEM OPERATION FUNCTION

Instantaneous operation	The values of the parameters obtained by real-time monitoring of system demand and loads, power generation, network power flow, and voltage levels are continuously compared with the defined technical and economic loading limits as well as contractual threshold to ensure satisfactory operation
Operations planning	• Short-term (few days): short-range load forecasting techniques • Long-term (few months): long-term load forecasting
Operations reporting	• Postmortem analysis is key to determine disturbance causes. • Reflects the need to keep statistics on performance, disturbances, and loadings as input into planning and accounting functions

2.2 Control Hierarchy in Power Utility Control

The power system network follows a structured control hierarchy that explains the need of different delivery layers of the network. This is possible with the ability to control a network from one point, the control center, or a number of distributed control centers with delegated control. This process is called SCADA, and relies on communication links from the control center to the primary device (generator, circuit breaker, tap changer, etc.) to be operated. Primary devices are fitted with actuators or mechanisms to perform the mechanical opening and closing operation. The IED (Intelligent Electronic Device) interfaces the actuator with the communication system. The relative size and sophistication of the IED depend on the control system configuration and its layer in the control hierarchy. With the combination of control room system, communication, and IED, SCADA system emerges. SCADA systems are deployed to control different layers of the network. The actual selection of how central control is organized depends upon the ownership of the network layers. Owners of simple distribution networks with voltages below 33 kV tend to use one SCADA system to control the entire network. Utilities with both medium-voltage and high-voltage (HV) sub-transmission networks (230–66 kV) tend to operate the HV through a dedicated SCADA, integrating both voltage levels in one system.

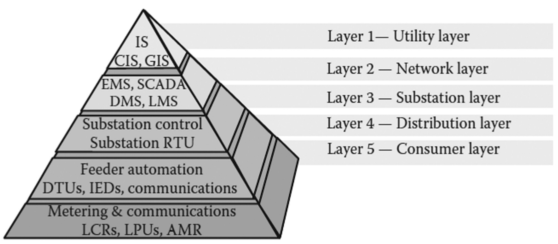
A typical network control hierarchy is shown in Figure 1 [1] and is comprised of five layers:

Layer 1: Utility: Control of

- Enterprise wide IT
- Asset management
- The energy trading systems

Layer 2: Network:

- Control of the bulk power transmission networks for economic dispatch of the generators.



IS	Information system	RTU	Remote terminal device
CIS	Customer information system	DTU	Distribution terminal unit
GIS	Geographical information system	IED	Intelligent electronic device
EMS	Energy management system	LCR	Load control device
SCADA	Supervisory control and data acquisition	LPU	Load point unit
DMS	Distribution management system	AMR	Automatic meter reading
LMS	Load management system		

FIG. 1 CONTROL HIERARCHY

Layer 3: Substation:

- Control of all circuit breakers inside the substation with the communication of all protection relay status.

Layer 4: Distribution:

- It covers the medium-voltage feeder systems. The feeder devices located below the primary substations are controlled by the remote controls and local automation, showcasing the real-time control capability.

Layer 5: Consumer:

- Delivery system directly interfaces with the consumer and constitutes flexible metering systems like automated meter reading (AMR) [7,8] systems to allow the customers to revise the tariff and control the load conveniently.

This division of the control process into control layers is made because in practice, the responsibilities for control within the utility are similarly organized. The power network is a vertically integrated system where each layer plays an essential role.

3.0 DISTRIBUTION SYSTEM

As shown in Figure 1, distribution systems [1] occupy the lower end of the control hierarchy. Distribution systems are predominantly configured to operate in a radial configuration, where feeders stretch from distribution substations and form a tree structure with their roots at the substation and branches spreading over the distribution area. Figure 2 [2] represents the radial configuration of a distribution system.

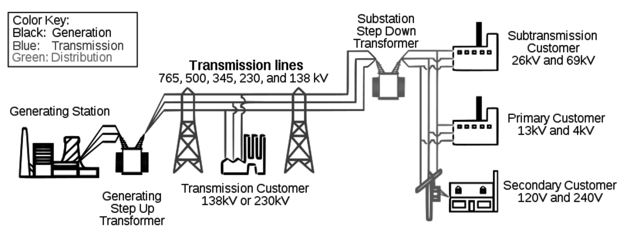


FIG. 2 BASIC STRUCTURE OF A DISTRIBUTION NETWORK

The depth of control possible distribution systems is restricted by the specific structure of the distribution network and the penetration of real-time monitoring and control facilities. Historically, with SCADA implementation in distribution networks, a control of around 10% of switching devices was possible and has been limited to circuit breakers at the larger primary substations. Hence, the concept of adaptation of the distribution automation (DA) came up, where control is extended to small substations and primary feeders. This will substantially increase the reach of real-time control.

Owing to the vastness of distribution network and the multitude of the elements that comprise it, it becomes necessary to handle considerable information to ensure satisfactory operation and crew safety. This operations environment imposes the following three conditions on distribution system control unit:

- Normal conditions
- Emergency conditions
- Administration

Administration includes the everyday tasks of logging events, preparing standard management reports, and supplying performance statistics which are time-consuming. It also takes care of privatization and changing external pressures that require improved auditing of system performance, audit trails of customer contacts, and increased attention to safety documentation. All these issues require more effort and accuracy from the operating personnel in addition to the generation of equipment statistics for improved asset management.

The three conditions correspond to the following four states [3] of the system.

1. Normal State
2. Alert State
3. Emergency State
4. Restorative State

These four states are shown in Figure 3 [3].

Normal State: This implies to the state where the existing generators can supply the power to the loads without violating any operational constraints. The operating constraints refer to

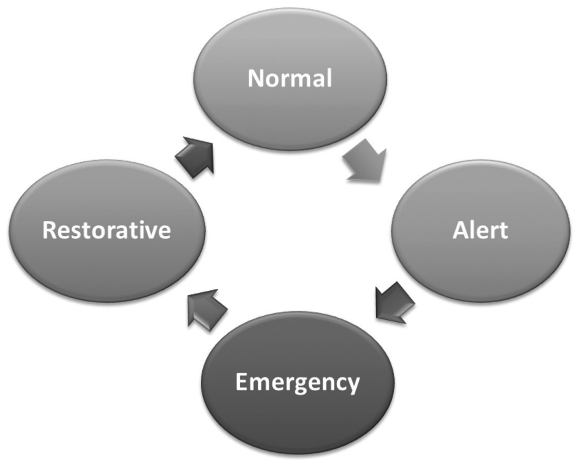


FIG. 3 OPERATING STATES OF A DISTRIBUTION SYSTEM

- Limits on the transmission line flow.
- Upper and lower limit on the bus voltage magnitude.

There are again two types of normal state:

1. Secure normal state: This system satisfies all the critical contingencies.
2. Insecure normal state: This system fails to satisfy the critical contingencies and inequality prevails in power flow balance at each bus.

During normal system conditions, the operator prepares switching plans for planned maintenance, monitors the system to check if it is out-of-tolerance zone, prepares configurations to establish optimum operation, and initiates remedies to bring down the overloads or push up low voltages into appropriate limits, takes care of the general maintenance of control room information such as the network diagram updating and management statistics.

Alert State: This state signifies that a disturbance has occurred and action should be taken directly (automatically or through operator intervention if time permits) to alleviate the situation.

Emergency State: This reflects the collapse of the power system usually from cascading protection intervention as a consequence of major generation or transmission line loss.

- In bulk supply systems, the *alert state* can move very rapidly into the emergency state, making it impossible for an operator to prevent system collapse.

This is a stressed state in which the operator must perform.

Primary objective is to organize restoration of the network as quickly as possible.

In such a condition, the operator prepares and executes the switching plans to isolate the fault and restore supply. This involves:

- Operating remote-controlled switching devices
- Dispatching and controlling repair crews to operate manual devices and verify fault locations
- Managing trouble calls information and inform customers, thereby taking care of the customer satisfaction

Restorative State: The operator, using all the facilities of the control center, is the main decision maker in system restoration. Effective control to move the system from emergency to restorative mode includes

- Disconnecting various loads, lines, transformers or other equipments. Hence, the operating limit violations will be eliminated. The system recovers to a stable state with a reduced load and reconfigured topology.
- In order to maintain an optimum load v/s generation ratio, power is supplied to all the loads and this brings back the system to normal state as a result
- Actions taken are called restorative controls

4.0 DISTRIBUTION MANAGEMENT SYSTEM

Traditionally the distribution companies had managed their networks through four key functions reflected by the organization of work within the company. These four key functions are given in Table 2.

TABLE 2

FUNCTIONS OF DISTRIBUTION UTILITIES

Functions	Responsibility
Operations	This function is responsible for the daily running of the network with the primary object of maintaining continuity of supply
Assets	All activities to do with the assets of the utility, essentially the electrical network, such as inventory control, construction, plant records, drawings, and mapping, are covered under this category
Engineering	Engineering department carries out all design and planning for network extensions
Business	The business function covers all accounting and commercial activity within the utility

All these functions were implemented in a coordinated manner and synchronized between the control center and field operations. These functions implemented independent applications to serve their own needs.

Current distribution management systems are extensions of segments of these different applications specifically packaged for use in the control room and accommodating the unique characteristics of distribution networks. Creation of the DMS structure is due to the ability to share data models and interface different data sources to form an integrated system that serves the needs of the operator.

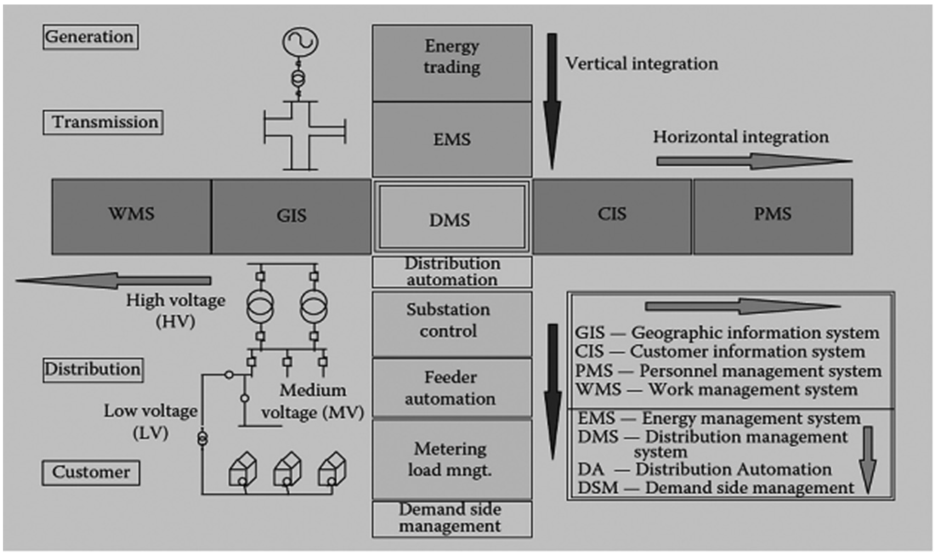


FIG. 4 VERTICAL INTERGRATION AND HORIZONTAL INTEGRATION

A full-fledged DMS is the focus of new management systems, wherein DMS lies at the intersection of vertical integration (real power delivery process) and horizontal integration (corporate IT systems) [4,5] of utility enterprise systems. This is shown in Figure 4 [4].

Vertical integration is the domain of the operation's organization of the utility, and is responsible for the extended control of the network beyond traditional SCADA. The horizontal integration element provides the source of corporate asset data (material and personnel) needed to support a full DMS implementation. A DMS requires interfaces with many different enterprise activities within the utility.

Overall concept of an active distribution management and control is illustrated in Figure 5 [5].

DMS uses state estimation to maintain the healthy working condition of the system. As state estimation reflects the workflows through which this is accomplished so that fault location is easily carried out with the help of state estimation.

State Estimation [6] is mainly used to

- Filter redundant data

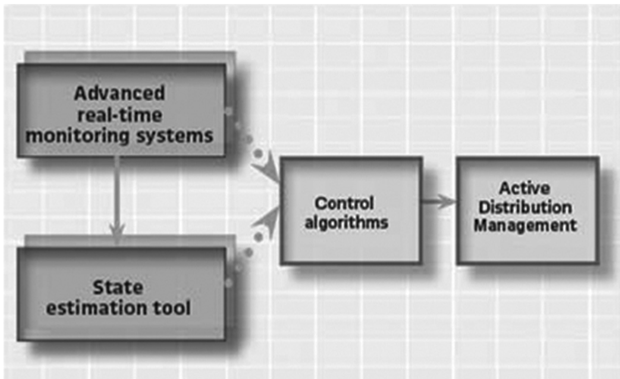


FIG. 5 ACTIVE DISTRIBUTION MANAGEMENT

- To eliminate incorrect measurements
- To produce reliable state estimates

It allows the determination of the power flows in parts of the power system which are not directly metered.

SE is a very useful tool for the economic and secure operation of transmission networks. A brief description of the process of SE can be referred from Figure 6.

This allows DMS to play an important role during the Normal and Emergency conditions of the system. As distribution systems allow a limited control, i.e. control over only about 10% of switching devices, manual operation by field crews dispatched to the switch is done. Hence, support outside traditional SCADA is needed.

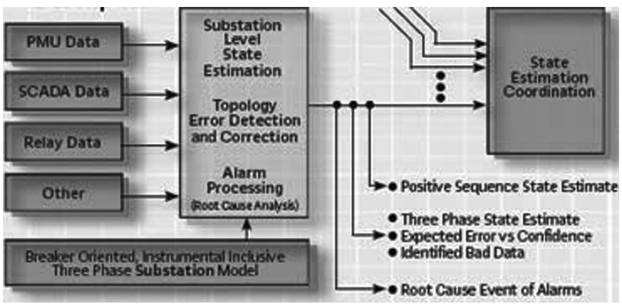


FIG. 6 BLOCK DIAGRAM ILLUSTRATING THE WORKING OF A STATE ESTIMATON (PMU: PHASOR MEASUREMENT UNIT)

This Outside Support can be:

- Operating diagrams and geographical maps showing the location of the network and devices
- Crew management methods to track and dispatch the correct resources and skills
- Repair truck inventory of network spares
- Trouble calls from customers to identify probable location of faults
- Mobile communications and data systems to allow command and data interactions between control center and field

5.0 FUNCTIONS OF DMS

A modular DMS for network control and automation is described by four main functions, each having the ability to be fully integrated with the other but can operate independently when required. The DMS is supported by other separate applications within the corporate information technology strategy. Table 3 gives a brief about the three main functions of DMS. And an elaboration of the fourth function has been done separately.

TABLE 3

FOUR MAIN FUNCTIONS OF DMS

Control room operations management (CROM)	• The user environment vital to a DMS • An umbrella function covering the facilities provided to the operator in the control room through the operator's console (HMI)
Supervisory control and data acquisition	• Provides the monitoring and control of the distribution system in real-time. • Data acquisition system for gathering data from remote location • The central real-time database that is the repository of this data to be processed • Displayed for the operator's use
Advanced applications	• Analytical applications that rely on the MV connectivity database • Evaluates in real-time • In case of advanced switching sequence

5.1 Outage Management

An outage is defined as the location of operated protection device or open conductor and the extent of the network de-energized as a result of the operation including the affected consumers. Outage management is one of the most crucial processes in the operation of the distribution network having the goal to return the network from the emergency state back to normal. The process involves the following steps:

1. *Taking a customer's call*: This helps in the prediction of location of fuse or breaker that opened upon failure.
2. *Diagnosing a Fault Location*: Prioritizing restoration efforts and managing resources based upon criteria such as locations of emergency facilities, size of outages, and duration of outages.
3. *Confirm and Repair Fault*: Providing information on extent of outages and number of customers impacted to management, media and regulators and Calculation of estimation of restoration times.
4. *Switching Operation to Restore*: Management of crews assisting in restoration and calculation of crews required for restoration
5. Closing the OUTAGE

Hence, as clear from the process, the process of outage management involves three discrete phases:

1. Outage alert
2. Fault location
3. Fault isolation and supply restoration

Utilities with very limited penetration of real-time control but good customer and network records use a trouble call approach, i.e. trouble call management system (TCMS).

This system structure provides the convenience to establish the customer-network link at ease, a necessity for trouble call management systems if outage management is to yield any realistic results.

The trouble call-based outage management works in the following manner:

Fault Alert

- The first trouble call signifies that there is potentially a network failure.
- This is quickly confirmed once additional calls are received.

Fault Location

Is carried out through following two steps to reflect the possible states of an outage

- Interference
- Verification

Outage Engine is the core of the process. It automatically maintains

- The status of different outages and
- The customers (loads) associated with each outage state by processing line device status and trouble groups.

The method relies on a radial connectivity model of the network, which includes a customer–network link pointing every customer in the CIS to a location on the network.

Those with good real-time systems and extended control are able to use direct measurements from automated devices. These are the systems with very extensive secondary systems and hence concentrate on implementing SCADA control, so that any MV fault would be cleared and prior to any customer call the affected feeder is known. In this structure, to be truly effective, a trouble call approach would have to operate from the LV system, where establishing the customer network link is more challenging. In such cases, trouble call response is aimed at maintaining customer relations as a priority over fault location, which is achieved faster through a combination of system monitoring applications (SCADA), FA (feeder automation), and FPIs (Fault Passage Indicator)) and advanced applications.

6.0 CONCLUSION

To understand the working of any electrical power system, it is essential to have a prior knowledge of the control and management functions that drive it. This study attempts to present the central control and management of a distribution system.

Distribution System lies at the bottom of the control hierarchy which signifies its essence, as it is a link between the load and supply. As the level of control in the distribution network is restricted owing to its specific structure and the penetration of real-time monitoring and control facilities which allows a limited access of information to SCADA control, DMS was created. Hence, the importance of DMS structure is due to the ability to share data models and interface different data sources to form an integrated system that serves the needs of the operator. DMS has four main functions out of which the Outage Management is elaborated.

Outage management is very crucial process that restores the system back to normal state when system encounters an unplanned failure. There are two kinds of outage management, one which is based on the trouble call from the customer and the other on data from the SCADA center. Utilities with very limited penetration of real-time control but good customer and network records use a trouble call approach. Those with good real-time systems and extended control are able to use direct measurements from automated devices.

Issues with the OM: Tremendous volume of data flowing into distribution operations centres will have to be managed. Ensuring that data is transformed into information to the distribution operators will be more critical than ever. So, probably we could manage this data by carrying out a data mining to understand the underlying pattern and after defining a pattern the data could be condensed to a smaller dimension. This set of condensed data will then have all the properties of the original data at the same time makes the storage easier.

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