# Distribution Management Systems

Ch=7

- Electricity distribution networks connect the high-voltage transmission system to users. Conventional distribution networks have been developed over the past 70 years to accept bulk power from the transmission system and distribute it to customers; generally they have unidirectional power flows.

The Smart Grid is a radical reappraisal of the function of distribution networks to include:

- **integration of Distributed Energy Resources;**
- **active control of load demand;**
- **more effective use of distribution network assets**.

- Real-time monitoring and remote control are very limited in today’s electricity distribution systems and so there is a need for intervention by the system operators particularly during widespread faults and system emergencies. However, it is difficult to deal with such a complex system **through manual procedure**

- A **Distribution Management System (DMS)** is a collection of Applications used by the **Distribution Network Operators (DNO)** to monitor, control and optimize the performance of the distribution system and is an attempt to manage its complexity.

- The ultimate goal of a DMS is to enable a smart, self-healing distribution system and to provide improvements in: supply reliability and quality, efficiency and effectiveness of system operation.
- The first generation of Distribution Management Systems integrated a number of simple Applications into a **computer system**. An interactive **graphical user interface** was then added to visualize the network being managed.

# Data sources and associated external systems

- ***DMS includes Applications:***
- for system monitoring, operation and outage management. These are the Applications responsible for the daily running of the network with the primary object of maintaining continuity of supply.
- to help manage the assets of the utility, such as inventory control, construction, plant records, drawings, and mapping. These include the automated mapping system, the facilities management system, and the geographical information system

- associated with design and planning for network extensions. These Applications are used for audits of system operation to determine short-term solutions and optimal expansion planning to achieve system reinforcement at minimum cost.

# SCADA

- SCADA (Supervisory Control And Data Acquisition) provides real-time system information to the modelling and analysis tools. Hence the data integrity and expandability of the SCADA database are critical.
- SCADA has the following attributes:

- **Data acquisition**: Information describing the system operating state is collected automatically by ***Remote Terminal Units (RTUs).*** This includes the status of switching devices as well as alarms and measured ***values of voltages and currents***. This information is passed to the control center in close to real-time.

- **Monitoring, event processing and alarms**; An important function of ***SCADA is to compare the measured data to normal values and limits***, for example, to monitor the overload of equipment (transformers and feeder circuits), and ***violations of voltage limits***. It also detects the change of status of ***switchgear and operation of protection relays***

- **Control:** Control through a SCADA system can be initiated manually or automatically. Control initiated manually can be the direct control of a particular device (for example, a circuit breaker or tap-changer). Some functions are initiated manually by the control room operator,

- **Data storage, event log, analysis and reporting**: Real-time measurements are stored in the real-time database of the SCADA system at the time received. Because the data update overwrites old values with new ones, the time-tagged data is stored in the historical database at periodic intervals, for example, every 5 minutes or every hour, for future use

## Customer information system

A Customer Information System (CIS) maintains databases of customers' names, addresses, and network connection.

**Metering**
Hold inventory of meters and locations.

**Billing**
- Collect meter readings from smart metering system.
- Apply tariffs from the customer information database.
- Process billing for all customers.
- Report outstanding information for field collection

**Payment**
- Deliver bills
- Allow various modes of payment (e.g. internet-based payment , budget payment).
- Implement credit control and monitoring processes

**Losses**
- Real-time or periodic reconciliation of energy purchased, distributed and billed to identify and locate technical and commercial losses

**Quality and reliability of supply**
- Identify customers affected by outages and provide information to customers regarding outages and their possible duration.
- Inform customers of scheduled system maintenance

**Complaint handling**
- Integrate call centre systems and the CIS. Provide access to customer information.
- Provide facilities to log complaints.

# Transformers

- The basic principles of transformers are covered in standard textbooks [1, 2]. Many distribution transformers are equipped with taps in one winding to change the turns ratio in order to control the system voltage. There are two common types of tap-changers used in distribution transformers: off-circuit tap changers (used in 11/0.4 kV transformers in the UK) and On-Load Tap Changers (OLTC) (used in 33/11 kV transformers).

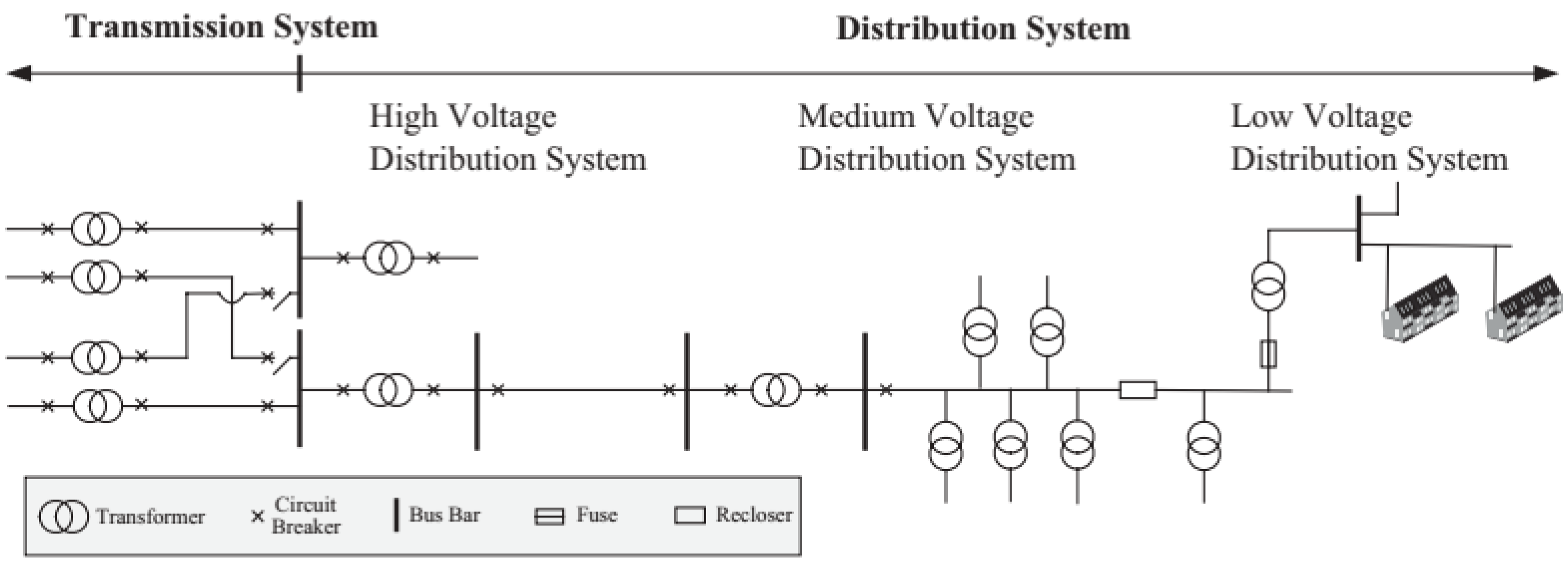



**Figure 7.3** A distribution network

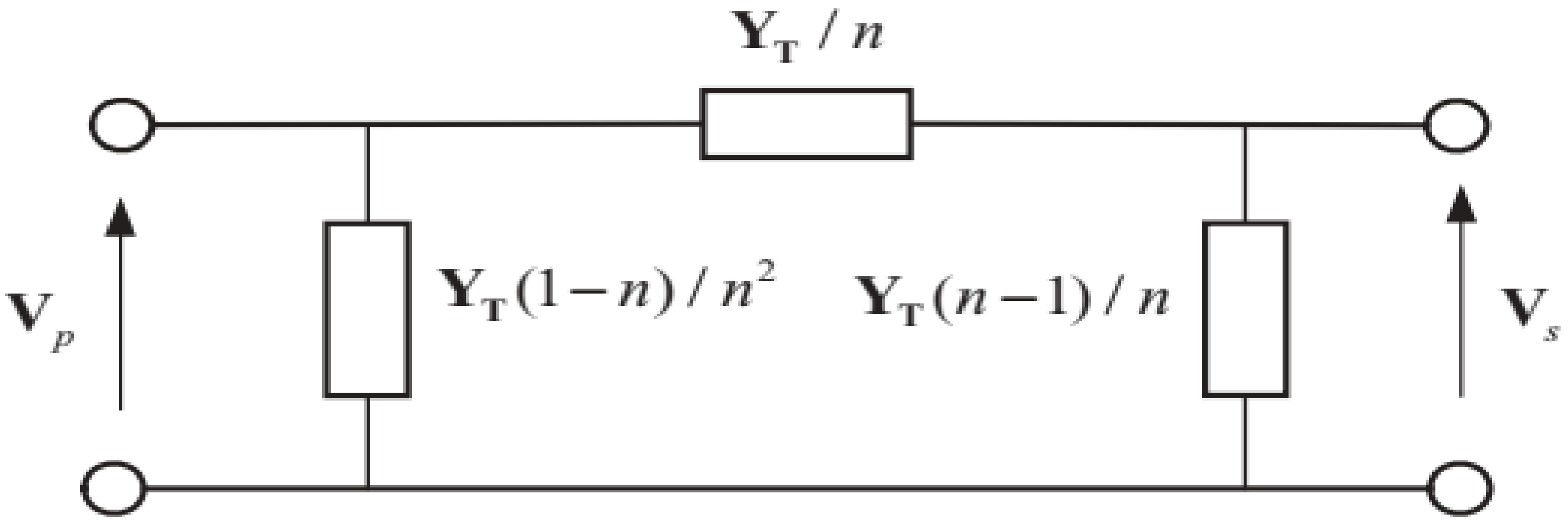



**Figure 7.6** Equivalent $\pi$-model of a transformer

***Loads***

Most loads are voltage dependent, which can be represented by an exponential model:

$$\begin{aligned} P_{\mathrm{L}i} &= P_{\mathrm{L}i\_0} V_i^{p} \\ Q_{\mathrm{L}i} &= Q_{\mathrm{L}i\_0} V_i^{q} \end{aligned} \tag{7.1}$$

where

$P_{\mathrm{L}i}$ and $Q_{\mathrm{L}i}$ are active and reactive load power at busbar $i$ when the nodal voltage at busbar $i$ is $V_i$ ;

$P_{\mathrm{L}i\_0}$ and $Q_{\mathrm{L}i\_0}$ are active and reactive load power at busbar $i$ when the nodal voltage at busbar $i$ is 1 pu;

# Distributed generators

- Distributed Generation (DG) is connected to distribution networks either directly or through power electronic converters. There are four DG grid-coupling techniques which are widely used: directly connected synchronous generator, directly connected induction generator, doubly fed induction generator and full power converters [3].
- Some large synchronous generators and voltage-controlled power converters can be modelled as P-V nodes although smaller units often have their control systems set so they operate as P-Q nodes. Induction generators can be modelled as P-Q nodes

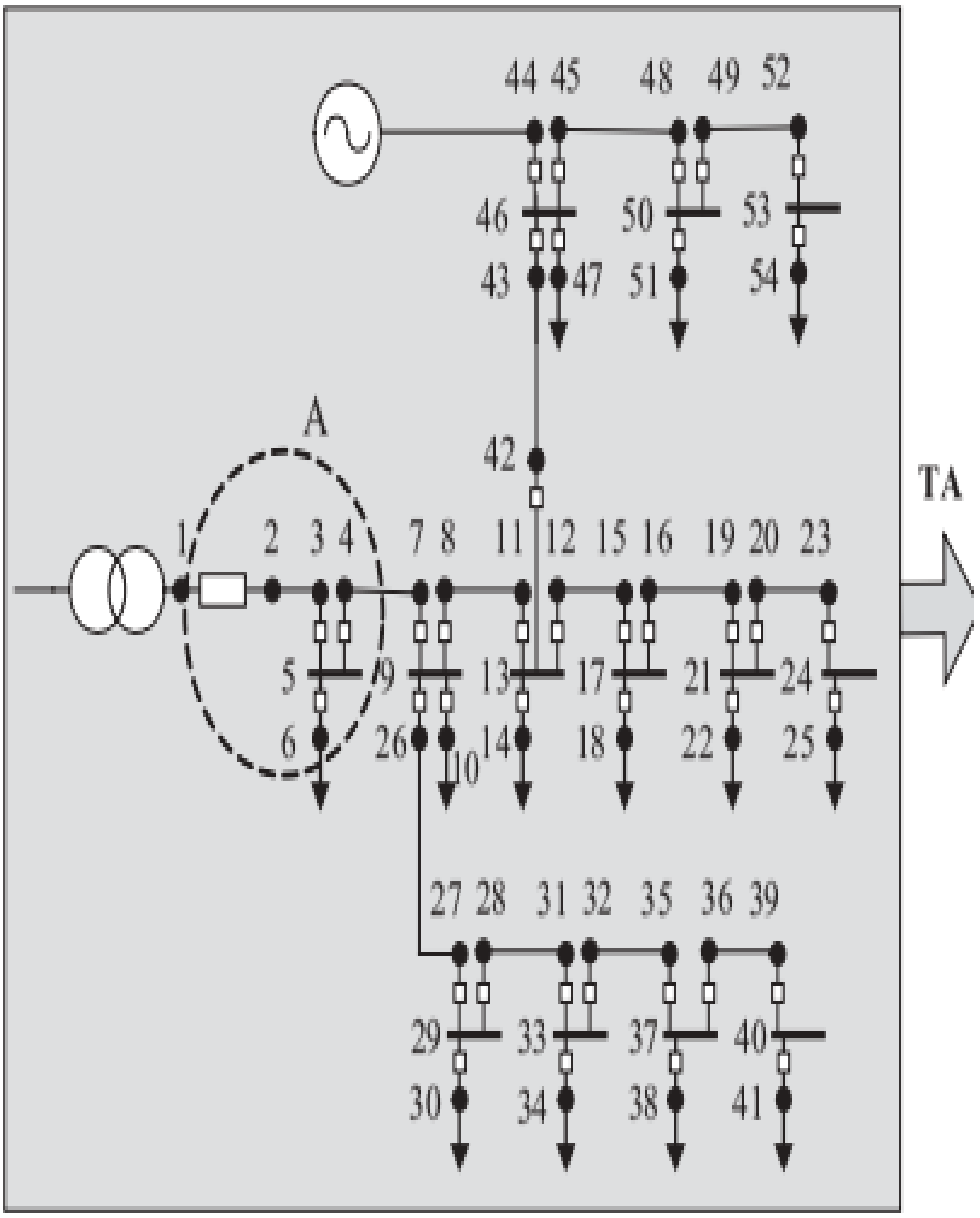
# New trends for smart grids

- The ICT infrastructure of a Smart Grid provides the opportunity for more accurate system modelling through the application of statistical system identification techniques.
- System identification, widely used in control engineering, can be used to build mathematical models of a distribution system based on the large amount of data measured by the ICT system. A set of more accurate, continuously updated models can then be obtained, and used by the DMS Applications.

# Topology analysis

- The topology analysis tool carries out network reduction. This reduces the amount of data feeding into other modelling and analysis tools and allows easier interpretation of results by the operator. For example, a substation that contains six sections of busbar2 which are linked by several open/closed items of switchgear may be represented by a single electrical node for power system analysis. The topology analysis tool is able to distinguish the energised parts of the power system from the de-energised parts, and can identify the electrically separated ‘islands’.

- Figure 7.8(a) shows a one-line diagram of a distribution network, which is represented by physical plant model with 54 busbars, and Figure 7.8(b) provides the equivalent power system analysis model with only 13 nodes derived from the topological tool.
- As can be seen by the encircled section in Figure 7.8(a), a number of circuit breakers/switches/fuses and busbar sections are represented by a single node (A) in the power system analysis model shown in Figure 7.8(b).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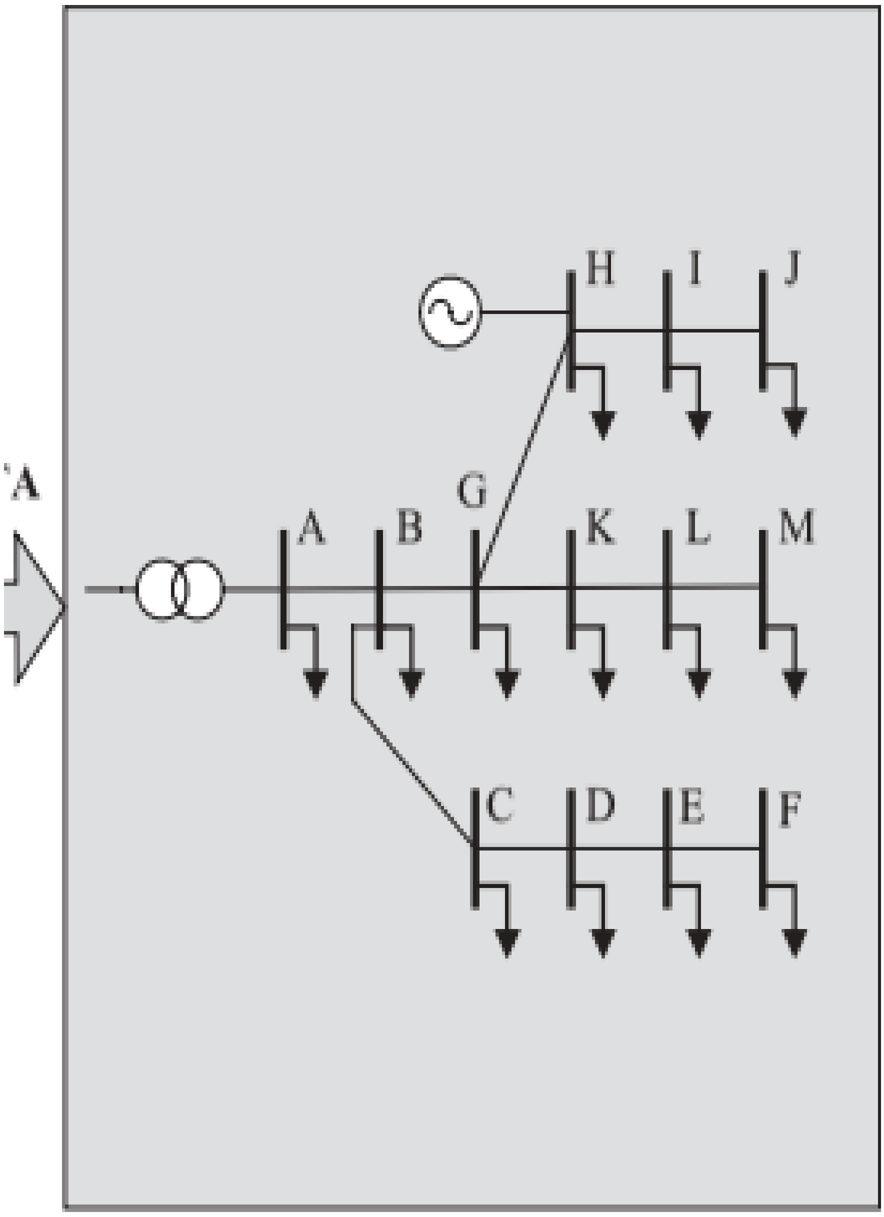

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# Load forecasting

- Load forecasting can be divided into three forecasting time horizons: short-term load forecasting which is usually from one hour to one week;
- medium-term load forecasting which isusually from one week to one year;
- and long-term forecasting which is longer than one year

- Load forecasting can also be divided into two categories based on the forecasting scope: regional load forecasting which provides load forecasts for a large geographical area and
- busbar load forecasting which provides nodal load information for network control functions.
- For a number of DMS Applications, short-term load forecasting is of most significance

- Load varies over the short term with: time (e.g. weekday, weekend, and holiday), weather (e.g. temperature and humidity), and the types of energy consumers (e.g. residential, commercial and industrial).

# Power flow analysis

- Power flow (or load flow) analysis provides the steady-state solution of a power network for specific network conditions which include both network topology and load levels. The power flow solution gives the nodal voltages and phase angles and hence the power injections at all buses and power flows through lines, cables and transformers. It is the basic tool for analysis, operation, and planning of distribution networks.

# Applications: System monitoring

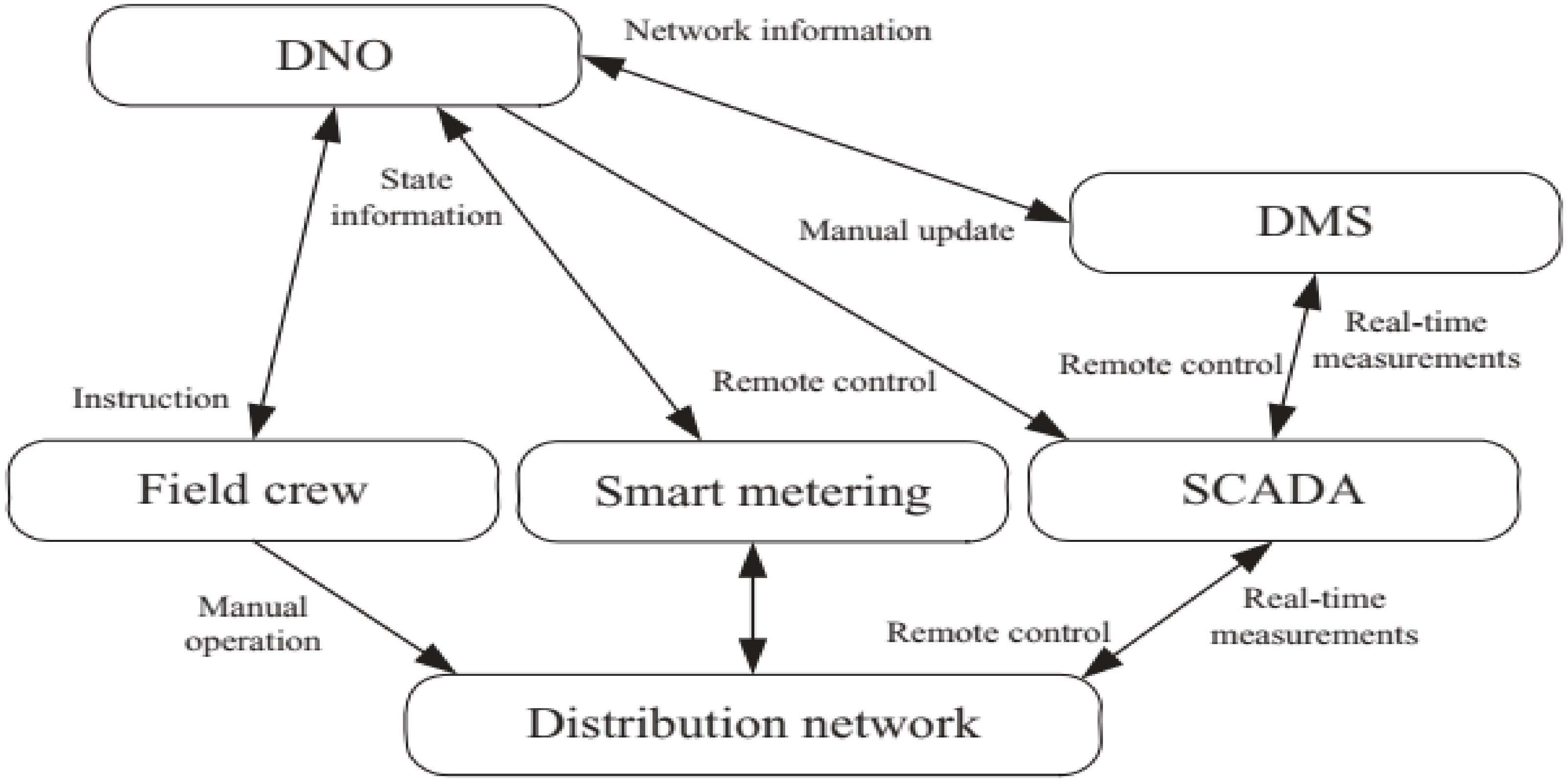


**Figure 7.15** Information flow of system monitoring

# Network reconfiguration

- Distribution networks are normally constructed as a meshed network but are operated in a radial manner with normally open points. The network configuration can be varied through changing the open/close status of switchgear, manually or automatically. The main objectives of network reconfiguration are:

- **Supply restoration**: This optimally restores electricity to customers using alternative sources. The Application is part of the fault location, isolation and supply restoration function.

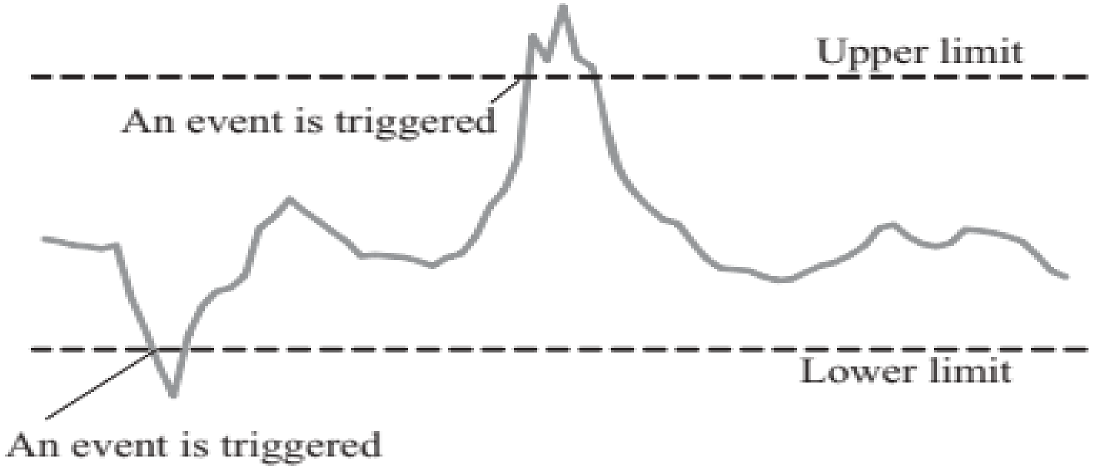


**Figure 7.16** Deadbands used by the system monitoring functions

- **Active power loss minimisation at a given time or energy loss minimisation over a period of time.**

- **Load balancing between different feeders or transformers and equalising voltages.**

- The methods used for network reconfiguration include those based on practical experience, mathematical methods, computational intelligence-based methods (for example, artificial neural networks, genetic algorithm, fuzzy logic), and hybrid methods which combine two or more methods.

# Volt/VAR control

- Volt/VAR control is used to improve voltage profiles and minimise network losses. This Application can be formulated as a multi-objective optimisation problem. Volt/VAR control calculates the optimal set points of the voltage controllers of OLTCs, voltage regulators, DER, power electronic devices, capacitor status and demand response.

# Relay protection re-coordination

- This Application adjusts relay protection settings in real time based on predetermined rules. This is accomplished through analysis of relay protection settings and operational modes of circuit breakers (that is, whether the circuit breaker is in a single-shot or recloser mode), while considering the real-time network connectivity, co-ordination with DER and MicroGrids, and weather conditions

# Operation of DER

- The integration of DER operation to the DMS has a large impact on the performance of a smart distribution network. This integration depends on the interface between the DER and the distribution system. For example, a large DER unit may be integrated with the distribution system directly or through a power electronic interface or a large number of DER units may be connected through a MicroGrid [8] or a Cell.

- Compared to a central generator, there are significant differences in the way that an individual DER is connected and controlled. The presence of DERs in the distribution network can **significantly alter the flow of fault currents** and change the source of ancillary services, so the operation of DER needs to be integrated to the DMS to guarantee reliable system operation

- A MicroGrid (Figure 7.17) can be defined as a low voltage electrical network of small modular distributed generating units (whose prime movers may be photovoltaics, fuel cells, micro turbines or small wind generators), energy storage devices and controllable loads. The integration of DMS and MicroGrids can be implemented through setting up the links between the DMS and the MicroGrid Central Controllers (MGCC).

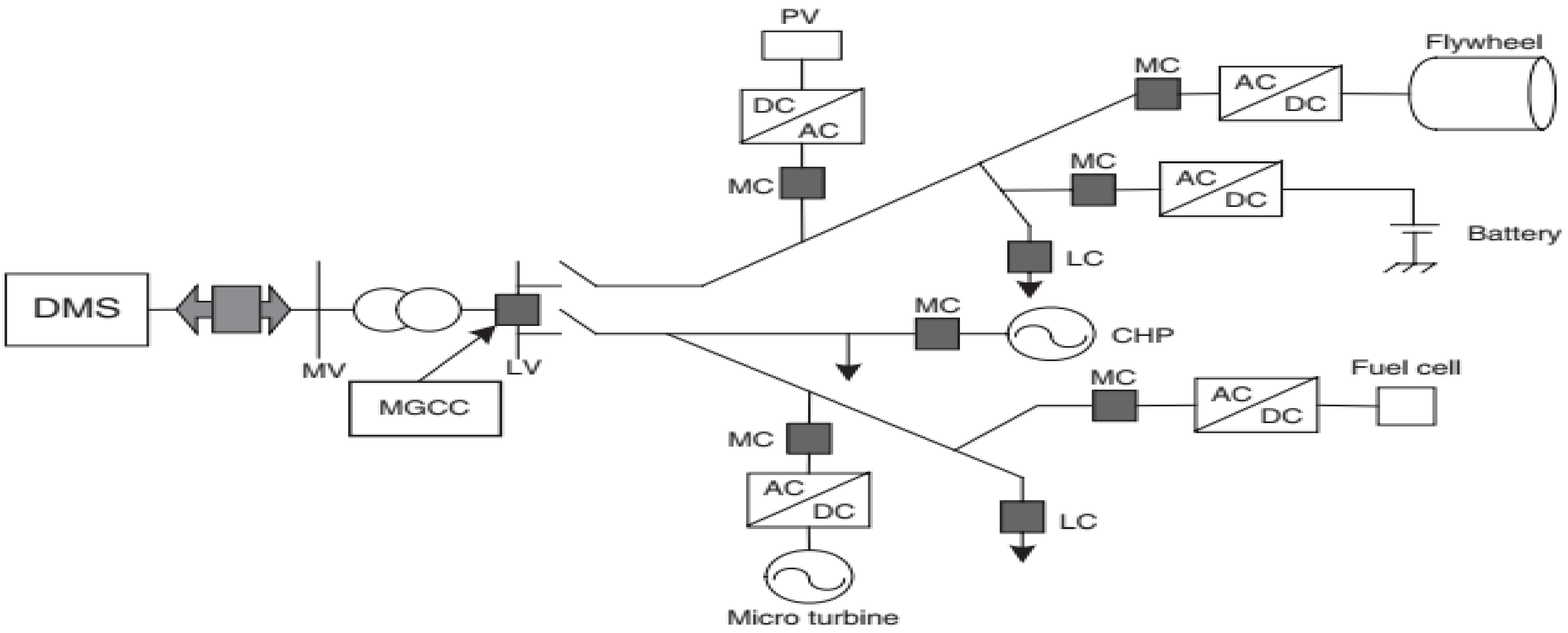


**Figure 7.17** Integration of MicroGrids to DMS through MGCC

# System management

- The Automated Mapping (AM), Facilities Management (FM), and Geographic Information System (GIS) functions act as an integrated platform which links the automated digital maps of utility infrastructure to databases. There are two major components of an AM/FM/GIS system; the graphical component and the database component.

# Outage management system (OMS)

- The OMS is a system which combines the trouble call centre and DMS tools to identify, diagnose and locate faults, then isolate the faults and restore supply. It provides feedback to customers that are affected

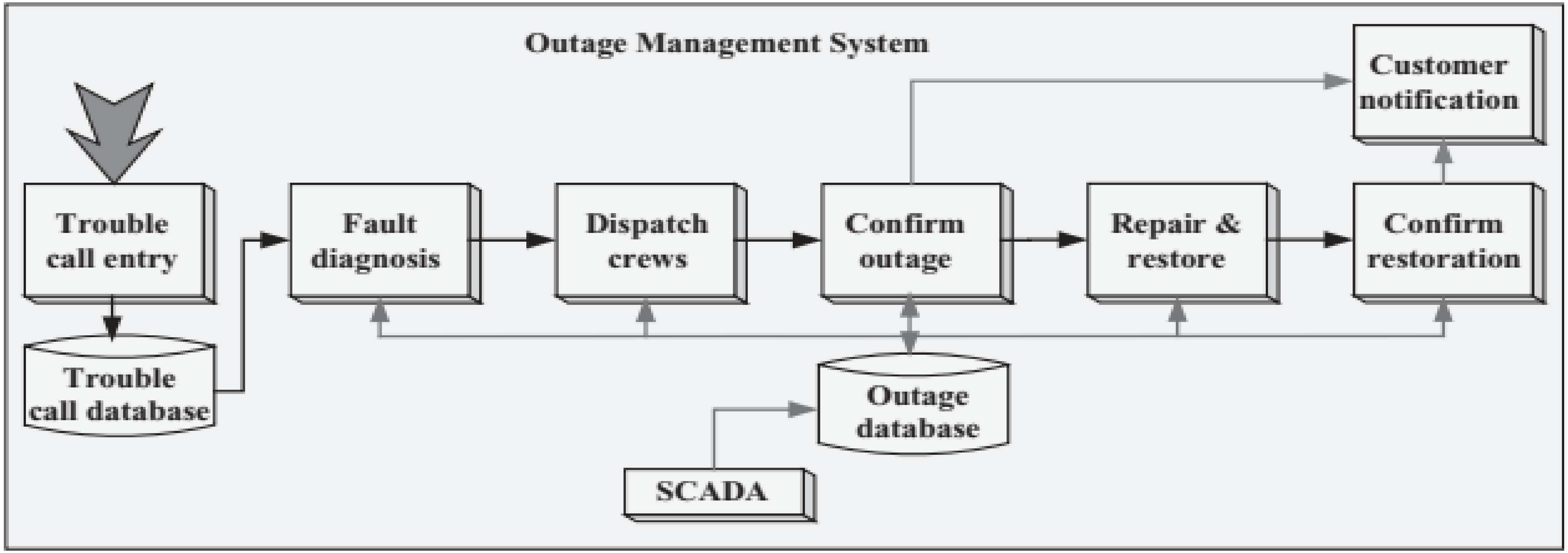


**Figure 7.18** Information flow of the OMS

# Fault identification

- Fault identification is based on customer calls through telephone voice communication. It may also use automatic voice response systems (Computer Telephony Integration – CTI), automatic outage detection/reporting system, or SCADA detection of circuit breaker trip/lockout

# Fault diagnosis and fault location

- Fault diagnosis and fault location are carried out based on the grouping of customer trouble calls using reverse tracing of the electrical network topology. It determines the protective device that is suspected to be open, for example, fuse, sectionaliser, recloser, or substation circuit breaker. Automatic feeder switching is also taken into account

- The extent of the suspected outage will be calculated including the number of customers affected and the priority of the affected customers. **Confirmation or modification of the fault diagnosis and its location is based on feedback from field crews**

# Supply restoration

- Remedial action depends on the severity of the problem. If the fault is a simple problem, the field crew can make the repair and restore supplies in a short time. If the fault causes a major outage, after the isolation of the faulted area, the un-faulted portions will be restored using normally open points.
- The OMS tracks partial restorations. Automated fault detection, isolation, restoration schemes with feeder automation are widely used. Computer-aided modelling of crews is also used to help to analyze the capabilities, tools, equipment and workload

# Event analysis and recording

- Any outage event will be analysed and the information kept as a historical record to record the cause, number of customers affected and duration. Such information is used for calculating performance statistics, for example, **Customer Interruptions (CI) and Customer Minutes Lost (CML)** as well as for **planning/budgeting maintenance** activities, for example, condition-based maintenance.

- It is anticipated that smart metering will enhance the OMS function. The benefits from integrating smart metering and outage management are derived from crew and dispatcher efficiency savings, reduction in restoration costs and reduction of outage durations.
- Figure 7.19 shows the integration of smart metering and the OMS.

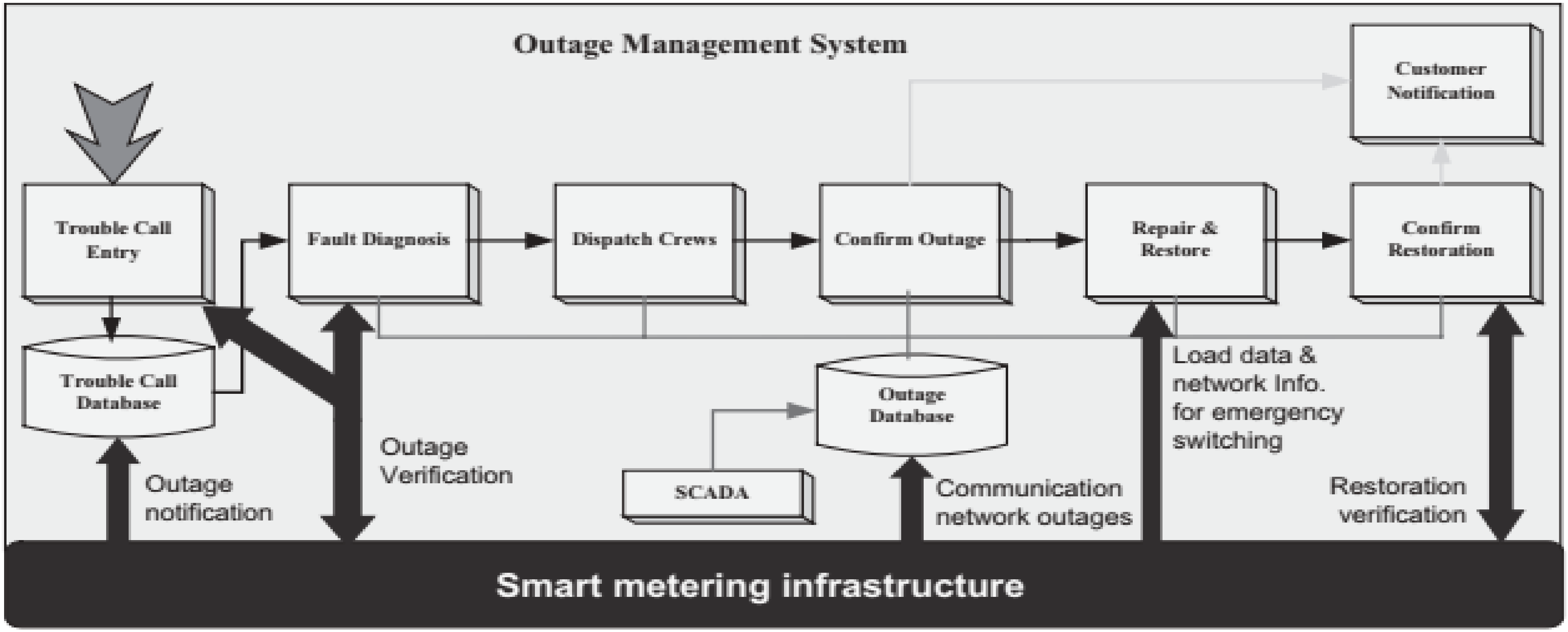


**Figure 7.19** Integration of smart metering and the DMS