Main Overview

- Distribution Reliability
- Distribution Automation
- Smart Grid
Distribution Reliability
Distribution Reliability - Overview

- Introduction to Distribution systems
- Distribution Reliability
- Standard Reliability Metrics
- Information Required for Reliability Evaluation
- Predictive Reliability Evaluation
  - Analytical Methods
  - Simulation Based Methods
- Methods to improve reliability
Introduction to Distribution Systems

- 5kV-69kV system class
- Layout
  - Substations
  - Primary distribution system
  - Secondary distribution system
- Largely a radial system with single, two and three phase lines.
- Responsible for the majority (about 80%) of customer interruptions that are either momentary or sustained.
Distribution Reliability

- Motivation/Objective
  - Determine the system reliability and customer satisfaction:
    - Number of momentary and sustained interruptions
    - Duration of interruptions
    - Number of customers interrupted
  - Improve system performance
  - Basis for new or expanded system planning
  - Determine performance
  - Maintenance scheduling and Resource allocation
Requirements for Distribution Reliability

- Utilities generally require an overall average of one interruption of no more than two hours’ duration per customer year.

- Corresponds to an Average Service Availability Index (ASAI) greater than or equal to $\frac{8758}{8760}$ service hours / 8760 hours,
  - 99.9772% Reliability
Standard Reliability Metrics

- **Load point indices**
  - Determine for each customer
    - The Number of outages (per year)
    - The Duration of outages (per year)
    - Unavailability / Availability of service

- **System wide indices**
  - SAIFI (System Average Interruption Frequency Index)
    \[
    SAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}} = \sum N_i \frac{N_i}{N_T}
    \]
  - SAIDI (System Average Interruption Duration Index)
    \[
    SAIDI = \frac{\text{Total Duration of Customer Interruptions}}{\text{Total Number of Customers Served}} = \sum r_i N_i \frac{N_i}{N_T}
    \]
Standard Reliability Metrics Contd.

- **CAIDI (Customer Average Interruption Duration Index)**
  
  \[ CAIDI = \frac{\text{Total Duration of Customer Interruptions}}{\text{Total Number of Customer Interruptions}} = \frac{\sum r_i N_i}{\sum N_i} = \frac{SAIDI}{SAIFI} \]

- **CTAIDI (Customer Total Average Interruption Duration Index)**
  
  \[ CTAIDI = \frac{\text{Total Duration of Customer Interruptions}}{\text{Total Number of Customers Interrupted}} = \sum r_i N_i \]

- **CAIFI (Customer Average Interruption Frequency Index)**
  
  \[ CAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Interrupted}} = \sum \frac{N_i}{CN} \]

- **MAIFI (Momentary Average Interruption Frequency Index)**
  
  \[ MAIFI = \frac{\text{Total Number of Momentary Customer Interruptions}}{\text{Total Number of Customers Served}} = \frac{\sum ID_i N_i}{N_T} \]
Standard Reliability Metrics Contd.

- **ASAI** (Average Service Availability Index)
  
  \[
  \text{ASAI} = \frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demand}} = \frac{N_T \cdot 8760 - \sum r_i N_i}{N_T \cdot 8760}
  \]

- **ASIFI** (Average Service Interruption Frequency Index)
  
  \[
  \text{ASIFI} = \frac{\text{Connected kVA Interrupted}}{\text{Total Connected kVA Served}} = \frac{\sum L_i}{L_T}
  \]

- **ASIDI** (Average Service Interruption Duration Index)
  
  \[
  \text{ASIDI} = \frac{\text{Connected kVA Duration Interrupted}}{\text{Total Connected kVA Served}} = \frac{\sum r_i L_i}{L_T}
  \]
## Typical Values for Basic Reliability Indices

<table>
<thead>
<tr>
<th>SAIDI</th>
<th>SAIFI</th>
<th>CAIDI</th>
<th>ASAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 min/yr</td>
<td>1.1 Interruptions/yr</td>
<td>76 min/year</td>
<td>99.82%</td>
</tr>
</tbody>
</table>
Historical Vs Predictive Analysis

• Historical Analysis
  ◦ Use system outage histories to compute indices that reflect past performance of the system
  ◦ Basis for most short term decision making
  ◦ Used in the computation of failure rates and repair times required as input to predictive analysis

• Predictive Analysis
  ◦ Combine system topology with a set of techniques to estimate load-point and system indices
  ◦ Basis for most long term as well as short term decision making
Information Required for Predictive Reliability Evaluation

- System topology

- Reliability parameters
  - Over-head and underground line segments
    - Permanent Failure Rate ($\lambda_p$)
    - Temporary Failure Rate ($\lambda_t$)
    - Mean Time to Repair (MTTR)
  - Protective and Switching Devices (Reclosers, Switches, Fuses, Breakers, etc.)
    - Probability of Failure (POF)
    - Protection Reliability (PR)
    - Reclose Reliability (RR)
    - Mean Time to Repair (MTTR)
    - Switching Reliability (SR)
    - Mean Time to Switch (MTTS)

- Customer and Load Information
How to Compute Reliability?

- **Analytical Methods**
  - Use system topology along with mathematical expressions to determine reliability indices

- **Simulation Based Methods**
  - Compute indices by simulating the conditions on the system by generating system states of failure and repair randomly

- **Assumptions made in Analytical Methods**
  - Temporary and Permanent fault processes are independent and mutually exclusive
  - Occurrence of a fault excludes the occurrence of another until the system is restored to normalcy. Can be a reasonable assumption if the system spends a majority of the time in its normal working state
Accounting for Protection and Switching Failures

- When a protective device fails to operate after a fault occurs downstream of it, the backup protective device operates and clears it causing more number of customers to be interrupted for a longer period of time.

- When a switch fails to operate, customers are not restored and experience a duration equal to the MTTR of the fault.
<table>
<thead>
<tr>
<th>Zone Number</th>
<th>Device Name</th>
<th>Branches in the zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Branch 1</td>
</tr>
<tr>
<td>1</td>
<td>BRK</td>
<td>M1</td>
</tr>
<tr>
<td>2</td>
<td>F1</td>
<td>L1</td>
</tr>
<tr>
<td>2</td>
<td>S1</td>
<td>M2</td>
</tr>
<tr>
<td>3</td>
<td>F2</td>
<td>L2</td>
</tr>
<tr>
<td>3</td>
<td>S2</td>
<td>M3</td>
</tr>
<tr>
<td>4</td>
<td>F3</td>
<td>L5</td>
</tr>
</tbody>
</table>

Alternative Supply

- Zone 1: 900 Customers, 1800 kVA
- Zone 2: 550 Customers, 1100 kVA
- Zone 3: 450 Customers, 825 kVA
- Zone 4: 125 Customers, 300 kVA
Methods to Improve Reliability

- Maintenance
  - Corrective Maintenance
  - Preventive Maintenance
    - Time based or periodic maintenance
    - Condition based preventive maintenance
    - Reliability centered maintenance
    Reduces both the momentary and sustained outage frequency

- Installing reclosers and breakers
  Reduces both the outage frequency and duration

- Fuse saving and Fuse clearing methods
  - Self resetting fuses
  Reduces both the outage frequency and duration
Methods to Improve Reliability Contd.

- **Switching**
  - Upstream switching
  - Downstream switching or back feeding
  *Reduces the outage duration experienced by customers*

- **Use of automation**
  *Reduces the outage duration*

- **Crew management**
  *Reduce the outage duration*

- **System reconfiguration**
  *Reduces both the outage frequency and duration*
Distribution Automation
Distribution Automation - Overview

- Introduction
- Distribution Automation
  - Necessity
  - Technology
  - Challenges
- Better Power Quality
  - Drivers
  - Power quality products
- Efficient Power Utilization
  - Different efficient power utilization
  - Efficient utilization solution
Issues in Distribution System

- **Reliability**
  - Continuity of power supply
  - Fault detection, isolation, service restoration after fault
- **Quality**
  - Voltage, power factor, Harmonics, Frequency variations
- **Efficiency**
  - Technical losses, commercial loss
- **Unplanned Growth of Electric Power Network**
  - In Distribution; cause of difficulty in Management of the network
- **Complexity**
  - Of network, Of technology
- **Cost**
  - Implementation cost, maintenance cost
- **Time**
  - To meet the requirement of customer within shortest time
Distribution Automation – A Necessity

- To measure, protection control and monitor the components which are remotely located outside the substation
- To integrate all substations within a circle and all such components which are remotely located outside the substation for performance analysis
- To make fault detection and automatic isolation
- To integrate automatic meter reading to avoid manipulation and loss of revenue by integrating DA with Automatic Billing and Collection Center
- To maintain load shedding schedule automatically
- To monitor network topology and network components (assets)
- To increase overall efficiency, reliability.
- To make operation and maintenance easy
- To save the time gap between a trouble call by a customer and actual service by integrating DA and Trouble Call Management
Components of Distribution Network:
- Transformers
- Ring Main Units
- Substations

Basic Components of Automation:
- Master Distribution Automation Software
- Engineering analysis software
- Data Acquisition and Control Hardware like Relays, Digital Multifunction Meters, Remote Tap Changer
- Communication Hardware

Basic Features:
- Monitoring
- Control
- Protection
Distribution Automation – Technology

Necessary Functions:

- System Level
  - Monitoring
  - Control
  - Substation Automation
  - Feeder Automation

- Customer Level
  - Remote Meter Reading and Billing
  - Load management
  - Customer Automation
Distribution Automation – Technology

- Monitoring and Control Functions:
  - Data Monitoring
  - Data logging
  - Remote Meter Reading and Billing
  - Automatic Bus/ Feeder Sectionalizing
    - Fault location, Isolation and Service Restoration
    - Feeder Reconfiguration and Substation Transformer Load Balancing
    - Substation Transformer overload
  - Integrated Volt/ VAR Control
    - Capacitor Control
    - Voltage Control
  - Emergency Load Shedding
  - Load Control
Global Architecture of Distribution Automation and Management System
Challenges in Distribution

- Covering Large Area
- Geographical and atmospheric Problems
- Interoperability Issues
- Huge Data Handling
- Data storage and related care
- Care of future expansion
Driving Force for Distribution Automation – Power Quality

• Increase in nonlinear loads has ignited a demand for increased power quality on the grid
  • Harmonics need to be accounted for

• Examples of nonlinear, harmonic causing loads:
  • Electronic equipment such as PC
  • Battery chargers
  • Lighting dimmer controls
  • Fluorescent lights
  • Welders
  • Electronic ballasts
  • Printers
  • Photocopiers
  • Fax machines
Power Quality Products

- Mechanical Switched Capacitor
  - Current based
  - p.f. based

- Thyristor Switched Capacitor (TSC)

- Static Synchronous Compensator (STATCOM)
  - LV (415V, extendable up to 690V), ratings 110kVAR, 200kVAR, 500kVAR
  - LV (415V) 1-ph STATCOM, 100kVAR & module paralleling for high power rating

- MV (11kV and above) STATCOM

- Voltage dip compensator

- Thyristor “Q” Compensator
IEC 61850

• Standard for the design of electrical substation automation.

• Features:
  • *Data Modeling* — Primary process objects as well as protection and control functionality in the substation is modeled into different standard logical nodes which can be grouped under different logical devices. There are logical nodes for data/functions related to the logical device (*LLN0*) and physical device (*LPHD*).

  • *Reporting Schemes* — There are various reporting schemes (*BRCB* & *URCB*) for reporting data from server through a server-client relationship which can be triggered based on pre-defined trigger conditions.

  • *Fast Transfer of events* — Generic Substation Events (*GSE*) are defined for fast transfer of event data for a peer-to-peer communication mode.
IEC 61850

• Features (cont):
  
  • *Setting Groups* — The setting group control Blocks (*SGCB*) are defined to handle the setting groups so that user can switch to any active group according to the requirement.
  
  • *Sampled Data Transfer* — Schemes are also defined to handle transfer of sampled values using Sampled Value Control blocks (*SVCB*)
  
  • *Commands* — Various command types are also supported by IEC 61850 which include direct & select before operate (SBO) commands with normal and enhanced securities.
  
  • *Data Storage* — Substation Configuration Language (*SCL*) is defined for complete storage of configured data of the substation in a specific format.
Distribution Automation and the Smart Grid

How The Grid Is Getting Smarter
Smart Grid
Smart Grid - Overview

- Motivation
- Sensing and Measurement
- Communications and Security
- Components and Subsystems
- Interfaces and Decision Support
- Control Methods and Topologies
US Electricity Grid

- Aged
- Centralized
- Manual operations
- Fragile
Northeast Blackout – August 14, 2003

- Affected 55 million people
- $6 billion lost
- Per year $135 billions lost for power interruption
Smart Grid

- Uses **information technologies** to improve how electricity travels from power plants to consumers
- Allows consumers to interact with the grid
- Integrates new and improved technologies into the operation of the grid
Smart Grid Attributes

- Information-based
- Communicating
- Secure
- Self-healing
- Reliable
- Flexible
- Cost-effective
- Dynamically controllable
Advanced Sensing and Measurement

- Enhance power system measurements and enable the transformation of data into information.
- Evaluate the health of equipment, the integrity of the grid, and support advanced protective relaying.
- Enable consumer choice and demand response, and help relieve congestion.
Advanced Sensing and Measurement

- Advanced Metering Infrastructure (AMI)
  - Provide interface between the utility and its customers: bi-direction control
  - Advanced functionality
    - Real-time electricity pricing
    - Accurate load characterization
    - Outage detection/restoration
  - California asked all the utilities to deploy the new smart meter
Advanced Sensing and Measurement

- Health Monitor: Phasor Measurement Unit (PMU)
  - Measure the electrical waves and determine the health of the system.
  - Increase the reliability by detecting faults early, allowing for isolation of operative system, and the prevention of power outages.
Advanced Sensing and Measurement

- Distributed weather sensing
  - Widely distributed solar irradiance, wind speed, temperature measurement systems to improve the predictability of renewable energy.
  - The grid control systems can dynamically adjust the source of power supply.
Integrated Communications and Security

- High-speed, fully integrated, two-way communication technologies that make the smart grid a dynamic, interactive “mega-infrastructure” for real-time information and power exchange.

- Cyber Security: the new communication mechanism should consider security, reliability, QoS.
Wireless Sensor Network

- The challenges of wireless sensor network in smart grid
  - Harsh environmental conditions.
  - Reliability and latency requirements
  - Packet errors and variable link capacity
  - Resource constraints.

- The interference will severely affect the quality of wireless sensor network.
Advanced Components and Subsystems

• Advanced Energy Storage
  ◦ New Battery Technologies
    • Sodium Sulfur (NaS)
  ◦ Plug-in Hybrid Electric Vehicle (PHEV)
    • Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G)
    • Peak load leveling
Advanced Components and Subsystems

Fig. 1. The IEEE’s version of the Smart Grid involves distributed generation, information networks, and system coordination, a drastic change from the existing utility configurations.
Improved Interfaces and Decision Support

- The smart grid will require wide, seamless, often real-time use of applications and tools that enable grid operators and managers to make decisions quickly.

- Decision support and improved interfaces will enable more accurate and timely human decision making at all levels of the grid, including the consumer level, while also enabling more advanced operator training.

- Smart Grid Application
Improved Interfaces and Decision Support

- Advanced Pattern Recognition
- Visualization
  - Human Interface
    - Region of Stability Existence (ROSE)
      - Real-time calculate the stable region based on the voltage constraints, thermal limits, etc.
Control Methods and Topologies

- Traditional power system problems:
  - Centralized
  - No local supervisory control unit
  - No fault isolation
  - Relied entirely on electricity from the grid
IDAPS: Intelligent Distributed Autonomous Power Systems

- Distributed
- Loosely connected APSs
- Autonomous
  - Can perform automatic control without human intervention, such as fault isolation
- Intelligent
  - Demand-side management
  - Securing critical loads
**APS: Autonomous Power System**

- A localized group of electricity sources and loads
  - Locally utilizing natural gas or renewable energy
  - Reducing the waste during transmission
    - Using Combined Heat and Power (CHP)
Multi-Agent Control System

- **IDAPS management agent**
  - Monitor the health of the system and perform fault isolation
  - Intelligent control

- **DG agent**
  - Monitor and control the DG power
  - Provide information, such as availability and prices

- **User agent**
  - Provide the interface for the end users
IDAPS Agent Technology

Communication between users, database, DG, devices and agents

Communication among agents within the same APS through LAN

DG = distributed generation; SW = switches; CB = circuit breakers;
TR = transformer; DB = database
Questions?