Basics of Interconnected Energy and Power Systems

S. S. (Mani) Venkata
Alstom Grid Inc.
University of Washington
Tel: 520-820-8005 (cell)
E-mail: mani.venkata@alstom.com
ssvenkata@comcast.net
NSF/ECEDHA Education Workshop
Atlanta, GA
July 10, 2011
Basics of Interconnected Utility Systems

• Basic technical terms
• Integrated (interconnected) power system
• Utility structure
• System functions
• Performance Indices
Have You Come to “Terms” with the Following?

- Integrated power system
- Utility structure
- Design
- Planning
- Operation
- Engineers role
- Business enterprise
- Regulatory/market environment
- Standards
Simple “Terms” defined

- Federal Energy Regulatory Commission (FERC): A quasi-independent regulatory agency within the Department of Energy having jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, oil pipeline rates, and gas pipeline certification.

- North American Electric Reliability Corporation (NERC): FERC approved eight delegation agreements by which NERC will delegate its authority to monitor and enforce compliance with NERC Reliability Standards in the United States to eight Regional Entities, with NERC continuing in an oversight role. FERC certified NERC as the “Electric Reliability Organization (ERO)” for the United States.
Principal “Terms” defined

- **Independent System Operators (ISO):** An independent, Federally-regulated entity that coordinates regional transmission in a non-discriminatory manner and ensures the safety and reliability of the electric system. Also known as Regional Transmission Operator (RTO).

- **Interchange:** The agreement among interconnected utilities under which they buy, sell, and exchange power among themselves. This can provide for economy and emergency power supplies.
Mission of Utility

• Cost of service (COS) model for rate making was the primary criterion under regulated environment

• Minimize Total Cost
  – Capital cost
  – Operations Cost
  – Maintenance Cost
  – Other associated costs

• Rate making was based on total cost and reasonable return to share holders

• A utility is committed to protecting and securing its systems, facilities, and employees, and ensuring customers continue to receive safe and reliable gas and electric service.
Thus far we have examined the major sub-systems or functions of utility systems.

In this part we will examine how these sub-systems fit together as an integrated or interconnected power system to meet customer expectations.

We will also examine the role of engineers in your utility to design, plan and operate your systems to meet your company objectives.
Vertically Integrated (Regulated) Utility Planning and Operational View

Other Utilities

Energy Control Center (ECC)
EMS Functions

Distribution Control Center (DCC)
DMS Functions

Utility

Generation

Transmission

Distribution

Customers

Engineering Design
Construction

Interconnection
(Tie Lines)

Planning

Operations
Maintenance
Why Integration?

• At the company level, the integration of generation, transmission and distribution allows cost-effective, reliable and secure power delivery from generating plants to customers.

• Transmission interconnection provides alternate paths in the event of the loss of a plant or a transmission lines (N-1) contingency. This assures better reliability and security.

• The interconnection of an utility with other contiguous utilities via tie-lines enhances the performance indices mentioned above one step further.
Why Integration?

- This will also optimize the generation resources, if power can be exchanged between utilities, both daily and seasonally instead of building new plants.
  - During the high demand, power can be purchased or excess power can be sold during low demand. This is a win-win situation.
  - During emergencies, the exchange of power implies less reserve capacity needed within the company.
Performance Indices

- Power Delivery System Efficiency
- Reliability of supply to customers
  - SAIFI, SAIDI and CAIDI
- Voltage Regulation
  - \( \pm 5\% \) (114-V to 126-V on 120-V basis)
- Frequency Regulation
  - \( \pm 0.05 \) Hz (59.95- to 60.05-Hz on 60-Hz basis)
- Minimum cost of operation
  - To assure lowest electric bill to consumers
- Security (system and cyber)
Planning, Design and Operations: Philosophical considerations

- Power and energy systems are complex and capital intensive
- Planning, design and operation are very complex process
- Generation, transmission and distribution functions are treated separately from this point of view.
- Multiple objectives and constraints
- Changes in customer base are occurring rapidly
- Challenges and opportunities to enhance system performance
- How do we adapt to the changes?
Role of System Planning

- Identify customer service, system reliability, and environmental expectations
- Provide consumer end-use and system-use forecasts
- Provide engineering system assessments using electric facility steady state and operational/dynamic models
- Assure additions have a good chance of reaching their planned economic life
Role of System Planning

- Consider economics, reliability, power quality, safety, new technologies, and public acceptance when planning
- Identify right-of-ways and land requirements for future expansion of substations and lines
- Recommend optimal electric system designs and operational practices
Planning Functions

- Meet the minimum lead time
- Achieve project objectives
- Keep constraints in mind
- Achieve goals at minimum cost
- Trade off between all of the above
Planning Objectives

- Multiple objectives
  - Affordable power delivery
  - Adequate capacity
  - Achieve highest performance levels

- Reliability
- Voltage and power quality
- Efficiency
- Security
Planning Objectives

- **Short-range planning**
  - Assure lead time times are met
  - Arrive at decisions and specifications for future additions and and/or changes

- **Long-range planning**
  - Be visionary
  - Assure that short-range goals are met at a minimum cost
  - Evaluation of short-range plans on continuous basis
  - Be cognizant of future changes and developments
Planning Objectives

• **Normal conditions**
  - System efficiency, reliability, security
  - Cost-effective design solutions (minimized total costs)
  - Minimum risk investments
  - Voltage regulation/load balancing
  - Re-configuration of system

• **Emergency conditions**
  - Adequate capacity and performance
  - Load transfer
  - Restoration
Planning Constraints

- **Multiple constraints**
  - Economic (long range total cost minimization)
  - Technical (voltage quality, capacity & reliability)
  - Societal (total consumer expectations)
  - Environmental (UG, dispersed generation)
System Planning Time Ranges

- Planning time ranges
  - Strategic: (>20 years)
  - Long Range: (5 to 20 years)
  - Short Range: (1 to 4 years)
System Planning Time Ranges

- Strategic planning methods provide strategic generation, transmission and distribution direction for long-range infrastructure expansion, operation, and maintenance.

- Long Range plans provide direction for short range planning.
Engineering and Design

- This is the process of selecting the proper size and ratings of individual components for each of the functions, namely, generation, transmission, substation and distribution.
  - Each function is treated separately due to its complex nature
  - Specifications include voltage, power (va), type of connections, temperature ranges, Insulation and other relevant parameters
  - Attention should to be paid for environmental conditions
Engineering and Design

- Standards assist in ensuring equipment reliability, safety and quality
- Different standards available are:
  - National Electric Manufacturers Association (NEMA): Equipment specifications
  - American national Standards Institute (ANSI): Legal entity for standards
  - Underwriter Laboratories (UL): Customer appliance standards
  - Institute of Electrical and Electronics Engineers (IEEE): created for engineering specifications.
  - International Electrical Commission (IEC): Used by many countries in the world. IEEE and IEC are cooperating in creating one standard.
  - National Electric Code (NEC): Safety code for equipment less than 600-V
Operations

- This is the process of ensuring reliable, safe and secure delivery of electric service to customers.
- Transmission and distribution functions are treated separately but coordinated as explained later in this module.
- It takes place in real-time with some level of automation.
- It involves monitoring, protection and control of equipment and system functions.
North American Transmission Interconnection Network

Source: NERC
North American Electric Reliability Councils (NERC)

Source: NERC
North American Electric Reliability Councils (NERC)

- RFC – Reliability First
- TRE - Electric Reliability Council of Texas, Inc.
- FRCC - Florida Reliability Coordinating Council
- MRO – Mid-American Reliability Organization
- NPCC - Northeast Power Coordinating Council
- SERC - Southeastern Power Coordinating Council
- SPP - Southwest Power Pool, Inc.
- WECC - Western Electricity Coordinating Council
Reliability First Corporation

Source: http://rfirst.org
The ISO/RTO Council (IRC)

- The ISO/RTO Council (IRC) is comprised of ten Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) in North America. These ISOs and RTOs serve two-thirds of electricity consumers in the United States and more than 50 percent of Canada's population.

- The IRC works collaboratively to develop effective processes, tools, and methods for improving competitive electricity markets across North America. The IRC’s goal is to balance reliability considerations with market practices, resulting in efficient, robust markets that provide competitive and reliable service to electricity users.
Structure of Operations

- Utility
- Generation
- Transmission
- Distribution
- Customers

- Other Utilities
  - Energy Control Center (ECC) EMS Functions
  - Distribution Control Center (DCC) DMS Functions

- Operations Maintenance
Operational Functions at Bulk Level (ECC)

- Energy Control Center (ECC) Operators Functions
  - Maintain energy balance under normal condition in real-time
  - Take control actions under emergency conditions
Operational Functions at Bulk Level (EMS)

- **Energy Management System (EMS)**
  - Hardware and software systems that enable different applications
    - Automatic Generation Control
    - State Estimation
    - Optimum Generation Dispatch
    - Unit commitment
    - System Restoration
Energy Control Center (ECC)
Operational Functions at Distribution Level (DCC)

- **Distribution Control Center (DCC) Operators Functions**
  - Maintain steady-state operations and dispatch load under normal condition in real-time
  - Take proper control actions under emergency conditions
Operational Functions at Distribution Level (DMS)

- Distribution Management System (DMS)
  - Hardware and software systems that enable different applications
    - Voltage/var management and control
    - System reconfiguration to minimize losses
    - Demand-side management
    - Equipment monitoring and control
    - Asset Management
    - Fault detection, location, isolation and system restoration
Engineers’ Role

- Conduct planning, design and operational planning and operations studies for
  - Steady-state time frame
  - Dynamic
  - Transient
  - Implies normal and emergency conditions

- Provide guidance to operators and other technical personnel
Typical Studies Conducted

- Power flow analysis
- Short-circuit or fault analysis
- Dynamic and transient analysis
- Transient analysis
- Reliability assessment
- Security analysis
- Power quality assessment
- Economic analysis
System Protection Overview

- Objectives: Prevent damage to equipment and circuits
- Prevent hazards to the public and utility personnel
- Maintain a high level of service by preventing power interruptions
- Minimizing the effects when an interruption occurs
Protection Philosophy

- It is like insurance
- The purpose is to assure
  - Dependability
  - Selectivity
  - Sensitivity
  - Reliability
  - Security
Additional Considerations

- In addition to meet the following objectives
  - Basic planning for the system
  - Proper phase spacing and conductor insulation
  - Vegetation management
  - Inspections for other potential problems
  - Equipment maintenance
Devices that Need Protection

- Adequate protection must be provided for all types of equipment
  - Generators
  - Transformers
  - Overhead lines
  - Underground cables
  - Capacitors
  - Voltage regulators
  - Segments of the system itself
Fault Causes

EPRI fault study
Permanent Faults

- One in which damage has occurred from
  - The cause of the fault or
  - The fault arc

- Examples
  - Broken insulator
  - Broken conductor
  - Automobile knocking down a pole

- When a permanent fault occurs, the line must be de-energized and a crew is dispatched to repair the damage
Temporary Faults

- Most faults on overhead distribution systems are temporary (70-80%)
- A temporary fault is one whose cause is transitory in nature
- Examples
  - Brief contact between two conductors
  - Tree branch falling across two conductors, then dropping clear
  - Bird or small animal that causes a brief arc from the live terminal to ground
Protective Devices

- They are the weakest links installed to protect expensive power devices mentioned earlier
- Single-action fuses
- Automatic circuit reclosers
- Sectionalizers
- Relay-controlled circuit breakers
Protecting Device Coordination

- By conventional definition, when two or more protective devices are applied to a system
  - The device nearest the fault on the supply side is the protecting device
  - The next nearest is the protected or backup device
Blackouts

- This phenomenon occurs when generation demand balance.
- The system could lose stability and falls out of step and creating islands of blackouts.
- Causes: Tornados, Trees, loss of generation, tie-line interconnection, lack of reactive power support and human error.
When the cascade was over at 4:13 pm, over 50 million people in the northeast US and the province of Ontario were out of power.
Summary

• In this part the purpose of the power delivery system is introduced.
• System planning and operational functions are described.
• The role of engineers for system performance studies are explained.

What questions do you have?