Power Systems Overview

Summer Programs
Part I

- Early History
- Key Developers
- Early Inventions
- AC versus DC
- Modern Power Grid
Electricity in History

- Attractive Force was studied in ancient times.
- Revealed that static electricity goes to the “Ground”.
- If person is insulated from the ground then they can store a charge.
- This led to the study of insulators and conductors.
- The study of lightning had a fair number of failures.
- Later the development of batteries, light bulbs and motors would change how people live.
Earliest ‘Electricians’
Early Devices
Early Electric Vehicles
Electric Trains and Trolleys
Edison vs Westinghouse
DC Vs. AC

- **Direct current (DC)**
  - DC machines
  - Batteries
  - Fuel cells
  - Photovoltaic

- **Alternating current (AC)**
  - AC machines
  - Power electronic converters
  - 60 Hertz in the US

\[ i(t) = I \]

\[ i(t) = I \sin(2\pi ft) \]
DC Vs. AC

• DC
  – Pushed by Thomas Edison (GE)
  – Could not change voltage levels (no transformer) so cannot transmit over long distances
  – DC generator (high maintenance)
  – Difficult to interrupt high currents (no zero crossing)

• AC
  – Nikola Tesla (moved from Edison to Westinghouse)
  – Can efficiently change voltage levels (transformer) and so transmit over long distances (high voltage)
  – Induction and synchronous machines
  – Easier to interrupt high currents

→ DC actually has many advantages
AC and DC

• Today, it is not a question of AC versus DC, but of AC and DC.
• DC is the only technology that allows power to be transmitted economically over very long distances, and DC is the type of power produced by photovoltaic panels.
• As far as using power is concerned, more and more equipment runs on DC, such as computers, cell phones and LED lights.
• Batteries are another technology that runs on DC power and there are more and more of these around us storing excess power produced from renewable energy installations.
3 Phase Generator
Major Power Grid Components

- Generation
- Transmission
  - 115 kV to 765 kV
  - Networked
- Distribution
  - 4 kV to 69 kV
  - Radial
- Load
Major Power Grid Components

➢ All power systems have three major components: Generation, Transmission/Distribution, and Load.

➢ Generation: Creates electric power.

➢ Transmission/Distribution: Transmits electric power from generation to load.

➢ Load: Consumes electric power.
Interconnections
AC Grid
DC Components
# Transmission & Distribution

<table>
<thead>
<tr>
<th>Transmission</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>networked connections</td>
<td>radial connections</td>
</tr>
<tr>
<td>power can be supplied from</td>
<td>power moves in one direction only</td>
</tr>
<tr>
<td>multiple sources</td>
<td></td>
</tr>
<tr>
<td>typically higher voltages,</td>
<td>typically lower voltages, below</td>
</tr>
<tr>
<td>above 100 kV</td>
<td>100 kV</td>
</tr>
<tr>
<td>mostly overhead, with some</td>
<td>most new construction is</td>
</tr>
<tr>
<td>underground in urban areas</td>
<td>underground, especially in</td>
</tr>
<tr>
<td>often source of large-scale</td>
<td>the source of most blackouts,</td>
</tr>
<tr>
<td>blackouts</td>
<td>but these are local</td>
</tr>
</tbody>
</table>

often source of large-scale blackouts
Synchronism

Since most generation is from synchronous machines, the interconnected power system swings together.
North American Control Areas
Part II

- Smart Grid
- Power-Net
- Electric Vehicles
- Phasor Measurements
- FNET
- Electricity Market
- Smart Home
The Smart Grid Concept

- A smart grid is not a single concept but rather a combination of technologies and methods intended to modernize the existing grid in order to improve flexibility, availability, energy efficiency, and costs.
  - Smart Grid 1.0:
    - Intelligent meters
  - Smart Grid 2.0 (“Energy Internet” enabler):
    - advanced autonomous controls,
    - distributed energy storage,
    - distributed generation, and
    - flexible power architectures.
- Distributed generation (DG), flexible power architectures, autonomous controls and loads constitute local low-power grids (micro-grids).
The Power-Net

- DOE view for a smart grid:
  - “An electrical grid is a network of technologies that delivers electricity from power plants to consumers in their homes and offices.”
- A Power-Net expands this view based on paradigms from the Internet.
- Some features compared with conventional power grids: more reliable, efficient, and flexible.
The Power-Net

- Like the Internet, the Power-Net involves diverse and redundant path for the power to flow from distributed generators to users.
- Its control resides in autonomous distributed agents.
- Contrary to the Internet, the Power-Net involves a local approach for power interactions.
• A hybrid ac (solid lines) and dc (doted lines) architecture with both centralized and distributed generation resources.
• Problem: Typical home peak power consumption is below 5 kW. An electric vehicle may require 1 kW to be charged in 8 hrs. or up to 8 kW for shorter charging profiles. Also, PEV and PHEV penetration is not uniform (higher for neighborhoods with higher economical household income).

Hence, grid’s distribution transformers can be easily overloaded

PEV and PHEV even if charging is done during nighttime.

• DG avoids overloading distribution transformers but economical issues still need to be addressed
• Combination of DG and energy storage may be a suitable solution.
Phasor Measurement Units

- The first experimental PMUs were developed at Virginia Tech in 1988, and Macrodyne built the first PMU in 1992.
- The modern PMUs use one pulse per second signals provided by the GPS satellite receivers.
  - The accuracy of the GPS timing pulse is better than 1 μs.
  - For a 60 Hz system corresponds to about 0.02 degrees.
  - Current PMU records data at the rate of 30 samples per second (This number can be adjusted).
Installed PMUs in US
PMU Applications

- Wide-Area Visualization and Monitoring;
- Angle and Frequency Monitoring;
- Inter-area Oscillation Detection & Analysis;
- Proximity to Voltage Collapse;
- State Estimation;
- Fast Frequency Regulation;
- Transmission Fault Location Estimation;
- Dynamic Model Validation.
FNET

- Operated by the Power Information Technology Laboratory at the University of Tennessee
- Frequency Disturbance Recorders (FDRs) are used to measure the frequency, phase angle, and voltage of the power system at ordinary 120 V outlets
- Measurements are continuously transmitted via the Internet to the FNET servers hosted at the University of Tennessee and Virginia Tech
- World-wide FDR deployment
Smart Phone Based FDR

Sensor and data acquisition board

Smart phone

Electrical field sensor
Amplifier part 1#

Voltage transducer
Amplifier part 2#

Lowpass filter & ADC

MCU

Voltage
Freq-Angle-Voltage
FNET Capabilities

FNet data can be used for:

- Event detection and location estimation
- Oscillation detection
- Animations of frequency and angle perturbations
- Detection of system breakup or islanding
- Predictions of grid instability

Used as an integral part of NERC’s
- Frequency event detection
- Rapid analysis of system events
FDR Locations

NERC
FDRs locations in US/Canada

- In Service
- Under Deployment
- Desired Location
Super Bowl
Frequency swings during commercials
FNET Recordings

Royal Wedding
Electricity Market

➢ Regulated power industry
  ➢ Regulated by government boards
  ➢ A monopoly system and “vertically” integrated
  ➢ Obligation to serve with guaranteed rate of return
Electricity Market

➢ To improve efficiency and reduce cost
➢ Create competition and market mechanism
**Smart Homes**

- The SHEMS test bed is a smart home prototype, developed in the Department of Electrical Engineering and Computer Science (EECS) at UTK.

The test bed is able to:
- 1) read real-time prices (if a privilege to real data is granted);
- 2) provide optimal control strategy with automatically adjusted loads including electrical water heaters (EWHs), heating/ventilation air conditioning (HVAC) systems, electrical vehicle (EV) charging stations, dishwashers, washing machines, and dryers;
THANK YOU!

Questions?