The Transmission Grid: Understanding How It Works to Understand Who Should Pay

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Thanks to:

- Dr. Wayne Galli, Director of Transmission Development for NextEra Energy Resources, for portions of this presentation
What is the Largest, Most Complex Machine Ever Built?

- The space shuttle?
- The Eastern Interconnection?
- The world wide web?
- The Large Hadron Collider?
Thomas Edison

- Advocate of direct current (DC) electric power system
- Founder of General Electric
George Westinghouse

- Advocate of alternating current (AC) electric power system
- Co-founder of Westinghouse Electric
AC vs. DC

- **Direct current (DC)**
  - Magnitude of current is constant

- **Alternating current (AC)**
  - Magnitude of current varies with time
AC vs. DC

• In the late 19th century, an often vicious battle was waged over whether to use AC or DC for electric power systems

• Edison tried to sway public opinion by claiming that AC was dangerous
  – electrocution of animals
  – development of the electric chair
A Winner!!!

- AC became the current of choice, largely because of the transformer
  - Transformers could easily increase voltage levels to transmit power from the generator and decrease voltage at the load
    - lower losses
- Also, AC is easier to disconnect because the current is equal to zero twice during each cycle
Without a Transmission System

- Loads must be located close to a generator
  - Less than a mile
  - Only cities have access to power
- Small generators
  - High cost
We Add a Transmission Line

Basic Structure of the Electric System

<table>
<thead>
<tr>
<th>Color Key</th>
<th>Description</th>
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<tbody>
<tr>
<td>Blue:</td>
<td>Transmission</td>
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<tr>
<td>Green:</td>
<td>Distribution</td>
</tr>
<tr>
<td>Black:</td>
<td>Generation</td>
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</tbody>
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Transmission Lines
500, 345, 230, and 138 kV

Transmission Customer
138kV or 230kV

Subtransmission Customer
26kV and 69kV

Primary Customer
13kV and 4kV

Secondary Customer
120V and 240V

Source: www.nerc.com
With Transmission

- We can build generation in areas removed from the loads
  - More desirable environmental and fuel factors
- We can build larger, more efficient generators
  - Economies of scale
- We can get power to remote areas with lower losses
  - Rural electrification
A Radial System

Distribution & loads

Transmission

Generator

Distribution & loads

Transmission

Distribution & loads

Transmission

Distribution & loads

Transmission

Distribution & loads

Transmission

Distribution & loads
Radial Systems

- Electric power flows from generator to transmission line to distribution system along a single path
- Failure of any component on the path means the lights go out
- This type of system is still used in some developing parts of the world
Parallel Path Systems

• The addition of a second (or more) transmission line increases reliability
  – If a line or transformer fails, power can still flow along another path
• Power losses in the transmission lines are reduced
• But, adding additional lines costs $$$
We Have a Network
Early Utility Systems

• A number of separate utilities operating as islands

• Transmission was built to serve local needs
  – Reliability
  – Allow for larger, more efficient generators located at a distance from the loads
Electrical Isolation

• Maintaining reliability was difficult and expensive with the utilities being electrically separated from each other
  – Each utility would need to build in enough redundancy to handle the problems that might arise, or the customers would have to live with the lights going out
  – It would be difficult for a utility to respond to rapid changes in load levels
Example

• Suppose I have a utility with 500 MW of load, supplied by three generators
  – 2 are 100 MW each
  – 1 is 300 MW

• In order to handle an outage of the largest generator, I would need 300 MW of excess generation capacity
Example w/ Interconnection

• Suppose my neighbor has an identical system
• If we interconnect, we could each carry 150 MW of extra capacity instead of 300 MW
  – Whichever utility experienced the outage would rely on his neighbor for the rest
Interconnection
Benefits of Interconnection

• Reserve margins can be reduced
  – Saves $$$

• It is easier to follow load changes (ancillary services)
  – More generators means each can handle a smaller portion of the load change

• Reliability is increased
  – My interconnected neighbor can help me keep the lights on when I experience a problem

• Bulk power transactions, power pools, and markets are possible
  – Saves $$$
Liabilities of Interconnection

• It is difficult to control the path over which electrical power flows (loop flow)
  – “Path of least resistance”
  – “Laws of physics”
• It is also more difficult to analyze
• Cascading outages
  – Instead of my neighbor keeping my system up when I have a problem, I pull his down with me
Interconnected Grid

- U.S. has largest power grid in world

Source: Based on data from Global Energy Decisions, LLC, Velocity Suite, June 2008
Interconnected Operation

- Power systems are interconnected across large areas. For example, most of North America east of the Rockies (with exceptions for Quebec and most of TX) is an interconnection.
- Individual utilities within each interconnection own and operate a small portion of the system (a balancing authority).
- Transmission lines known as tie lines connect the individual utilities to each other.
3 Interconnections, 8 Regions, 135 Balancing Authorities
Balancing Authority and System Control

Generating Plant #1

Generating Plant #2

Control Center

Customers

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Supply and Demand Balance

- Electrical energy cannot be stored easily
  - Must be converted to another form
- Thus, supply and demand must always be kept in balance
What Happens in Vegas...

• ….does not stay in Vegas
• Anything that happens in one part of the interconnection affects the rest of the interconnection
• Usually, an event is so small that the impact is lost in the noise of all the other events in the interconnection
August 14, 2003

Southwest Power Pool
8/14/03
Simple Bi-lateral Transaction

Sale from A to B at 4-5 pm of 100 MW

- 3:40 pm  Schedule
- 3:55 pm  Confirm
- 4:00 pm  Begin interchange
  - Seller increases generation
  - Buyer decreases generation
- 5:00 pm  End
  - Seller decreases generation
  - Buyer increases generation

Areas A & B may be separated by thousands of miles. Price may be affected by various factors including transmission congestion.
Power Flows According to Laws of Physics

The power from A does NOT flow directly to B.
Transmission Limitations

- Physical limits of components
  - Overheating of lines and transformers
  - Line sag

- Stability limits
  - Angular
  - Voltage

- Contingencies
  - Some capability left unused to handle outages
Congestion

• When these limitations become binding, congestion occurs

• Congestion costs $$$
  – Re-dispatch means using less economic generators
  – Reserve margins may need to be higher to maintain adequate reliability
  – Potential for market power increases
  – Ancillary services
Recent Developments

• Open access/regional transmission organizations
  – Increase in economic transactions
• Environmental considerations
  – Increase in renewable generation
• Increasing consumption
• Very little new transmission constructed
Regional Transmission Organizations
Wind Generation

• Over a tenfold increase in installed wind generation this decade in the U.S.
  – 12/31/00 2,566 MW
  – 9/30/08 22,613 MW

• Best wind sites are often located a long distance from the demand
  – Transmission network is not highly developed

• Wind is intermittent, so it does not always produce at full capacity
  – But the transmission system has to be able to handle full capacity
Wind Resources
Installed Wind Capacity

[Map showing current installed wind power capacity with states highlighted]
Wind Generation is Likely to Increase in the Future

- Renewable Portfolio Standards
- Green consumers
- Future greenhouse gas legislation
- Fossil fuel price volatility
Renewable Portfolio Standards

Source: DSIRE
What Does This Mean?

• We have an aging transmission infrastructure
• It is being relied on more heavily than before
  – Increasing demand for electricity
  – Wholesale competition
  – Power markets
  – Diverse sources of generation
• Scheduling maintenance on existing system becomes more difficult
  – When can I take a line out of service?
Reasons to Build New Transmission Lines

- Largely the same as the reason to build the old ones
  - Save $$$
  - Increase reliability

- And some new ones
  - Allow new generation sources
  - Reduce local market power
New Transmission Affects Many Entities

- Reliability and efficiency benefits are felt throughout the interconnection, not just locally
- The degree to which each entity is impacted can vary greatly
Summary

• The electric transmission system has had tremendous impact on all of us
• It enables us to get electric power at a lower cost with greater reliability
  – Economic development
  – Fuel diversity
  – Reduced price volatility
  – Renewable resources
  – Market power mitigation