What makes a Transmission Grid Smart?

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ELECTRICITY is Fundamental to our Civilization

- Conveys both Energy and Information
- Delivers Energy to the user with no emission at the point of use
- Provides an increasing array of innovative products and services
Key Characteristics of a Smart-Grid

- **Self-healing**, Grid rapidly detects, analyzes, responds, and restores
- **Empowers and incorporates the consumers**, Ability to incorporate consumer equipment and behavior in grid design and operation
- **Tolerant of attack**, Grid mitigates and resilient to physical and cyber attacks
- **Provide power quality needed by 21st-century users**, Grid provides quality power consistent with consumers and industry needs
- **Accommodates wide variety of supply and demand**, Grid accommodates variety of resources (including demand response, combined heat and power, wind, photovoltaic, and end-use efficiency
- **Fully enables and is supported by competitive markets**
Smart Electricity- Vision Statement

Electricity is the most versatile and widely used form of energy, global demand is growing continuously. Generation of electrical energy is currently the largest single source of carbon dioxide emissions, making a significant contribution to climate change. To mitigate the consequences of climate change, the current electrical system needs to undergo significant adjustments.

Any adjustments to electrical system must meet four requirements:

**Capacity:** Satisfying increasingly demand for electrical energy

**Reliability:** Satisfying quality and reliability/availability of electricity

**Efficiency:** From production and transport to consumption of electricity, energy has to be saved

**Sustainability:** Integration of low carbon energy sources
“Auto-balancing, **self-monitoring** power grid that accepts **any source of fuel** (coal, sun, wind) and transforms it into a consumer’s end use (heat, light, warm water) with **minimal human intervention**.”

“A system that will allow society to **optimize** the use of **renewable energy** sources and **minimize** our collective **environmental footprint**.”

“It is a grid that has the ability to **sense** when a part of its system is **overloaded** and **reroute power** to reduce that overload and **prevent** a potential **outage** situation.”

“A grid that enables **real-time communication** between the consumer and the utility, allowing the consumer to **optimize energy usage** based on environmental and/or price preferences.”
**DEFINITION?**

Could be defined as:

**An integrated array of technologies**, devices and systems that provide and utilize digital information, communications and controls to optimize the efficient, reliable, safe and secure delivery of electricity.
Smart Transmission Technology-Based Ideas and Concepts

- Flexible AC Transmission System (FACTS) Technology
- High Voltage Direct Current (HVDC) Technology
- Grid Shock Absorber Concept
- Dynamic Thermal Ratings Technology
- Reactive Power Management Concept
- Synchrophasor Technology
FACTS Technology

Electricity flows passively

\[ P = V_1 V_2 \frac{1}{X} \sin(\delta_1 - \delta_2) \]

Smart control of Electricity flows

Gate Turn Off Power Switches

GTO

IGBT

ETO

Unified Power Flow Controller (UPFC)

System operation control

System variables: \( P, Q, V_1, V_1', \text{ etc.} \)
Smarter Power Electronics-based Dynamic Voltage Support

**Smarter (Converter-Based Technology)**

**Converter-based Controllers**

- Superior performance
- Versatile functionality
- Smaller footprint

**Smart (Thyristor-Based Technology)**

**Thyristor switched and/or controlled capacitors/reactors**

- Limited performance
- Limited functionality
- Large footprint
Example of Field Application of Converter-Based Technology

Relieving Major Transmission Bottleneck

New York State Transmission System (230 kV and above)

Transmission bottleneck at Marcy Substation

2x 100 MVA Convertible Static Compensator - a smart solution
NYPA’s Marcy Convertible Static Compensator
“Smart Technology” Relieving Transmission Bottlenecks

Relief of major transmission bottleneck

Strong dynamic voltage support at Marcy has resulted in increase of transmission capacity by about 200 MW, approximately enough power for about 200,000 homes.

Introduction of unprecedented “Smart” controllability and flexibility in transmission grids
AC versus HVDC – Right of Way

Comparison of Towers for 800 kV AC Line a) and 500 kV DC Line b), at same Transmission Capacity

3000 MW

AC

DC

Edris
High Temperature Superconductors for the Grid

5GW, 765kV Overhead Power Lines
600' Wide ROW

5GW, 200kV Superconductor Electricity Pipeline
3' Diameter Pipe
## Two Smart HVDC Technologies

### HVDC Classic – VSC HVDC (PLUS/LIGHT)

<table>
<thead>
<tr>
<th>HVDC Classic</th>
<th>HVDC PLUS/LIGHT</th>
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</thead>
<tbody>
<tr>
<td>Line-commutated current-sourced Converter</td>
<td>Self-commutated voltage-sourced Converter</td>
</tr>
<tr>
<td><strong>Thyristor</strong> with turn-on Capability only</td>
<td>Semiconductor Switches with turn-on and turn-off Capability, e.g. IGBTs</td>
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AC Grid 1 | DC | AC Grid 2

[Diagram showing AC Grid 1, DC line, AC Grid 2 with converter symbols and thyristor/IGBT images]
VSC Back-to-Back Concept
HVDC Light/HVDC Plus Technology

Back-to-Back Asynchronous/Synchronous Tie

Smart Idea
Segmentation with **Grid Shock Absorbers**

*Proof of Concept (US Eastern Interconnection)*

[Diagram showing the Eastern Interconnection with voltage supported buses marked.]

- **System 1**: Voltage supported buses labeled as A, B, and D with corresponding voltage markers $V_1$.
- **System 2**: Voltage supported buses labeled as C with corresponding voltage marker $V_2$.

**Back-to-Back Asynchronous/Synchronous Tie**

**Eastern Interconnection**

- **Ontario**
- **Quebec**
- **New England**
- **Hydro Quebec**
- **New York**
- **PJM**
- **Outside World**
Segmentation with Grid Shock Absorbers

Proof of Concept (US Eastern Interconnection)

2003 Blackout

Lights on
The benefits of HVDC and FACTS

“HVDC and FACTS” have the ability to **help in rerouting power** to eliminate transmission bottlenecks and **prevent** a potential **of cascading outages** situation.

- Increased transmission capacity
- Improved flexibility and controllability of transmission grid
- Bulk power transmission in the GW range over distances of 1,000 kilometers and more
- Reduction in CO₂ emissions, grid access of large wind, hydro, and solar power plants
- Increased robustness and reliability of transmission grid
Smart Idea Mitigating SubSynchronous Resonance (SSR) Problem

- Electric Resonance Circuit
- Mechanical Resonance System

Generator / Turbine Masses

Electrical side

Mechanical side

[Graph showing Electrical side and Mechanical side with SSR]

Time, seconds

LP1-GEN1
Creating Phase Imbalance is a Smart Idea Mitigating SubSynchronous Resonance (SSR) Problem

Conventional series compensation

Series Resonance Phase Imbalance Scheme

Frequency characteristics of phase reactance
Smart Idea Mitigating SubSynchronous Resonance (SSR) Problem

Conventional series compensation

Series Resonance Phase Imbalance Scheme
Smart Idea Enhancing First Swing Stability
keeping synchronous generator in synchronism

30% Series Compensation
Smart Idea Enhancing First Swing Stability
keeping synchronous generator in synchronism
Transient Power Characteristic

Applying the "Smart" idea

30% Series Compensation
Extremely long Fault Clearance Time (400 ms)

\[ A_2 = A_1 \]

\[ P_{(p.u.)} \]
Dynamic Thermal Ratings Technology

Results in 10%-15% Increase of transmission capacity

Heat Balance Equation

\[ Q_{gen} + Q_{sun} = Q_{rad} + Q_{conv} + mC \frac{dT}{dt} \]

Dynamic Thermal Rating

Static Thermal Rating
Conservative Criteria, low wind speed, high ambient temperature

Monitoring

Video Sagometer

Line Tension Monitor

Weather Station

Substation Boundary

Smart Idea

Number of 15 minutes periods

Rating - amperes

Number of Weather Only (22 deg wind angle) Tension Weather Static Rating
C3 – Conditionally Committed Capacity for Overhead Transmission Lines- “Smart idea” for time-ahead generation scheduling
Power System Monitoring and Control Today

Control center
SCADA / EMS

Communication channels

RTUs

Measurements:
- Voltage magnitude
- Current magnitude
- Active power
- Reactive power
- Breaker Status

- No time stamp
- Measurements/sec: 2 – 10
Power System Monitoring and Control with Phasor Measurement Units (Backbone of Real-Time Monitoring)

- Satellite
- Control center SCADA / EMS
- Phasor measurement unit (PMU)
- Communication channels
- GPS signal

Measurements:
- Voltage vector
- Current vector
- Frequency
- Breaker status
- Time synchronization
- Measurements/sec: 6 - 60
Applications

- Loss of synchronization
- Heavy Load
- Inter-area oscillations
- Reactive power shortage
- Line Trip
- Inter-area oscillations
- Loss of generation
- Transmission corridor congestion
- Cascading outages
- Reactive power shortage
- Voltage collapse
- Frequency deviation
- Inter-area oscillations
- Line Trip
- Loss of generation
Reactive Power Puts a Limit on Full Utilization of Transmission Grid

FOAM = Reactive Power

- Mvar Support is Exchangeable with MW
- The Exchange Rate could be up to 0.5 MW/Mvar

Source: Nils Falen
System conditions and contingencies that limit operation or decrease voltage stability conditions?

What are the available **reactive power reserve**?

Where in the power system would **reactive power reserve, compensation, and control** be most effectively located and managed?

What are the most **effective and economic** reactive compensation options to reduce or eliminate these limits?

What are the ratings and other functionality required to achieve these benefits?

What are the **economic benefits** of removing limitations?
Identifying Areas Prone to Voltage Instability and Reactive Power Reserve- *Smart Idea*

Load Increase and/or Transmission Contingencies

Control Area Changes Shape and size with Load Levels and/or Transmission Contingencies
Smart Grid (Evolutionary Development)

Driving Factors:

- Greater network complexity and vulnerability
- Increased energy trading
- Grid Conditions and Requirements
  - Cost pressure
- Fluctuating infeed
  - Increasing distance between generation and load
  - Integration of distributed energy resources
- High supply quality
- Integration of intelligent buildings
- Integration of renewable energy sources
- Power quality
- ExTERNAL Influences
  - CO$_2$ reduction
  - Legal and regulatory framework
  - Operational Factors

Energy Efficiency

- Aging infrastructure and lack of experts
Turning the Entire Energy Conversion Chain into a Smart Infrastructure

- Decentralized energy management system
- Communications solutions
- Smart substation automation
- Condition monitoring/asset management
- Power transmission
- Distribution automation
- Smart metering
- Building automation
THANKS FOR YOUR ATTENTION

Questions and Ideas?

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Smart Transmission Grid?