Fault-Tolerant Substations for the Smart Grid Vision

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PSERC Summer Planning Workshop  
Lake Tahoe, CA  
August 4-7, 2008
The Smart Grid

• The **Smart grid** can be defined as using communications and modern computing to enable the current power grid to operate more efficiently, **reliably** and **safely**.

• Substations are key to achieving reliable and safe operation:
  – They serve as communication gateways
  – They are nodes that interconnect parts of the system
  – They host data acquisition and control equipment

• A fault in a substation can jeopardize the reliable and safe operation of the whole system.
Fault Tolerant Systems

- Fault tolerance $\equiv$ Robustness $\equiv$ Self-repair $\equiv$ Resilience:
  - The ability of a system to adapt and compensate in a planned, systematic way to random faults of components that can cause the overall system to fail to deliver its function.

- Fault tolerance is usually achieved by redundancy and fault detection, isolation and reconfiguration (FDIR) mechanisms.

- Fault tolerance is key in safety-critical and mission-critical systems, where continuous operation is paramount.

- There is a great body of work in fault-tolerant system design in:
  - Aircraft/Aerospace
  - Computer
  - Nuclear
  - Automotive

- The establishment of rigorous foundations for Fault-tolerant system design began in the late 1960’s:
  - The Apollo spacecraft was mainly a single-string system.
  - The Space Shuttle has triple and quadruple redundancy in many of its systems, and very sophisticated FDIR mechanisms.
Legacy Substation Design

- **Switchyard architectures:**
  - Single bus-single breaker
  - Double bus with bus tie-single breaker
  - Main and Transfer bus-single breaker
  - Double bus-single breaker
  - Double bus-double breaker
  - Ring bus
  - Breaker-and-a-half bus
  - Bus and Transformer-single breaker

- **Control and protection architectures:**
  - Remote and local Back-up protection
  - Breaker failure initiate
  - Bus transfer
  - Each IED wired directly

- **Communication architecture**
  - Intrastation, interstation, station-to-control-center
  - dedicated wires for IEDs
  - Wide area protection
  - Separate communications for each enterprise system
Issues with legacy substation design (examples)

• Breaker failure initiate action results in a serious degradation of the substation functionality
• Remote back-up protection also trips healthy parts of the system
• Failure of communications between relays at line ends disables unit protection
• Process bus failure is a common mode failure for the entire substation protection and control
• RTU/SCADA failure leaves no other means for effective system control
Questions to be answered

• How fault tolerance can be combined with predictive maintenance and control to assure significantly higher level of the overall system resilience
• How fault tolerance may be used for achieving highly reliable and safe operation of the substations under N-1 contingencies
• How fault tolerance can assure substation resilience under N-m contingencies due to simultaneous faults in primary, secondary and communication systems
• How the design of fault tolerant systems may be implemented through a cost-effective retrofit and green-field approaches
• What would be the benefit over existing designs and how the impact on the overall system performance may be quantified