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Protective Relaying Trends

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Changing the World's Energy Future

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The Renewable Transition & Climate Change Impacts to Power System Protection

Protective Relaying Trends

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Overview

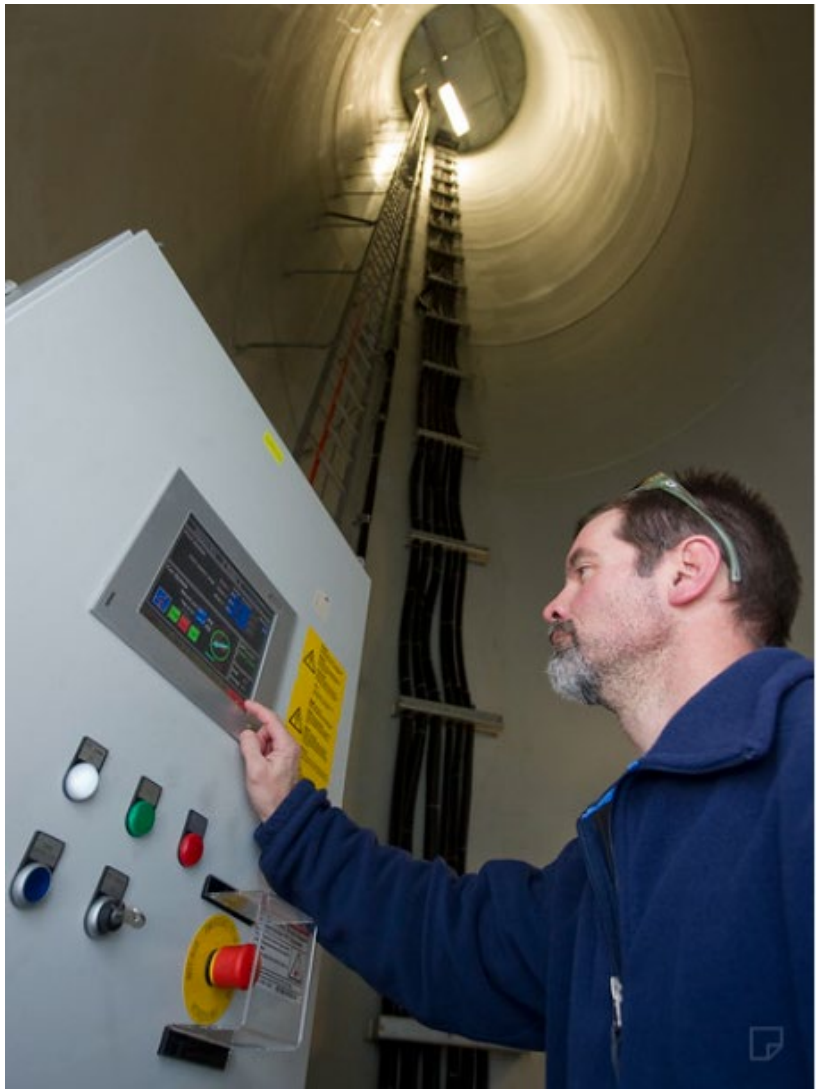
- High Level Driving Forces
- Inverter Based Resources
- Distributed Generation
- Microgrid & Islanding
- Environmental Extremes

Driving Trends

- Increased Renewable Generation
  - Carbon Reduction Goals, Sustainability, National Security
- Wildfire & Natural Disaster Risk to Infrastructure
  - Climate Change

Challenges - Inverter Based Resources (IBRs)

- Low Fault Currents (1.2-2x load)
  - 3 Phase fault or high load?
  - Ground fault or load imbalance?
  - Traditional overcurrent elements fall short
  - Security and Sensitivity cannot be balanced
- Isolated Inverter Behavior
  - Faults not isolated
  - Unexpected topology change
- Low Inertia
  - Frequency instability
  - Voltage drops on microgrids



Solutions - Inverter Based Resources (IBRs)

- Existing Advanced Protection
  - Load Encroachment
  - Negative-Sequence Overcurrent
  - Directional Overcurrent
  - Line Differential
  - Direct Transfer Trip
- Research
  - Improve all of the above
  - Simulated Inverter-based Inertia
  - Higher frequency sensors & protection functions

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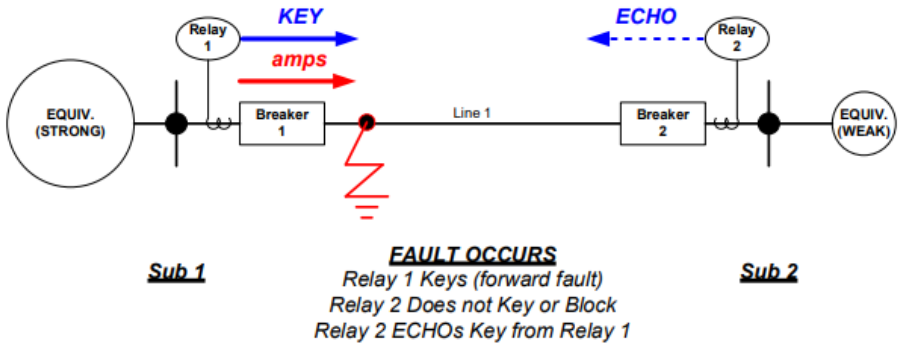
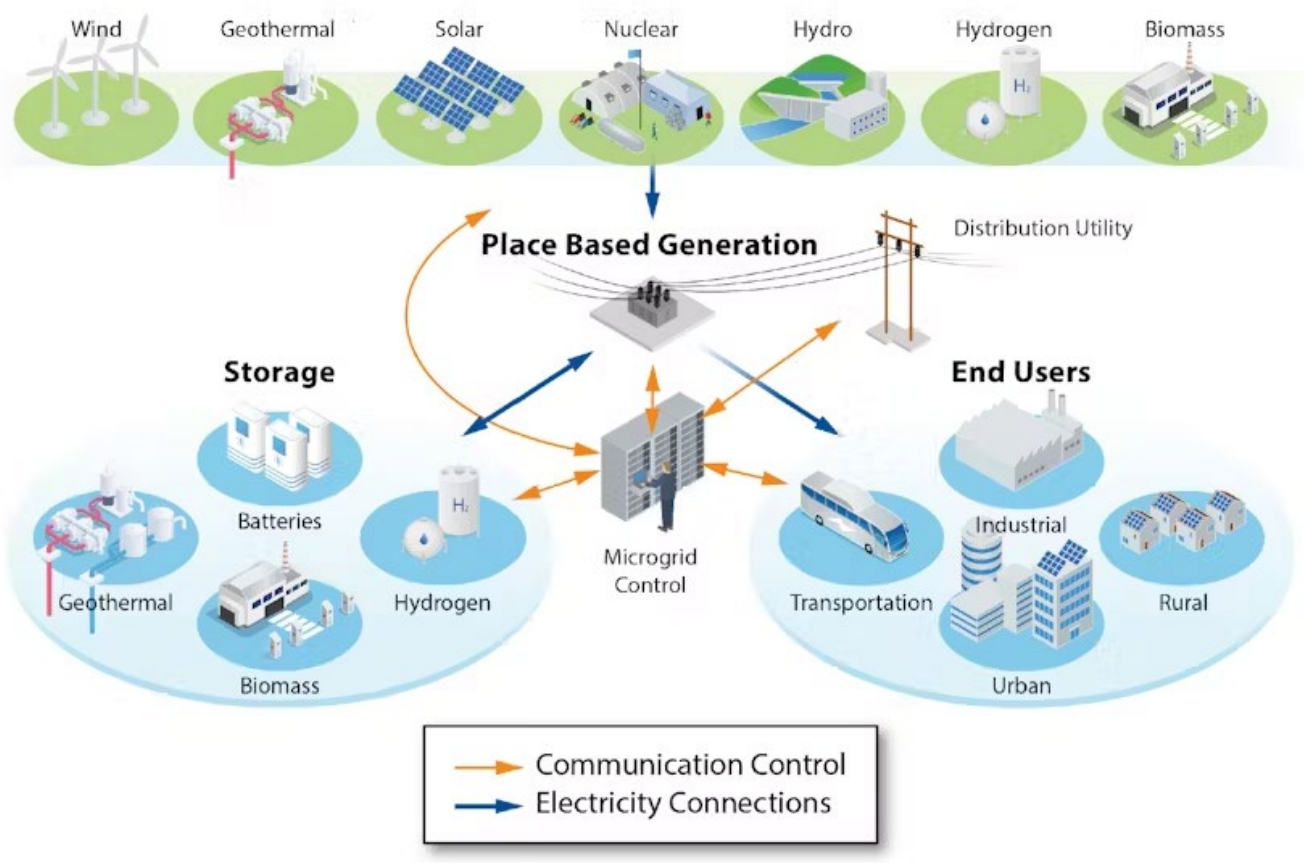


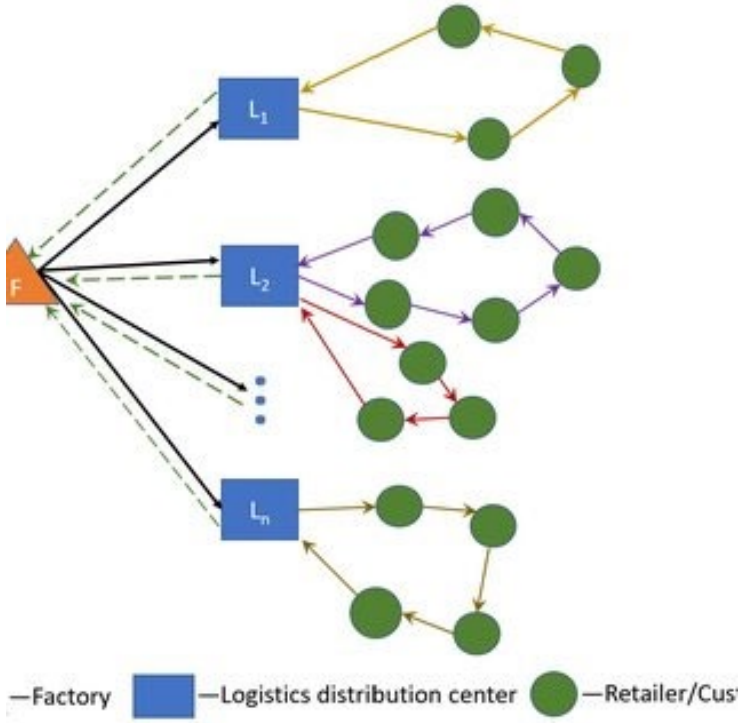
Challenges – Distributed Generation

- Overcurrent coordination Protection
  - Bi-Directional Current Flow
  - Multiple loops
- Distance & Differential Protection
  - Multi-terminal lines
  - Infeed & Sensitivity Issues
- Complexity
  - Protection mistakes more common
  - Low visibility of generation and voltage
  - Urban mesh networks



Solutions – Distributed Generation

- Existing Solutions:
  - Multi-terminal line protection packages
  - FLISR (Fault location, isolation, service restoration) comms
- Research needed:
  - Flexible multi-terminal protection
  - Adoption of non-proprietary, protection-speed communications (IEC-61850)
  - Digital Twin & State Estimation
  - AI coupled with secure failsafe backup protection



Challenges – Microgrids & Islanding

- Microgrids
  - Coordinating Microgrid Controller & Protection
  - Grid-Forming Inverters
  - Vendor interoperability
- Anti-Islanding
  - Human Safety
  - Re-Synchronization
- Intentional Islanding
  - Slow Transfer
  - Voltage sag conditions
  - Low reliability

Solutions – Microgrids & Islanding

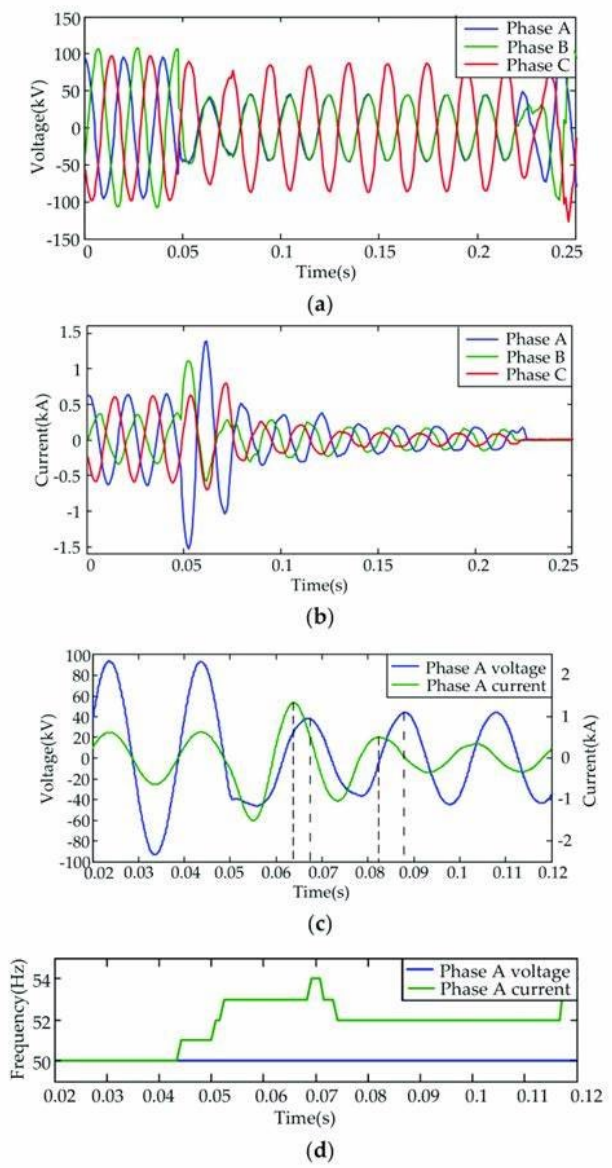
- Overlap with IBR, DER research
  - Inertia, communications, controllers
- Overlap with Modeling challenges
  - Vendor behavior models
  - Dynamic modeling
- Engineering Templates
  - Lower cost
  - Vendor specifications
- Testing & Maintenance
  - Test plans & validation

Challenges – Environmental

- Wildfire
  - Arcing faults cause wildfire
  - Smoke-induced faults
- High Ambient Temperatures
  - Dynamic and Ambient Adjusted Line Ratings
- Storms, Wind, and Vegetation
  - Disruptions for momentary faults

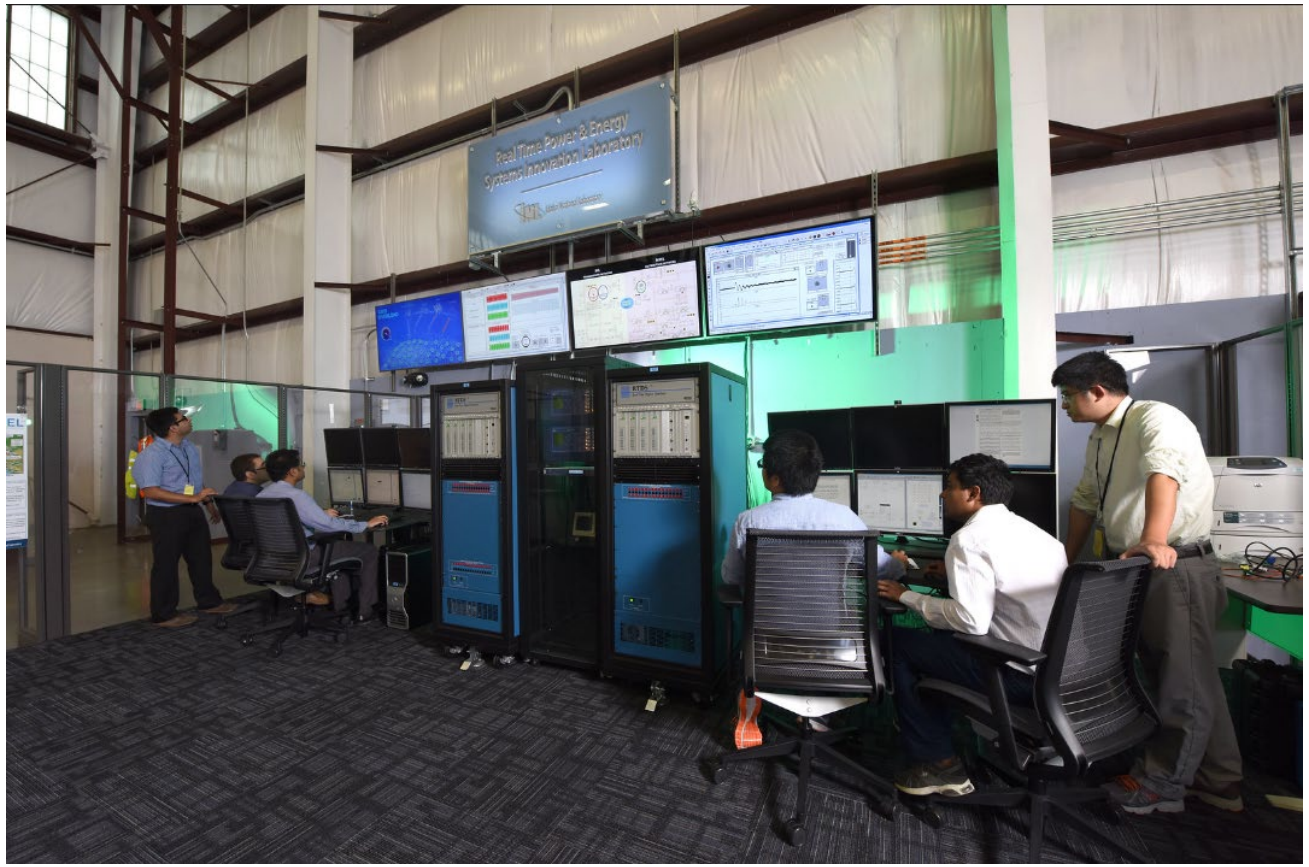
Solutions – Environmental

- Specific Fault Detection
  - High-impedance arcing
  - Wildfire Smoke
  - Incipient detection
  - Momentary vs permanent fault detection
- Data Incorporation
  - Weather
  - Dynamic line ratings
  - Active fire/smoke zones



Key Conclusions

- Challenges
  - Low Fault Currents
  - Increased Network Complexity
  - Lack of Grid Inertia
  - Climate Extremes
- Moving Forward
  - Advanced Fault Detection
  - Secure, protection-speed communication
  - Digital Twin & State Estimation
  - Relay setting automation



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