MADRI Working Group Meeting #45

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Technical Considerations for Transforming the Electric Grid

Presented by: Rob Stewart

March 7, 2017

Exelon Utility Operating Companies at a Glance

Operating Statistics

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Commonwealth Edison	
Customers (electric):	3,800,000
Service Territory:	11,400 sq. miles
Peak Load:	20,162 MW

Potomac Electric Power	
Customers (electric):	852,000
Service Territory:	640 sq. miles
Peak Load:	6,584 MW

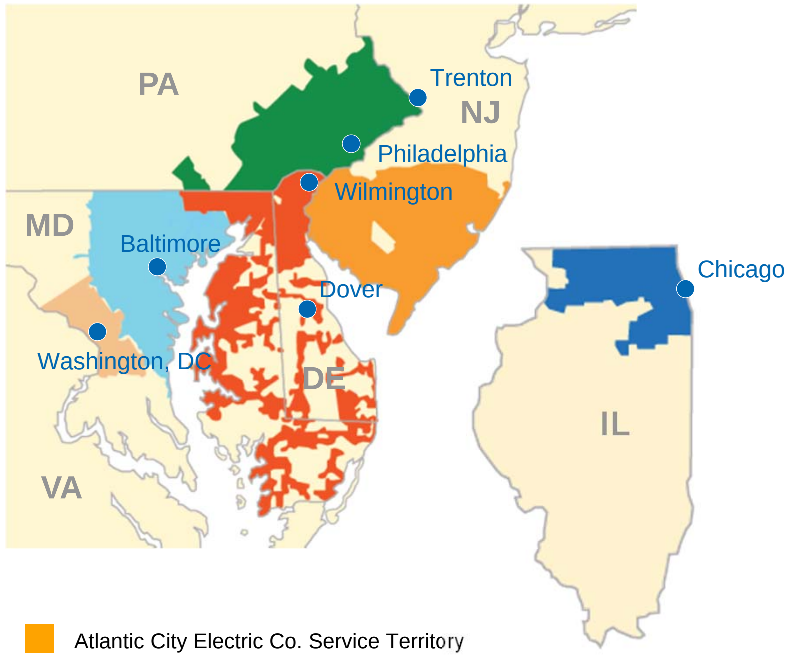
PECO Energy	
Customers (electric):	1,612,000
Customers (gas):	506,000
Service Territory:	2,100 sq. miles
Peak Load:	8,364 MW

Delmarva Power & Light	
Customers (electric):	632,000
Customers (gas):	126,000
Service Territory:	5,000 sq. miles
Peak Load:	4,127 MW

Baltimore Gas & Electric	
Customers (electric):	1,250,000
Customers (gas):	650,000
Service Territory:	2,300 sq. miles
Peak Load:	6,601 MW

Atlantic City Electric Co.	
Customers:	545,000
Service Territory:	2,700 sq. miles
Peak Load:	2,673 MW

Combined Service Territory



- Atlantic City Electric Co. Service Territory
- Baltimore Gas and Electric Co. Service Territory
- ComEd Service Territory
- Delmarva Power & Light Service Territory
- PECO Energy Service Territory
- Potomac Electric Power Service Territory

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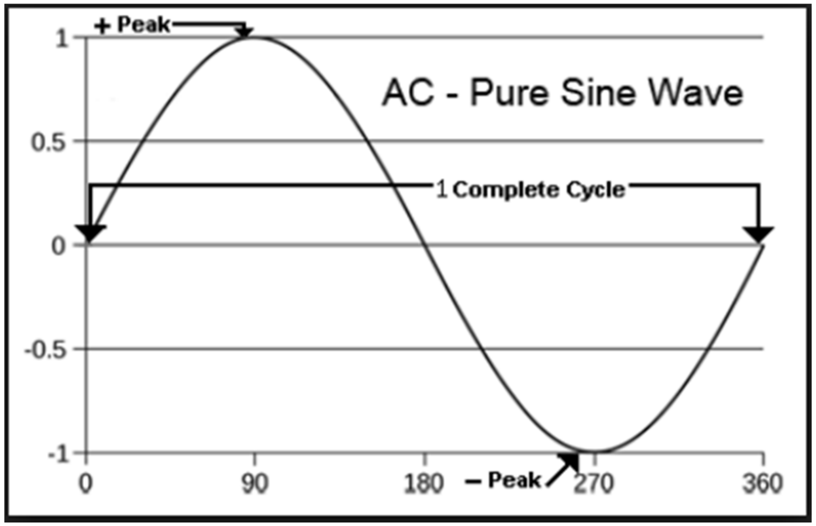
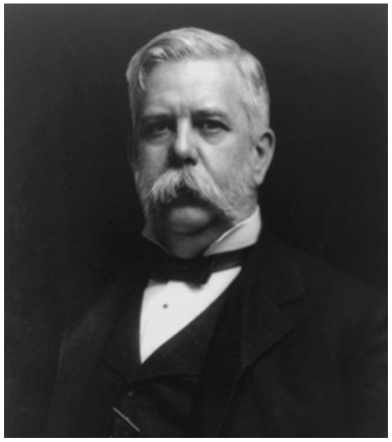
Alternating Current AC

- Alternating current (AC), is an electric current in which the flow of electric charge periodically reverses direction, whereas in direct current (DC, also dc), the flow of electric charge is only in one direction

- Electric power is distributed as alternating current because AC voltage may be increased or decreased with a transformer. This allows the power to be transmitted through power lines efficiently at high voltage, which reduces the power lost as heat due to resistance of the wire, and transformed to a lower, safer, voltage for use.
  - Use of a higher voltage leads to significantly more efficient transmission of power. The power losses (P) in a conductor are a product of the square of the current (I) and the resistance (R) of the conductor, described by the formula $P = I^2R$
  - This means that when transmitting a fixed power on a given wire, if the current is doubled, the power loss will be four times greater





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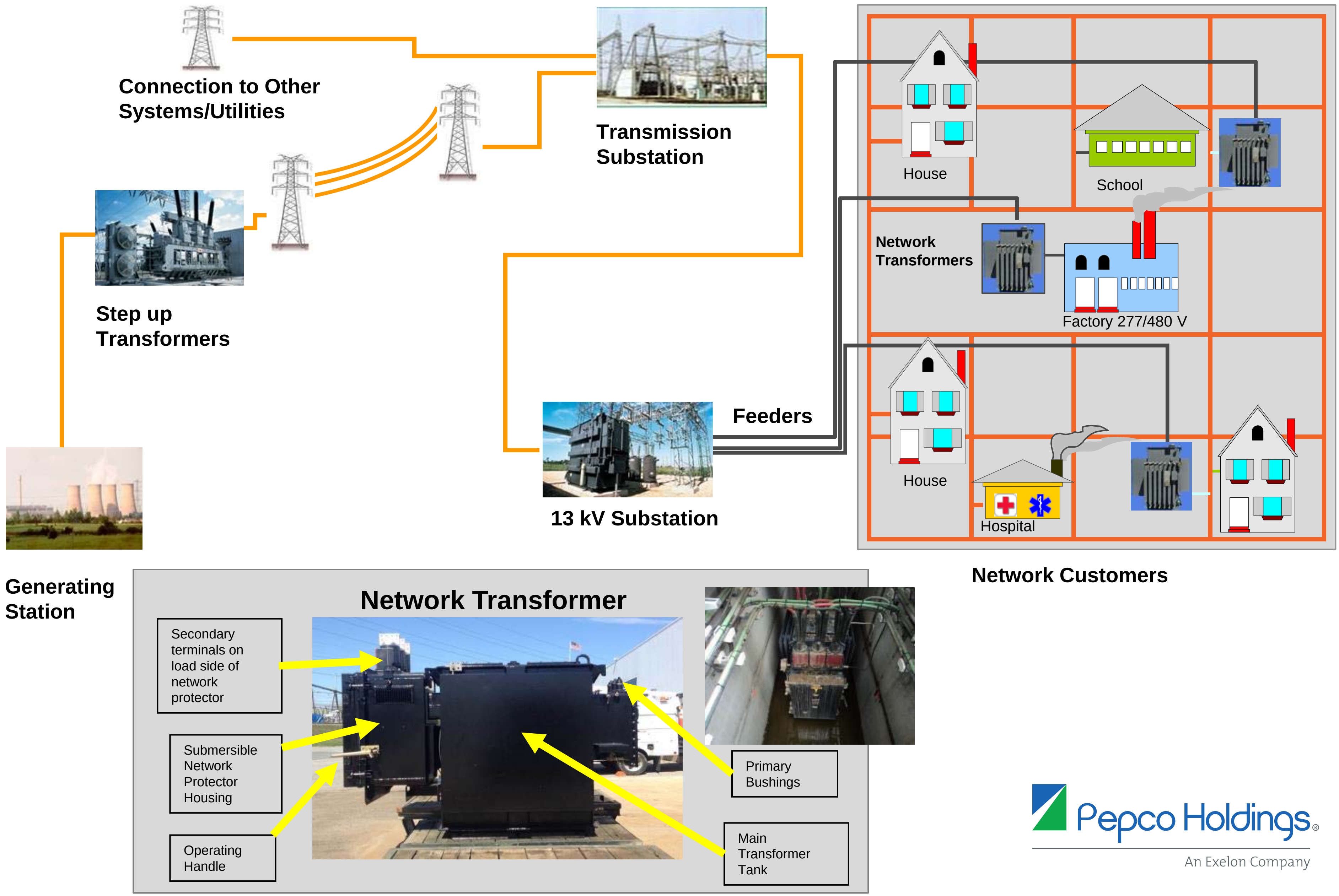
Network System (LVAC)



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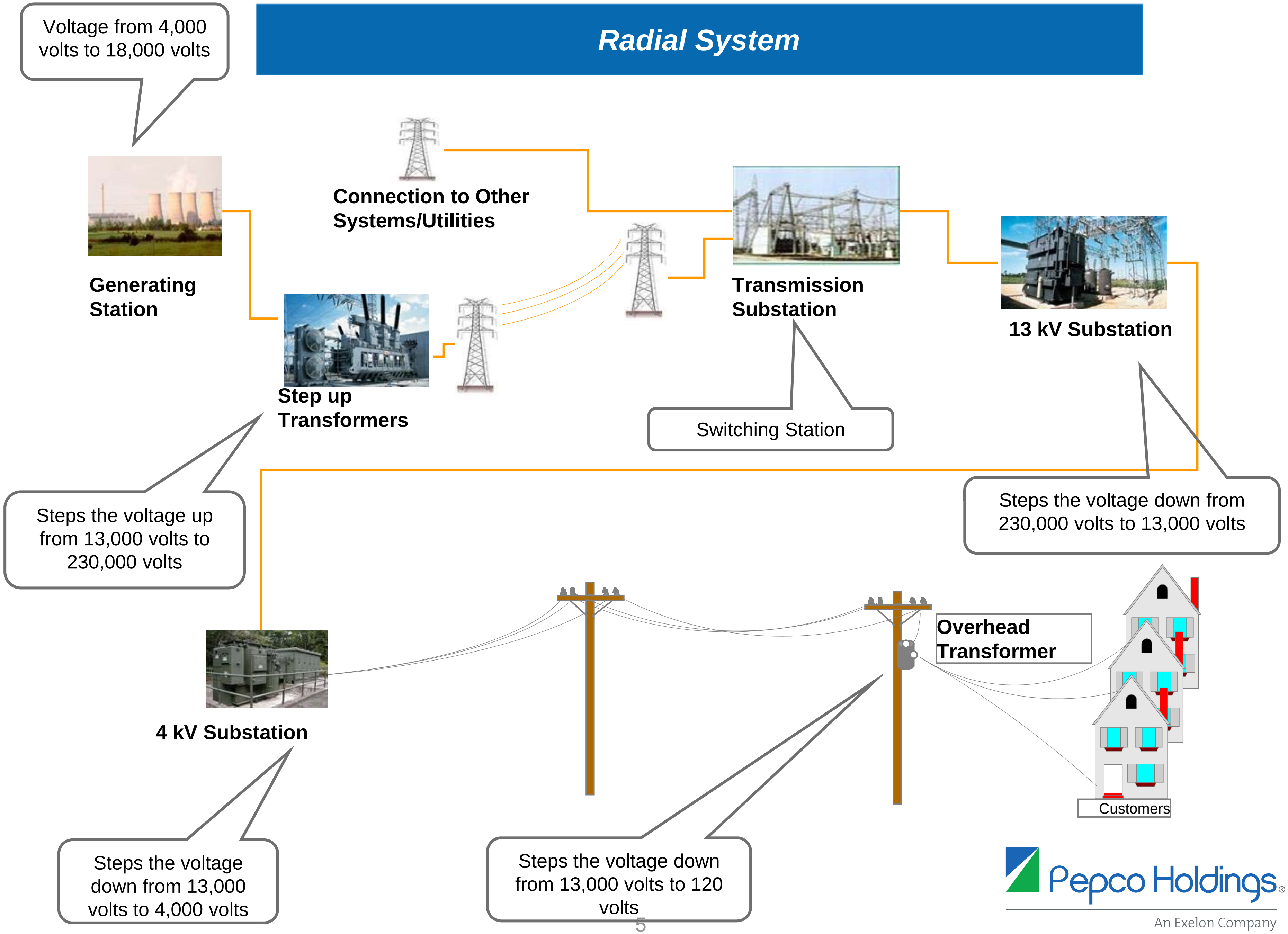
Radial System



Substation

- A substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltages, or at the interconnection of two different transmission voltages
- Complex arrangement of several types of devices that serves as an interface between two subsystems, includes:
  - Power transformers
  - Breakers
  - Busses
  - Metering and communications equipment
- Typically built inside a fenced yard or enclosed building
- Footprint varies dramatically in size depending on purpose
  - A large room to numerous acres

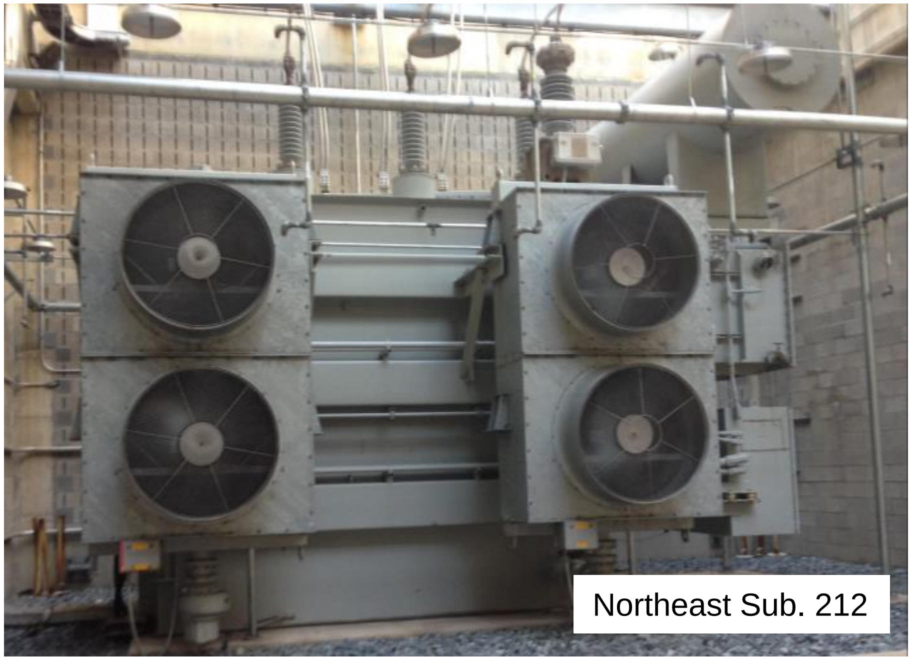
Sub. 168

Sub. 212

Power Transformer

- Electromagnetic device located at a substation
  - Increases the voltage as electric power leaves the power plant so it can travel long distances
  - Lowers the voltage of electric power as it leaves a substation
  - Not to be confused with line/service transformers that step-down voltage for delivery to individual customers
- Load-Tap-Changer (LTC)
  - Accessory that works with the transformer to regulate its output voltage

69 kV – NJ Ave. Sub. 161



Northeast Sub. 212

500 kV - Burches Hill Sub. 202

1-Phase

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Circuit Breakers

- Automatically operated electrical switch designed to protect an electrical circuit from damage caused by overcurrent or overload or short circuit.
- Its basic function is to interrupt current flow after protective relays detect a fault.
- May or may not be insulated
  - Live / Dead Tank Design
  - Air / Oil / Gas insulated
    - Live / Dead Tank Design

138 kV – Buzzard Pt Sta. B

138 kV – Buzzard Pt Sta. B

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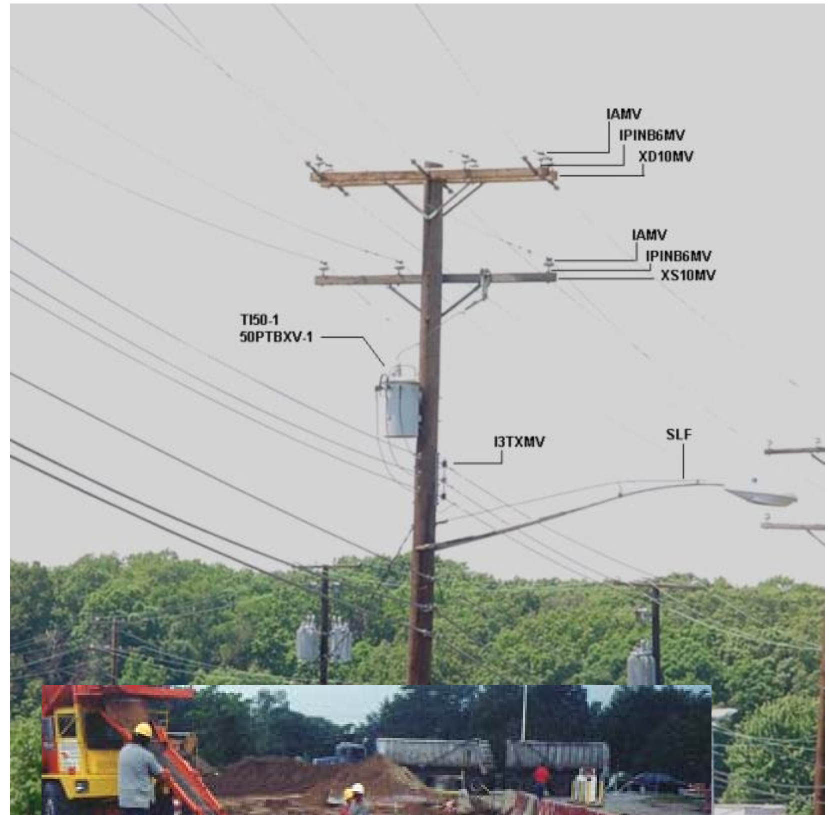
Distribution Feeders

- Electrical connection between points within a subsystem, includes poles, towers, wire, cable, fixtures, & devices
- Can be overhead or underground
  - Underground typically 5 to 10 times the cost of overhead to install
- Can be connected in a radial or networked (meshed) fashion
  - Distribution is mostly radial
  - Densely loaded areas frequently networked
    - Central business districts
    - Downtown metropolitan areas



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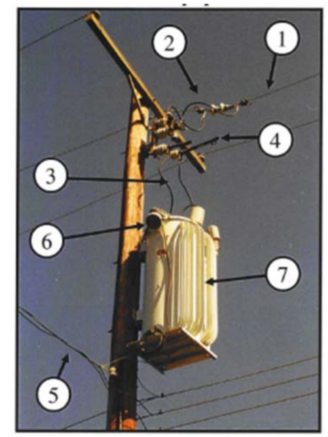
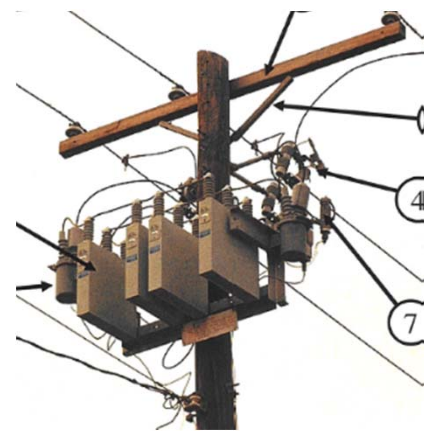
Distribution Feeder Devices

- **Voltage regulators**
  - Special type of transformers, usually located in a substation or on a pole, that automatically raise or lower downstream line voltage to maintain required voltage levels for service



1. Primary Conductor
2. Primary Tap
3. Primary Conductor to Regulator
4. Manual Disconnect Switch
5. Regulator Control Cables
6. Regulator Position Indicator
7. Voltage Regulator

- **Capacitor banks**
  - Electrical devices, usually located in a substation or on a pole, that supply reactive power, "corrects" power factor, and maintains or increases voltage - improves the efficiency of the electric system by reducing inductive losses which produce wasted energy



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Service transformers

- Transformers for converting primary distribution voltage to a voltage suitable for customer use (aka Distribution Transformer or Service Transformer)

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Smart Relays

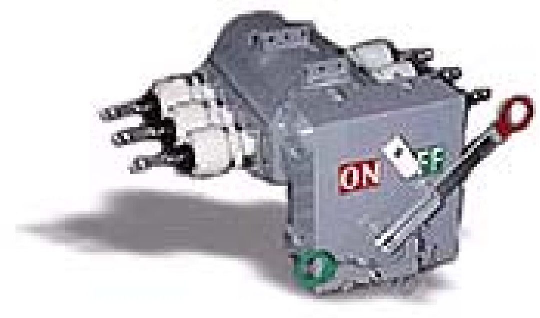
Features and Benefits:

- Programmable logic;
- Virtual I/O (reduce hardware cost);
- Expandable I/O;
- Flash memory for field upgrades;
- Optional user programmable pushbuttons;
- User programmable LEDs, fault reports, display messages, and self tests;
- Drawout modules for serviceability;
- Contain advanced algorithms for High Z faults and Distance to fault calculations;

- *Security:*
- Remote and Local Setting and Control passwords;
- Configurable lockout responses to unsuccessful password access attempts;
- Successful password access logged in Event Record.

Sectionalizing Switches

The Sectionalizing switch is a motorized spring stored energy mechanism that is adopted for high-speed automatic operation. It is a maintenance free 3-phase gas sectionalizing switch designed for 15-38kV distribution.



- **Standard features of the Sectionalizing switch include:**
- **Manual operation handle;**
- **Mechanical counter;**
- **Low Pressure alarm flag;**
- **Low pressure interlock mechanism;**
- **Provision for platform installation;**
- **Grounding terminal;**
- **Motorized spring stored mechanism;**
- **Tripping coil;**
- **Weather proof control terminal plug (switch side);**
- **Auxiliary contacts (1C);**
- **Control cable and receptacle.**

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Automatic Circuit Reclosers

Available in triple – triple and triple-single configurations

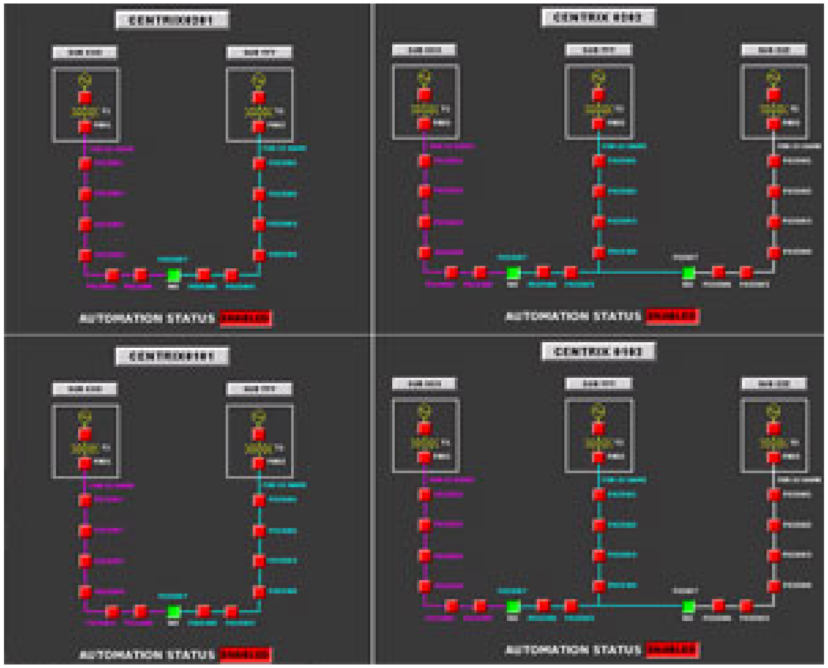
The recloser is available with voltage ratings of 15 kV, 27 kV, and 38 kV. The rated continuous current can be as high as 800 Amps.

- Fault current sensed by (3) sensing CT's embedded in recloser;
- Ampere and Voltage analog monitioring (3Ø);
- The recloser always maintains energy for a tripping operation;
- Single break on each phase is accomplished by separating contacts inside the vacuum interrupter. Vacuum is used as the interrupting medium;
- Recloser controlled by a Cooper Power System three phase electronic recloser control;
- Auto sectionalizing/restoration functionality.

Advanced Distribution Automation

Fault Detection Isolation and Restoration (FDIR)

- Allows for the rapid identification, isolation and restoration of select segments of feeders under fault conditions.
- Requires alternate tie feeders and favors higher customer density areas
- Reliable communications is critical to performance



Example Vendors

- DC Systems
- GE
- ABB
- Cooper
- Efacec

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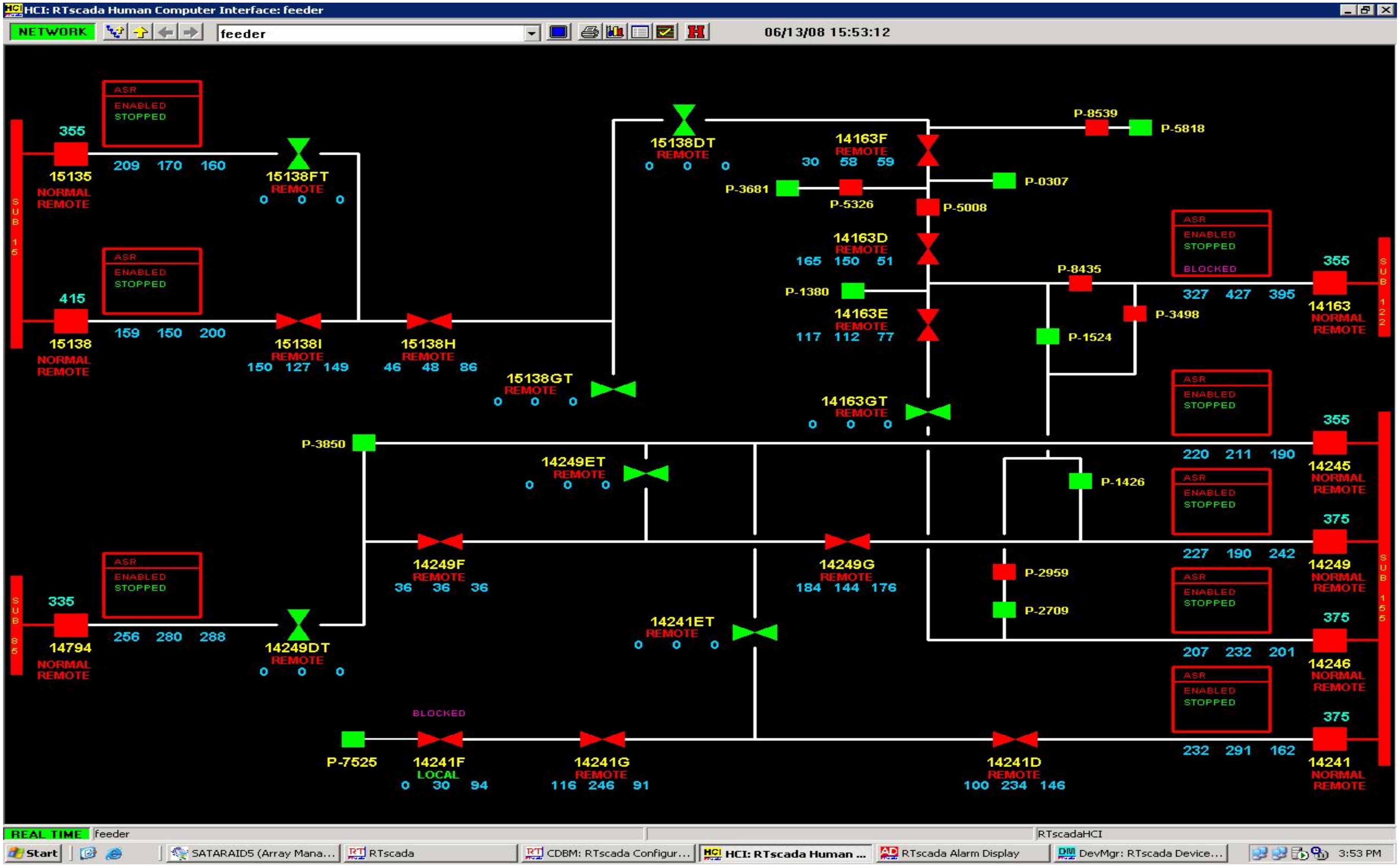
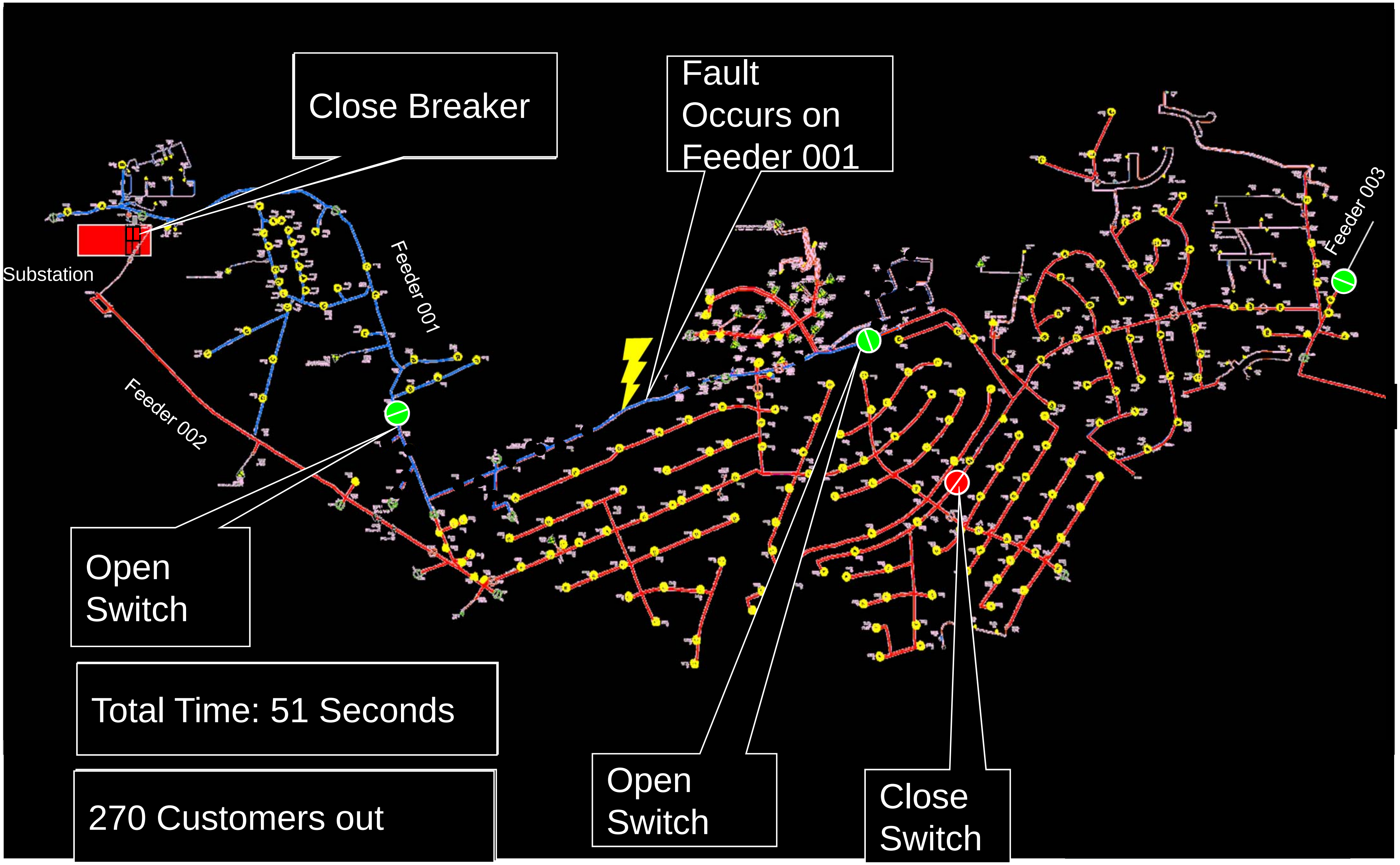
One-Line Representation of ASR Scheme



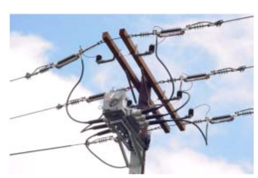
PHI's ASR System - Demonstration



Smart Grid Devices and Technologies

Customer — Meter — Collector — Substation — Central Operations — PJM

	Home Intelligence	Feeder Automation	Substation Automation	Transmission Automation
Advanced Metering Infrastructure	• Smart Meter			
Distribution Automation		• Automatic Circuit Reclosers (ACRs) • Automatic Sectionalizing and Tie Switches • Advanced Voltage Control • VAR Control / Capacitors • Network Protector Monitoring & Control • Network Cable / Vault Monitoring • Smart Remote Terminal Units (RTUs) • Fault Detectors	• Automatic Sectionalizing & Restoration (ASR) scheme • Substation Local Area Network • Microprocessor, or ‘Smart’ Relays • Application Servers • Smart Monitoring & Controls • Distributed Smart Remote Terminal Units (RTUs) • Voltage Control, Substation-Level by Smart Relays or EMS	
Transmission Automation				• Synchrophasor • Motor Operated Disconnect (MOD) • Dynamic Ratings • State Estimation • High Voltage Direct Current (HVDC) • Static VAR Compensator (SVC)
Demand Response (DLC & Dynamic Rates)	• Smart Thermostat • In-Home Display • Plug-In Hybrids			
Distributed Generation	• Micro-generation (solar, wind) • Electric Vehicles/Vehicle-to-Grid	• Upgrades to monitor DG	• Upgrades to monitor DG	
Energy Efficiency	• Smart Appliances • Weatherization			



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Rapid innovator: Business Intelligence Data Analytics (BIDA)

Exelon Utilities is launching the BIDA platform to develop data analytics required to drive improvements across the customer experience and operations

Initial launch: Smart Energy Services domain

- Identified 60 preliminary opportunities across five domains

Selected use case examples

Domains	Grid (T&D)		Customer		Business Support
	AMI	Grid (T&D)	Smart Energy Services	Customer Experience	Business Support
Use Cases	• Meter Malfunction identification • Theft Detection • Meter System • AMI Performance • Meter Deployment • […]	• CVR /Voltage • Outage (ex post) • Outage (real-time) • Asset Health (T&S) • Asset Health (Dist) • Grid Monitoring • […]	• Home Energy Reports (HER) • Web Presentment • Peak Time Rebate • […]	• Call Center Effectiveness • Channel Effectiveness • Social Media Feed • […]	• Crew Prep & Routing • Credit & Collections • Inventory Mgmt • Remote Visualization • Field Safety Analytics • Vehicle Fleet Analytics • […]

- Initial launch focuses on Smart Energy Services to more efficiently achieve state mandates for energy efficiency, and drive higher customer engagement and satisfaction, including use cases such as:
  - Advanced peer to peer energy comparisons (based on dwelling, heating type, size and age of home, number of occupants, etc.)
  - Online dashboard displaying intra-day interval usage and cost data in user friendly navigation

Status

ComEd An Exelon Company · BGE An Exelon Company · PECO An Exelon Company · Pepco Holdings An Exelon Company

- Smart Energy Services go-live expected early 2017
- Refining use cases for remaining four domains, with use case deployments over the next 36 months
- PHI developing new grid analytics capabilities (e.g., real-time monitoring of dissolved gas analysis to extend transformer life)

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Stages of Grid Modernization

Stage	Smart Grid	DER Integration	DER Visibility	Fully Integrated Grid
Power Flow	Unidirectional	Bidirectional	Bidirectional	Multidirectional
Sensors	High	High	High	High
Behind the Meter Visibility	Limited	Low (Simulation or backcasting)	Medium	High
Behind the Meter Control	Minimal	Minimal	Low	High
PHI Progress	Integrated as Current Design	In Progress	In Progress	Future State

Current State (DER Integration and DER Visibility)

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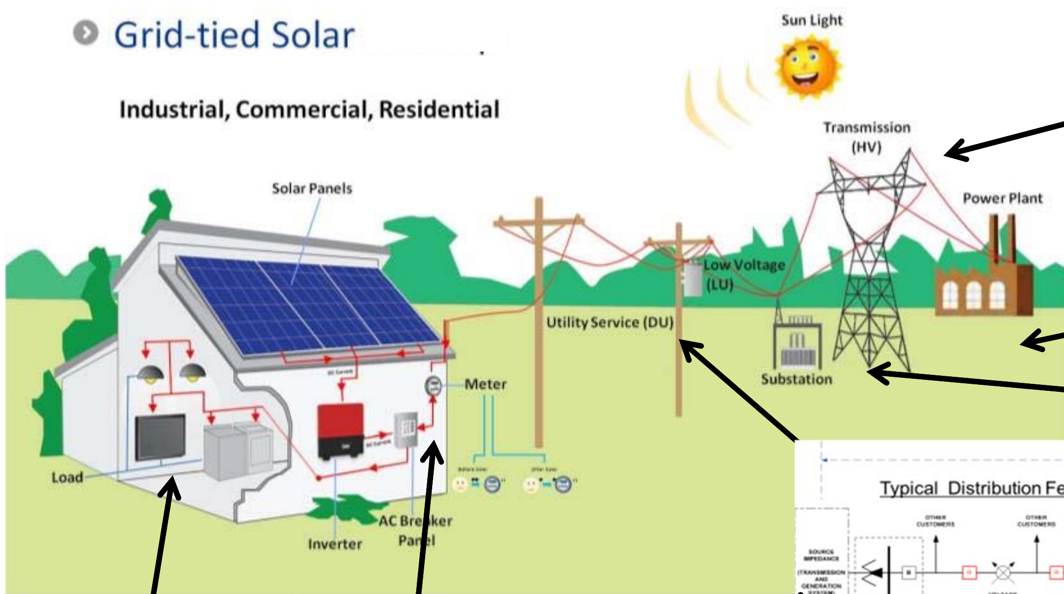
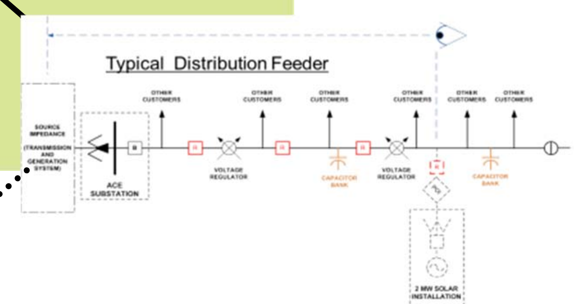
DER Affects the Entire Electric System





Transmission

- Voltage challenges at low load.
- Near term, it will reduce losses, with high penetration losses may increase

Generation

- Scheduling changes required to meet volatile load.
- May increase need for ancillary services.
- Steep ramp rate when sun goes down, impacts capacity needs

Feeder & Substation

- Increase phase unbalance for three phase circuits.
- Capacity spikes may overload equipment.

Home Power Quality

- Higher voltage caused by generation reduces efficiency of appliances and HVAC,
- Can stress appliances or motors.

Interconnection Point

- Inverters trip or cloud shear can create volatility
- Must maintain voltage within mandated bands.
- Net metering masks true load demand.

Point of Injection

- Every POI requires study to determine impacts to the system and other customers
- The customer is required to pay for the upgrades

Distribution Automation

- DER can prevent DA schemes from locating fault
- True load to be transferred not easy to calculate

Voltage

- High or low voltage can result in mis-operation, damage, or reduced equipment life – both on the grid or at premises

Safety

- Can increase fault current level
- Trip of breaker or recloser may result in inverter out of synchronization
- Reduction of protective reach

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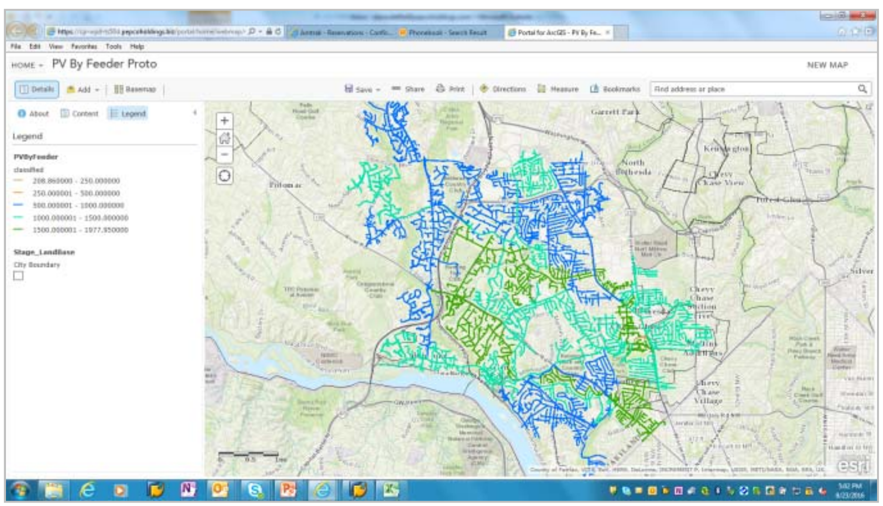
Activities Underway to Help Accommodate Increased DER

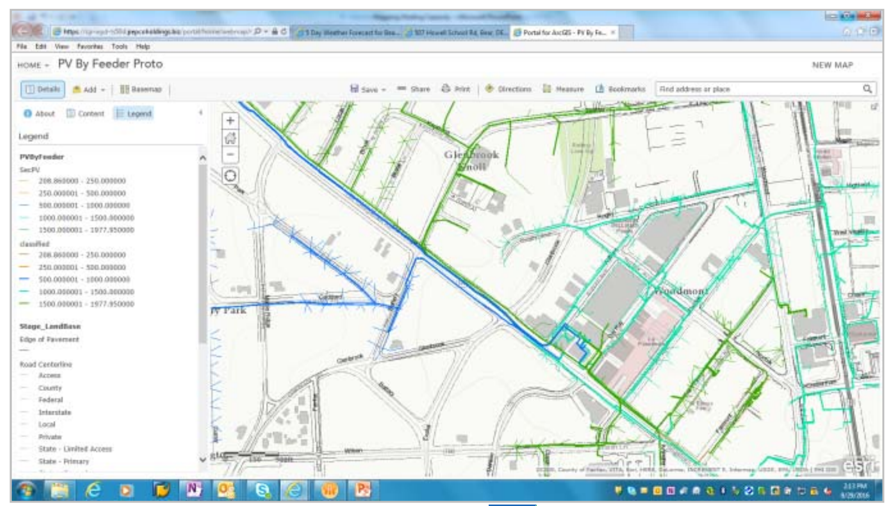
Customer Facing Improvements:
- Online application portal released March 2016, improves the accuracy and speed of processing, improves customer experience, provides real-time customer usage data over request portal for contractors
- Green Button Standard for usage data
- My Account Functionality

Modelling & Analytics: Advanced load flow being implemented, developing the capability for publishing hosting capacity to the customer level

Collaborative R & D: Inverter technology, advanced voltage regulation control, penetration studies with a variety of different partners, leveraging AMI backbone, integrating PV data into DA schemes, implementing cellular telemetry.

DER Integration into Planning: Demand Response Programs (PJM, DLC, Peak Energy Savings); Energy Efficiency Programs (Management Tools, Conservation Voltage Control, Residential Energy Efficiency, C&I Efficiency and Conservation); Distributed Generation (NEM, Non-NEM PV, Other DG)





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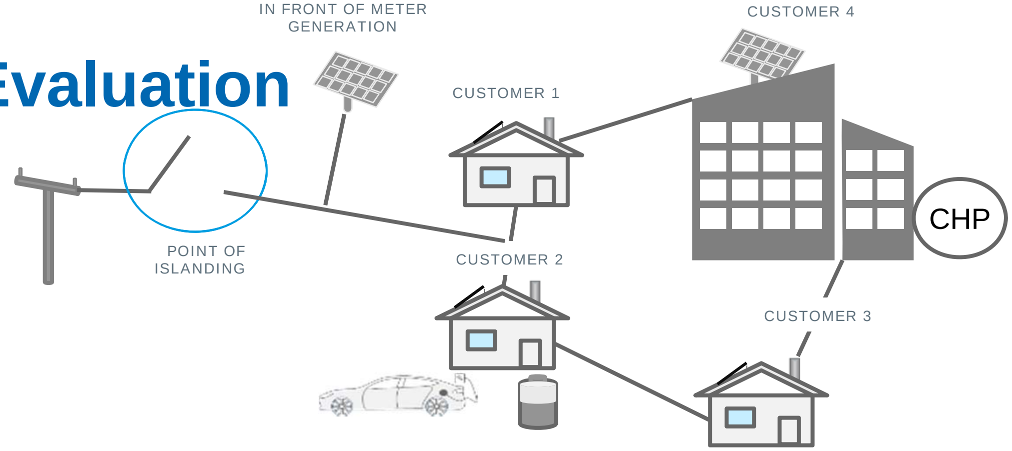
Technology Areas Under Evaluation



Storage

Design Considerations
- Connection Point
- Inverter Type & Functionality
- PJM Market Interaction
- Discharge rules for NEM net-exporter

Challenges
- Variable battery technical and operating characteristics
- Degradation
- Customer usage protocols

Electric Vehicles Infrastructure

Grid Investment Required for Large-Scale EV Adoption
- At-Home Charging
- Public and semi-public EV supply equipment

Utility's Role
- Maintaining Reliability
- Existing Smart Grid investments and equipment
- System knowledge and customer fairness
- Customer interface experience and education

Microgrids

Campus Microgrids
- Owned and operated by a single customer.
- Owner has complete responsibility for the operation, maintenance and performance of the system.

Public-Sited Microgrids
- Serve multiple customers.
- Owner of the generation will likely be different than the customers served by the microgrid.

Merger Commitments

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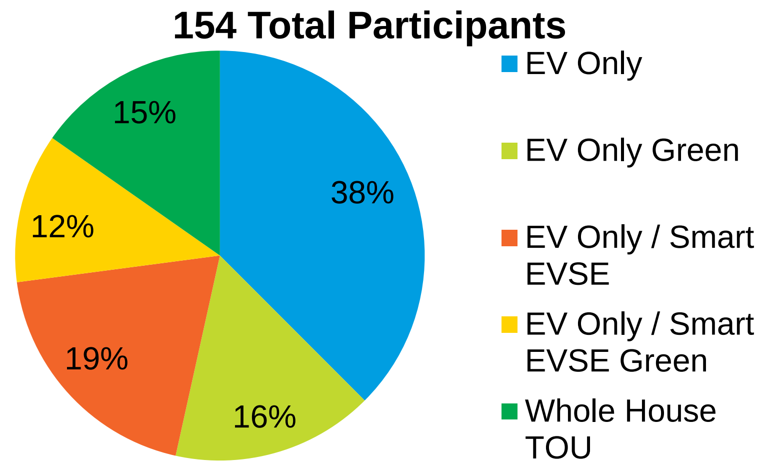
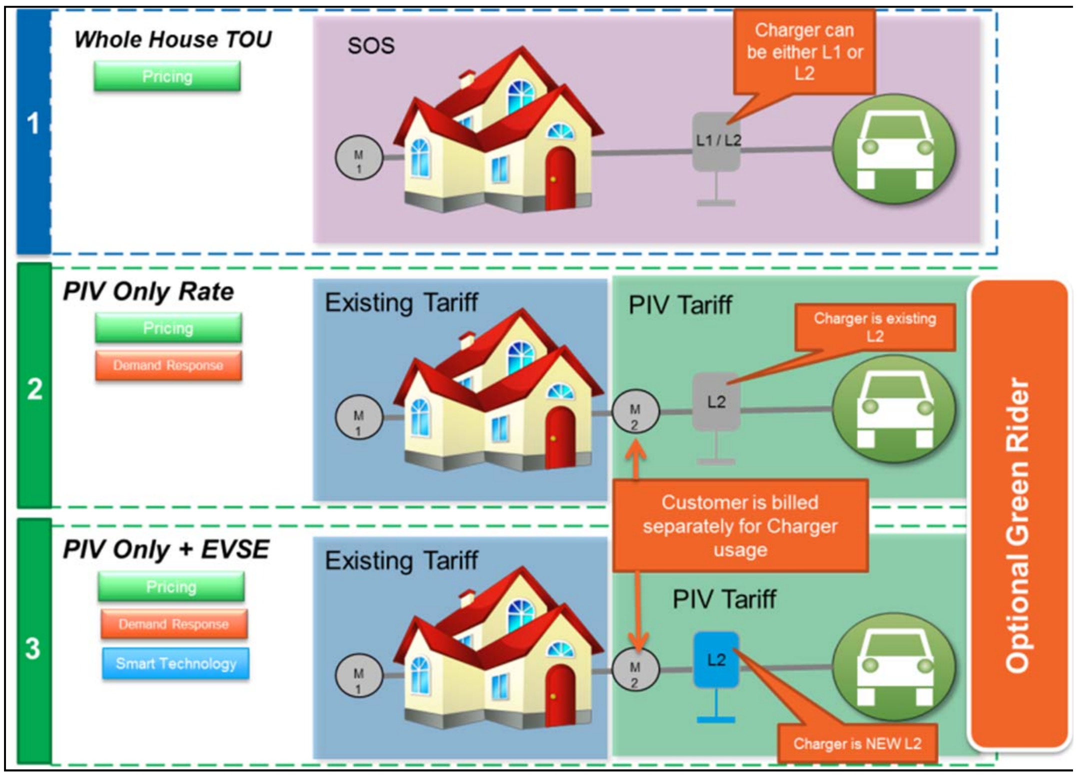
MD EV Pilot Program Details

Completed 12/31/15

- Established through MD Legislation for Demand Response
- Demonstrated Passive and Active control for EV Charging
- Over 90% of the customers charged off-peak
- Included installation of 50 smart chargers
- Performed active EVSE control in concert with Demand Response events
- EPRI compiled and published results





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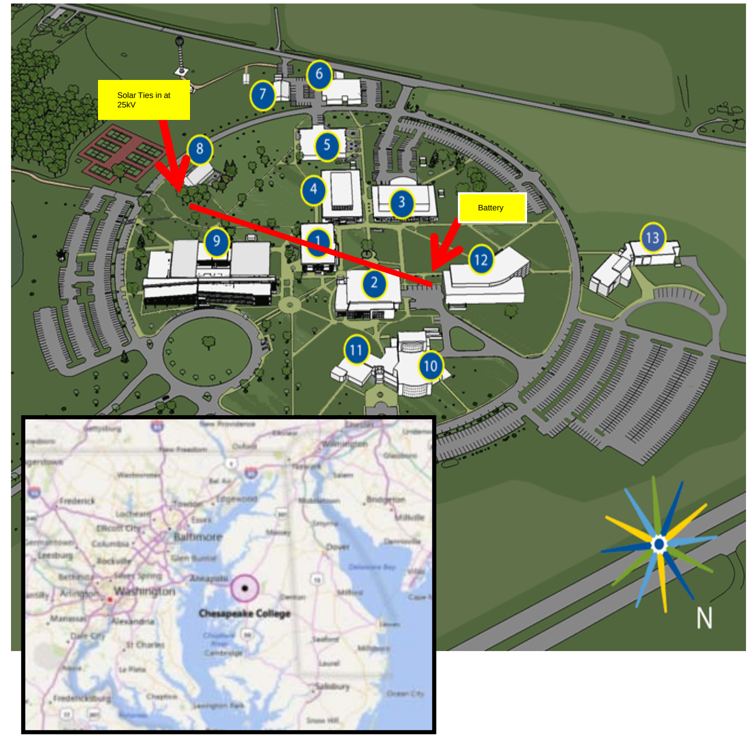
PHI Current Microgrid Projects – Chesapeake College

- Started as a solar DER system on a high penetrations feeder
- Delmarva applied for, and received, $250K grant from MEA or installing batteries to help mitigate the effects on the Distribution System
- College is identifying critical loads to create microgrid



Building Loads to Back Up:

2 – Caroline Center

12 – Learning Resource Center

The College has a 25kV system for the campus with switchgear connecting to DPL in Bldg 12

Distance from Solar Tie in at 25kV to where Battery System will be located (shown as red line) is about 2,000'

PV System

Size: 2.18 MW DC, 1.76 MW AC

Installer/Owner: Solar City

Inverters: Solectria (with smart inverter functions)

Output from inverter will be 480V then tied to 480/25kV transformer to step up to 25kV

System is split into a 1,464 kW ground mount array and 300 kW carport with EV charging capability

In-service date: May 2016

Battery System

Proposed size is 500kW, 250kWh (half hour battery)

Installer/Owner: AF Mensah

Battery and PV system will have separate inverters for independent operation

Electrical interconnection design to be proposed by AF Mensah

Next Steps

Work with Solar City, AF Mensah, and Chesapeake College to develop final design and present to appropriate stakeholders

Develop project charter and project plan

Finalize central and local control strategy after selecting Central Control vendor

Develop any needed contracts/agreements

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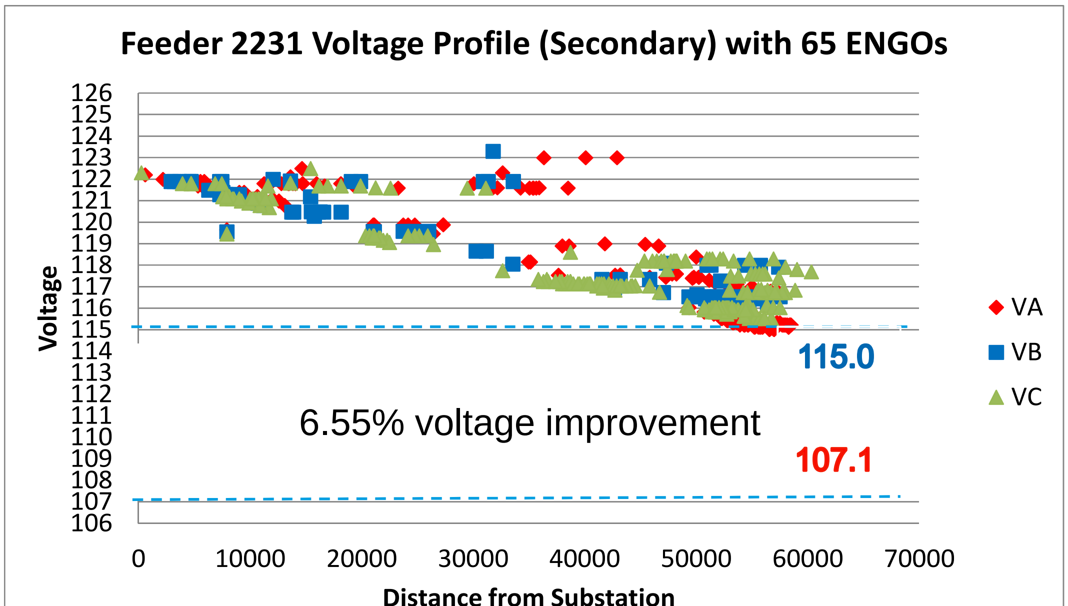
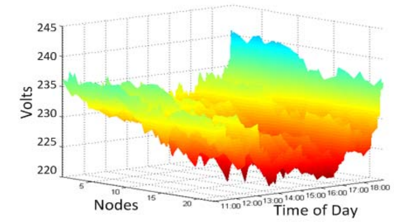
PHI Current Microgrid Projects – Chesapeake College Cont’d

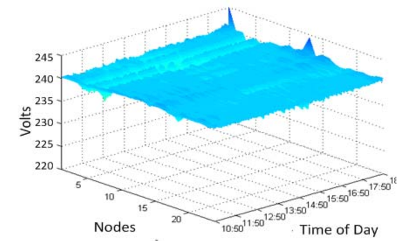
Varentec ENGO Deployment

- ENGO = Edge of Network Grid Optimizer
- Flattens the feeder voltage profile and ultimately relieve operational burden from primary side assets
- Completely and autonomously injects reactive power to control the secondary voltage to be equal to the set point voltage commanded by the Grid Edge Management System





Without ENGO



With ENGO

ENGO Hardware

+

GEMS Software

To further the improve the voltage levels of the associated feeders, PHI is testing optimization devices from Varentec. The proposal includes the installation of 65 devices on the secondary side of the distribution transformers where modelling has shown a voltage improvement of 6.55%

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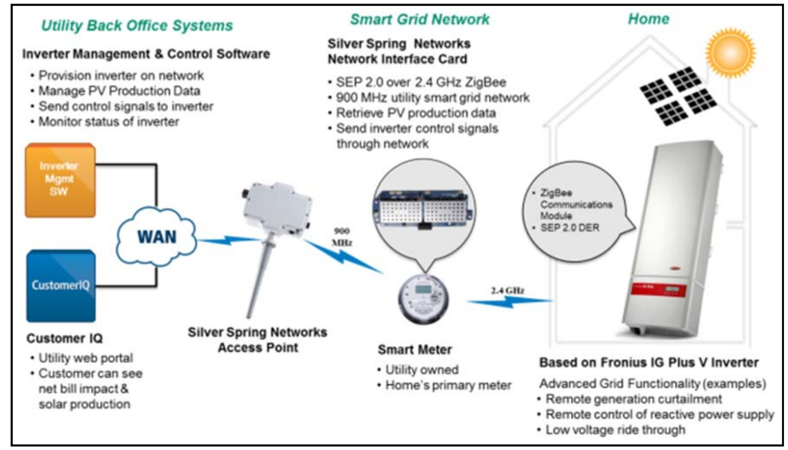
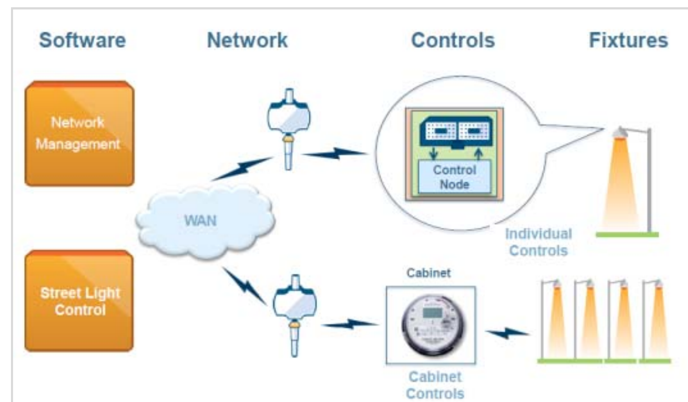
Additional Enabled Benefits

- Smart Inverters
  - Smart Grid Inverters can effectively regulate the power flow of distributed PV systems to improve grid performance and prevent the back feed of network protectors on a networked distribution system



- Smart Street Lights
  - Can provide enhanced functionality
    - Remote Control
    - Dimmable
    - Revenue Grade Meter
    - Day Burner Notification
    - Group Management
  - Improved AMI Network performance



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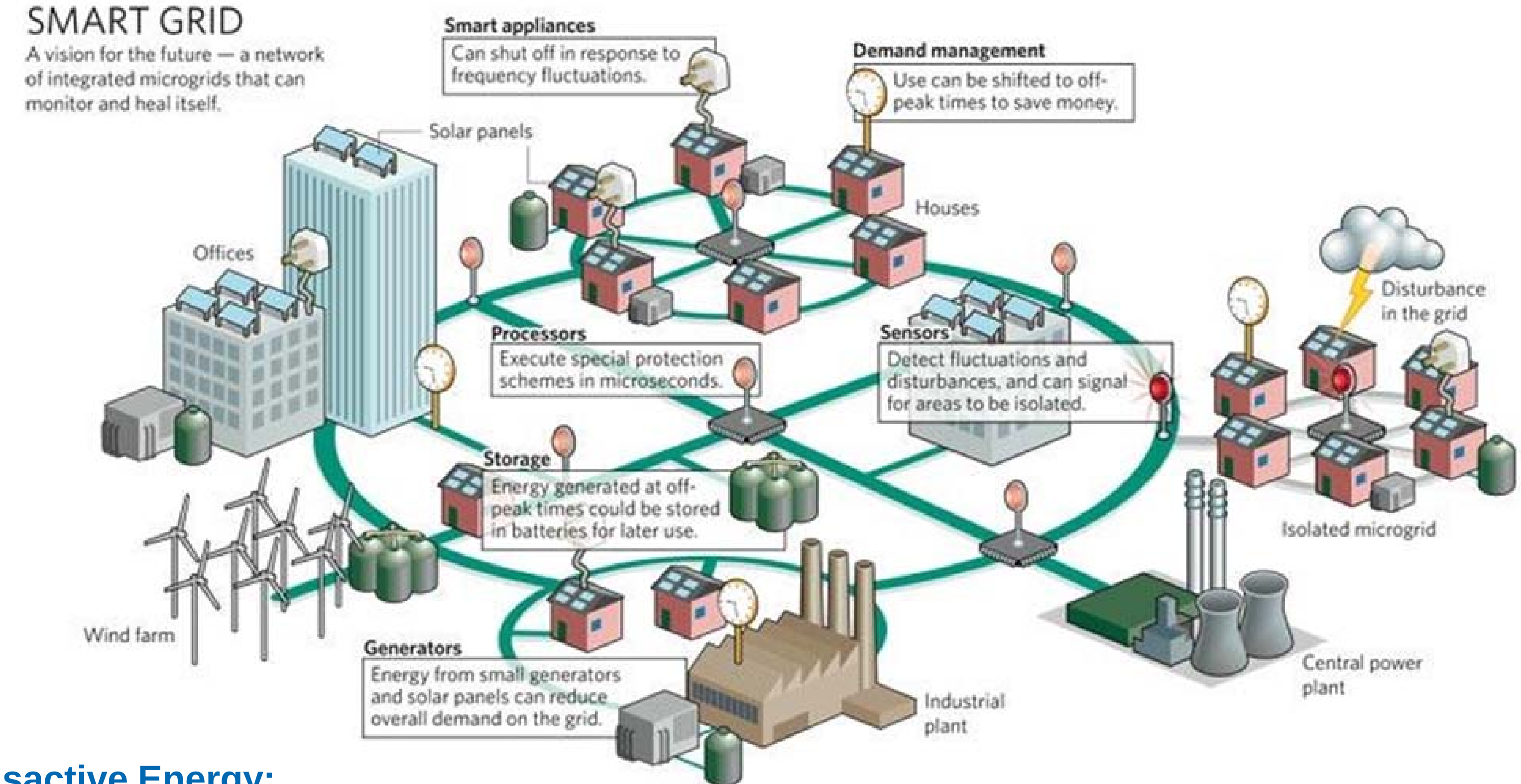
Distribution System of the Future

- With the increase of distributed and community-scale generation, energy storage, and potential new capacity loads (i.e., electric vehicle), existing distribution systems will need to change in order to manage a load that is less predicable than in the past. Distribution systems of the future will not only require internal investment in controls, but also will need to integrate with smaller networks across the larger grid and be able to monitor and dispatch small scale distributed generation.



Transactive Energy:

A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.

Source: Gridwise Alliance

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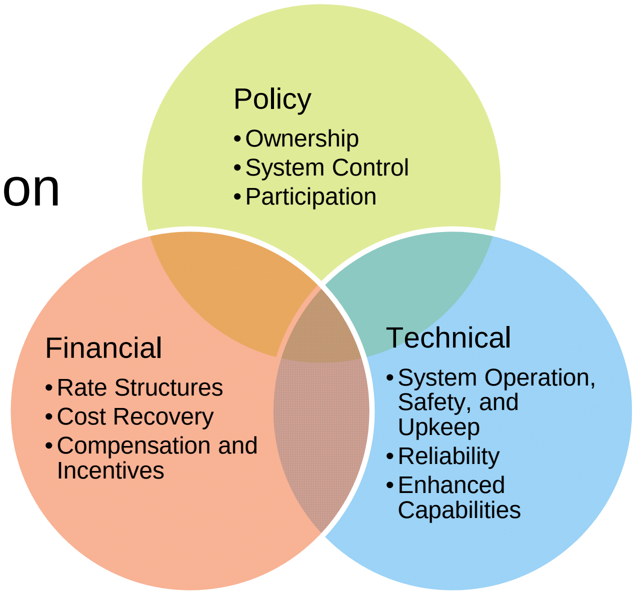
Points to Consider…

- Planning and Operating the future Distribution Grid will become more complicated
  - Higher penetrations of DER
  - Deployment of storage
  - Microgrids
  - Electric Vehicles / Vehicle to Grid
  - Advanced Demand Response



- Distribution System Operators will need to manage the Distribution System using a much higher level of visibility, control and automation
  - Control, Measure, Dispatch, Protect, Optimize

- In order to maximize the amount of DER connected to the grid, the way systems are operated and dispatched will need to be better understood

PHI is well positioned to support the Grid of the Future with expertise, system knowledge, and technical capability.

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Questions