

Role of Protective Relaying in the Smart Grid

Summary paper of C2 Protective Relay Applications using the
Smart Grid Communication Infrastructure

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- The US Department of Energy implemented the Modern Grid Initiative (MGI) to facilitate the creation of Smart Grids
- Benefits of a properly implemented smart grid for utilities and customers include:
 - More reliable and cost effective system
 - Aids system operators during events or possible attacks
 - Allows customers to view energy usage in real-time
- The information that can be provided by protective relay devices (PRDs) is crucial for the implementation of a smart grid

- A modernized grid would create an energy system that will:
 - Detect and address emerging problems on the system before they affect service
 - Respond to local and system-wide inputs and have much more information about broader system problems
 - Incorporate extensive measurements, rapid communications, centralized advanced diagnostics, and feedback control that quickly returns the system to a stable state after interruptions or disturbances

- The US Energy Independence and Security Act (2007) lays out eleven (11) characteristics of a smart grid:
 - Increased use of digital information and controls technology to improve reliability, security and efficiency of the electric grid
 - Dynamic optimization of grid operations and resources with full cyber-security protection
 - Deployment and integration of traditional generation and distributed energy resources (DER) including renewable resources
 - Development and incorporation of demand response (DR), demand-side resources and energy-efficiency resources
 - Deployment of 'smart' technologies for metering, protection, monitoring, control and communications concerning grid operations and distribution automation (DA)
 - Integration of 'smart' power system devices
 - Integration of 'smart' appliances and consumer devices
 - Deployment and integration of advanced electricity storage and peak-shaving technologies
 - Provision to consumers of timely information and control options
 - Development of standards for communication and interoperability of appliances and equipment
 - Identification and lowering of barriers to adoption of smart grid technologies, practices, and services

Why do we need a smart grid?

- The electric power grid in North America has historically been very reliable
- However demands on the grid have continued to increase and investment has not always matched the increased performance requirements
- Operational and security risks associated with current centralized generation, but new types of risks involved with distributed generation
- Rapid increase in amount of energy traded between regions
- Increased digital technology use increases power quality requirements
- The grid of the future will need to meet all of these challenges

- Minimize system disruptions
- Consumer participation
- Resist attack
- High quality power
- Accommodate generation options
- Enable electricity market
- Optimize assets
- Enable high penetration of Intermittent Generation Sources

Smart Grid Features

- Load adjustment
- Demand response support
- Greater resilience to loading
- Decentralization of power generation
- Price signaling to customers

- Smart grid technology supports the role of PRDs
- The use of interoperative formats can aid in the transfer of data to and from PRDs, allows for the communication between PRDs, phasor measurement units, metering equipment, etc.
- Some of the interoperative formats that are currently in use are:
 - IEC-61850
 - MultiSpeak
 - IEEE Synchrophasors (C37.118)
 - IEEE 2030
 - UCA

Industry Sectors and Smart Grid Segments

- The smart grid is really the convergence of three industries which provide the knowledge on how to create the three high-level layers of a the smart grid:
 - Electric Power (Physical Power Layer)
 - Telecommunications Infrastructure (Data Transport and Control Layer)
 - Information Technology (Application Layer)
- For a smart grid to fully function end-to-end communication from the utility to the consumer, and even to specific appliances owned by the consumer, is necessary
- Advanced metering infrastructure (AMI), and a Field Area Network (FAN) would provide connectivity between the utility an the customer
- Smart grid segments and applications include demand response, grid optimization, DER integration, energy storage, EV's, PHEV's, advanced utility control systems, and smart homes and networks

- This section of the paper provides example smart grid projects that a utility could implement.
- Some of the projects discussed in more detail include:
 - Retrofits to transmission apparatus with smart grid capabilities including modifications to both terminal and line equipment
 - Smart grid technologies focusing on the integration of renewable resources
 - Communications infrastructure
 - Implementation of reliable and resilient microgrids
 - Cyber security projects to harden the system

- Active Network Management (ANM) allows the utility to dynamically optimize system performance by automatically reconfiguring the network as system conditions change
- Is only possible to implement by using information from PRDs and other smart grid components

- The paper discusses how PRDs can affect dynamic load management and power transformer asset management
- By using locally measured current from a PRD, or by using a PMU, and incorporating weather data or conductor properties, a dynamic line rating can be used rather than a fixed line rating. This can allow for better power transfer capabilities
- Due to the cost of power transformers, and the cost of their maintenance, condition based maintenance (CBM) has become more attractive. Use of inputs from digital monitoring devices and computer algorithms to determine when a transformer requires maintenance can save unplanned outages and money on unnecessary maintenance.

- Traditional load shedding schemes rely on a simple underfrequency element
- Typically the least critical loads are what are tripped off
- However, if all loads are deemed equally important, but load must still be shed, a cyclic load shedding scheme can rotate through the loads so that the burden is shared by customers equally
- This is accomplished through the logical programming available in PRDs

Adaptive Protection During Changing System Conditions

- Adaptive protection settings aims to adjust the settings in the PRDs based upon the system conditions
- This can be accomplished currently with the settings groups available in digital relays
- Adaptive protection could be set to account for variations in load, changes in system topology, or automatic feeder reconfiguration
- This kind of application must carefully consider operator awareness, technician training, and the impact to protection during the changes

- As more and more data becomes available from PRDs, sensors, PMUs, etc. it is imperative that:
 - Communication channels that can move the data be built
 - Data be processed fast enough to be useful
 - Data be adequately described and organized
 - Information be available to those who need it across an enterprise
- The report describes some of the components of the smart grid that can be employed to address these challenges

Using Existing Protection Functions

- Modern PRDs already have many of the functions, programmability, and information gathering capabilities to perform many smart grid applications
- PRDs are now available that may act as PMUs as well, which, when linked with a global reference, can provide wide area snapshots

	Smart Grid function/area/features						
	Self healing grid	Consumer Participation; demand response support	Resist Attack	High quality power	Accommodate Generation options; decentralization of power generation; distributed generation	Enable Electricity Market	Optimize Assets; load adjustment; grid optimization
Common Protective Relay Device (PRD) Status							
Direct Status							
Bkr/disconnect/swc status	x	x	x			x	
Pressure Status	x						
Derived Function							
Fault location/direction	x		x				
Power Factor/Quality		x		X	X	x	
Load Encroachment					X		x
Access Level Alarm			x				
Device Malfunction Alarm	x		x				
Out of Step condition		x			X		x
Operation Counter/Rate		x	x	X			
Measured Values							
Frequencies		x		x			
PMU				x	X		
Equipment loading characteristic/history		x		x		x	x
Equipment rating capability		x		x		x	x
Equipment health	x		x				x
Currents	x						x
Voltages	x						x
Temperature		x			X	x	x

Application for P2P Communications Between IVVC Controls and PRDs

- LTC and capacitor controls function to maintain healthy voltages on a circuit and reduce the losses through the reduction of reactive current
- This was originally handled entirely through local settings
- More recently wireless communication has allowed for communications to a centralized SCADA system, or distributed gateways located at the substations where the circuits originate
- Most utilities have focused on a master/slave communication structure, but there are benefits for P2P applications
- One example in the report involves the paralleling of transformers. While the transformers are in parallel the controls need to work to limit circulating current, but with the breaker open they must be operated independently. A PRD can communicate the breaker status to all controls in the scheme, rather than the status wired to each controller individually.

Using Relay Data to Defer Network Investments

- Without enough actual loading data on a network, assumptions may be made that cause unnecessary investments
- With more information available, more accurate use of capital spending can be realized
- With the inherent monitoring capabilities of PRDs, there is an opportunity to leverage this data

- The following features and functions were some of the ones compiled by a group of utility engineers, see the full report for more information.
 - Configurable programmable logic with graphical logic equations
 - Adaptive relaying
 - Waveform recording
 - Hardened product – surge immunity
 - Local and remote serial communication
 - PMU functionality for data collection and as part of a wide area protection system
 - Monitoring function of the logic elements in order to avoid mis-operation
 - Logic which provides information about the availability of the scheme
 - Monitor for abnormalities that would result in a permanent outage; alarm and disable reclosing
 - Integration of cyber security
 - Improved fault location accuracy

- The functions and capabilities discussed in the report are enabled by the inclusion of systems and protocols common across platforms
- IEC 61850 (messages/file transfer), IEEE C37.118 (PMU data transfer), COMTRADE (event records), and other standard protocols allow for the use of data between devices, software, and platforms.
- As the use of interoperable protocols expands it becomes easier to expand the use of the information in PRDs

- PRDs have many advanced features, capabilities, and functions that go beyond traditional protection elements
- The use of these elements can improve power system performance
- Organizational challenges can arise as the use of these functions increase, and they need to be addressed
- This summary paper is complementary to the C2 report “Protective Relay Applications using the Smart Grid Communication Infrastructure”