A SURVEY ON POWER SYSTEM PROTECTION IN SMART GRIDS

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The electric power system is facing a great number of challenges nowadays. Energy efficiency and environmental impact have to be considered for each component of the power grid. The power system operator need better grid reliability while dealing with an aging infrastructure. So, a modern protection system has to be implemented. The IEC 61850 communication protocol appeared as one of the key components in the protection systems of a smart grid.

Keywords: power systems, smart grid, protection, IEC 61850.

1. Introduction

The task of the control system starts with the position of the HV circuit-breaker and ends in complex systems for substation automation, network and load management as well as for failure- and time based maintenance. For all of these functions the data acquisition at the switch yard and – if applicable – the command execution at the switchyard are part of the network control and management.

Modern automation technology provides all the means necessary for processing and compressing information at the actual switchgear locations in order to simplify and secure normal routine operation. This allows more efficient use of existing equipment and quick localization and disconnection of faults in case of troubles, thereby also reducing the load on the communication links and in the network control centers, [1], [2].

Protection devices are required to safeguard the expensive power equipment and transmission lines against overloads and damages. Therefore, they have to switch off very quickly short circuits and earth faults and to isolate very

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selectively the faulted or endangered parts in the power system. They are thus a major factor in ensuring the stability of the power system.

The purpose of the power system control as a subdivision of power system management is to secure the transmission and distribution of power in the more and more complex power systems by providing each control centre with a continually updated and user friendly overall picture of the entire network.

All important information is transmitted via communication links from the substations to the control centre, where it is instantly evaluated and corrective actions are taken. Figure 1 provides an overview of the functions and subsystems that make up the control technology in the context of electric power transmission and distribution.

Load management is directly influencing the system load, e.g. with the help of ripple control communication via power network. It is selectively disconnecting and reconnecting consumers or consumers groups. On the basis of actual and forecasted load figures it is possible to level out load curves, to make better usage of available power resources, or to buy or sell energy on the market.

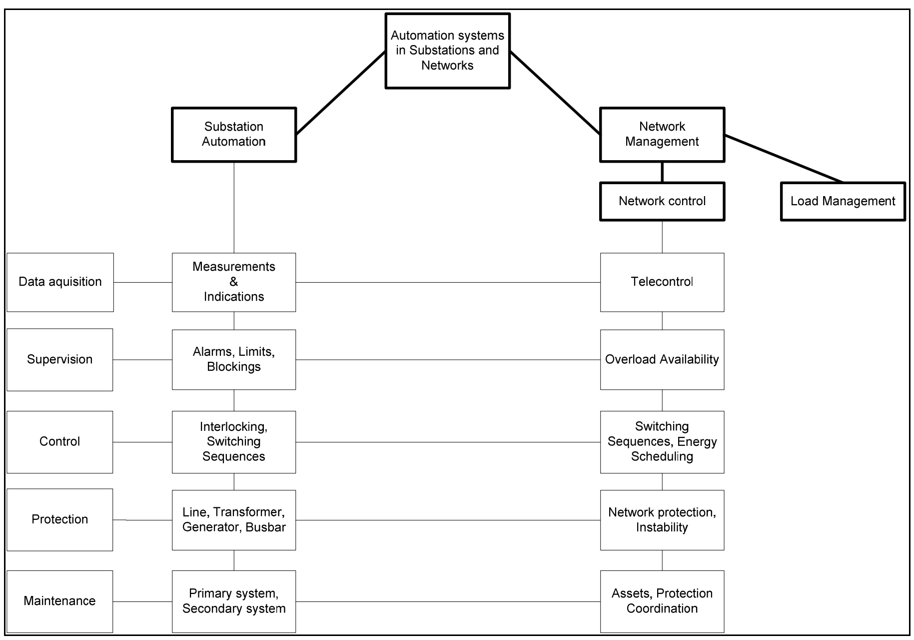

Fig. 1. Automation in substations and networks: functions and subsystems [3]

2. Modern protection systems

Various protection devices in power systems with rated voltages higher than 1kV are available to protect generators, transformers, cables, bus bars and consumers,[4]. The purpose of these devices is to detect faults and to switch off and isolate these selectively and quickly from the network as a whole so that the consequences of the fault are limited as much as possible. With today's high fault current levels and highly integrated networks, faults have far-reaching consequences, both direct (damaged equipment) and indirect (loss of production). Protection relays must therefore act very fast with the greatest possible reliability and availability, however also very selectively, to not switch off parts where it is not needed. Relays can be divided into various categories,[5]. A basic distinction with respect to function is made between switching (contactor) relays and measuring relays.

The relays used for protection purposes, together with supervisory relays, fall into the category of measuring relays and appeared according to their technology first as electromechanical and later as solid-state measuring relays. Today new protection relays are nearly exclusively numerical relays, i.e. based on software running in microprocessors. Therefore, more and more the term protective device is used instead of protection relay. More precisely, there are protection functions which are implemented in devices singly or in combination with other functions. Protection functions supervise dedicated values of the power system or of its components and respond very quickly and selectively if critical limits are exceeded.

Important for measurements in multi-phase systems, common is the three-phase system, is that values may be single-phase or three-phase related. In addition, the sinusoidal voltages and currents are shifted against each other by the so-called phase angle. The sinusoidal values may be also represented as rotating phasors with amplitude and angle facilitating lots of protection algorithms.

Nearly all protective devices are today integrated in systems requesting information like start and trip events from the protection function(s) and providing access to these e.g. for changing parameter sets. Numerical relays provide often also disturbance recording and, therefore, disturbance recorder file transfer over a serial link. Parameters determining the behavior of the protective device are loaded and changed from outside via communication interface. Also dynamically self-adapting protection is feasible, as part of the smart grid developments. All this information has to be exchanged over the so-called station bus according to IEC 61850 or one of the older proprietary protocols.

At the output of protective devices, there are switching relays which open e.g. the circuit breaker by closing the trip circuit. These relays act normally also as galvanic separation between power system equipment (primary technology) and the substation automation system including protection (secondary system). It is important that the output (trip) relays are able to switch the applied high currents and to not stick together. Because of their importance for the protection function, they are supervised in most cases.

Secondary systems are all those facilities needed to ensure reliable operation of the primary system, e.g. of the HV substation. They cover the functions of controlling, interlocking, signaling, monitoring, measuring, counting, recording and protecting. The power for these auxiliary functions is taken from batteries, so that they continue to work also in the event of network faults. Whereas in the past conventional techniques were used for decentralized control, e.g. from a local panel, this can now be done using computer based substation control techniques, often called “substation automation”, with or without protection.

The interface that this requires, is moving ever closer to the process, i.e. to the primary system. How near this interface can be brought to the process depends, for example, on how practical and reliable it is to convert from electromechanical methods to electronic (numerical) techniques, or whether the information to be transmitted can be provided by the process in a form which can be directly processed by the electronics. The communication standard IEC61850 even defines a serial interface to the process, which provides sampled analog values of voltage and current from the instrument transformers or sensors.

Today, overall network management is undertaken by computer-assisted systems based at regional or supra-regional control centers and load-dispatching stations. The conventional means to connect these to the substation is via remote terminal units (RTU). If however a computer based substation automation system exists, the RTU can be reduced to a protocol converter to the SA system. The trend to use the IEC 61850 up to the network control can reduce this even further to a data filtering and concentrating unit.

A major innovation of the new approach is the screen based human-machine interface (HMI). While the access interface to conventional secondary technology is focused on switch or mimic control panels with switches, buttons, lamps and analogue instrumentation, access to the new automation systems is usually given by a display at bay level and by screen-based operator places all with a keyboard and a mouse. This is valid both for the station level in the substation and the network control level. Operation is mostly application near and menu-guided, no programming or computer skills are necessary.

3. IEC 61850 – the communication standard for the electrical substations

The IEC 61850 is based on Ethernet, allows direct communication between any of the connected devices, and supports communication within the system hierarchy levels as well as between the hierarchy levels, and also communication for process near applications. To guarantee real time performance, classical Ethernet busses have not to be used, but only switched Ethernet networks. Further the priority handling and VLAN features as defined in the Ethernet standard have to be supported by the switches. For availability reasons the networks are mostly ring based instead of tree based. The point – point connection between devices can be electrical for short distances within a screened environment, otherwise fiber optical networks, as seen in [6].

IEC 61850 offers more than a communication protocol to connect devices of different manufacturers. It improves the system operational safety and offers availability in transmission, through the possibility of distributed architecture implementation. Its uniform data model with standardized semantics and the standardized description of substation automation configurations including their functional connection to the switchyard (Substation Configuration description Language) supports uniform maintenance of all secondary devices, provides long life time of engineering data within a system configuration, supports the exchange of engineering data between the engineering tools of different manufacturers, and reduces the effort for engineering and maintenance, [7].

4. Smart grid challenges

Smart grid initiatives seek to improve operations, maintenance and planning using modern technology in order to better manage energy use and costs. Many governments sustain modern networks in the global context of energy saving and environment issues. United States Department of Energy have defined the functions required for smart grids[8]: the ability to heal itself; to motivate consumers to actively participate in operations of the grid, to resist attack, to provide higher power quality, to accommodate all generation and storage options, to enable electricity markets to flourish, to manage more efficiently the assets and costs.

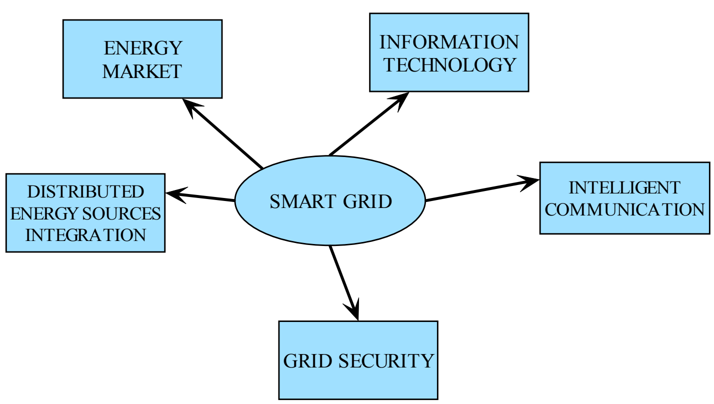

Fig. 2. The smart grid components, [9]

Demand Response: Moving from a Load-Following to Load-Shaping Strategy

Load management has been around since the early 1980s. Direct load control, peak shaving, peak shifting, and various voluntary load management programs have been implemented by many utilities with varying degrees of success. Now, with the push for energy conservation and demand-side management as a key strategy for environmental compliance, demand response (DR) is taking on new realities. In addition to traditional load management, the advanced metering infrastructures (AMIs) being deployed by many utilities will enable the implementation of targeted dynamic tariffs, management of demand-side energy resources, and integration of retail demand-side capabilities with wholesale energy markets. Many expect that dynamic and market-based rates will become the default retail tariff in many regions with AMI capability.

Initiatives, such as NIST/Gridwise Architecture Council efforts to define Home-to-Grid (H2G), Building-to-Grid (B2G), and Industry-to-Grid (I2G) interoperability requirements, as well as International Electrotechnical Commission (IEC) standards for home area networks (HANs), will enable the integration of demand-side resources with distribution and, in the aggregated form, with transmission operations. The end-use devices, such as intelligent appliances and smart chargers, will have visibility of possible distribution grid conditions (congestion) and dynamic prices, and they will be able to make local decisions to control their consumption. The system operator will be able to monitor and, either directly or through price signals, manage demand. The grid will be ready to move from the traditional load following operating strategy to a load-shaping strategy, in which demand-side resources are managed to meet the available generation and the grid's power delivery capabilities at any time.

The Critical Role of Information and Automation Technologies

A broad-based implementation of the smart grid will impact many of the existing utility operational and information systems. In addition to advanced metering and utility wide communications infrastructure enabling DR and distributed resource management, the smart grid impacts many of the operational and enterprise information systems, including supervisory control and data acquisition (SCADA), feeder and substation automation, customer service systems, planning, engineering and field operations, grid operations, scheduling, and power marketing. The smart grid also impacts corporate enterprise systems for asset management, billing and accounting, and business management. Many expect that by between 2012 and 2014, there will be a significant number of plug-in vehicles and utility-grade solar generation on the distribution grid. As discussed earlier, this could result in system overloads, voltage/reactive power deviations, and excessive phase imbalances. To mitigate these issues and to maintain system reliability, coordinated voltage and reactive power control, automated switching and relay coordination, and extensive monitoring will be required. In addition, a combination of distributed intelligence and centralized analysis and control, congestion management strategies, and market based dynamic pricing will be needed. As illustrated in Figure 2, many information technology (IT) systems will be impacted, including those for distribution management and automation, operations planning, scheduling and dispatch, market operations, and billing and settlements.

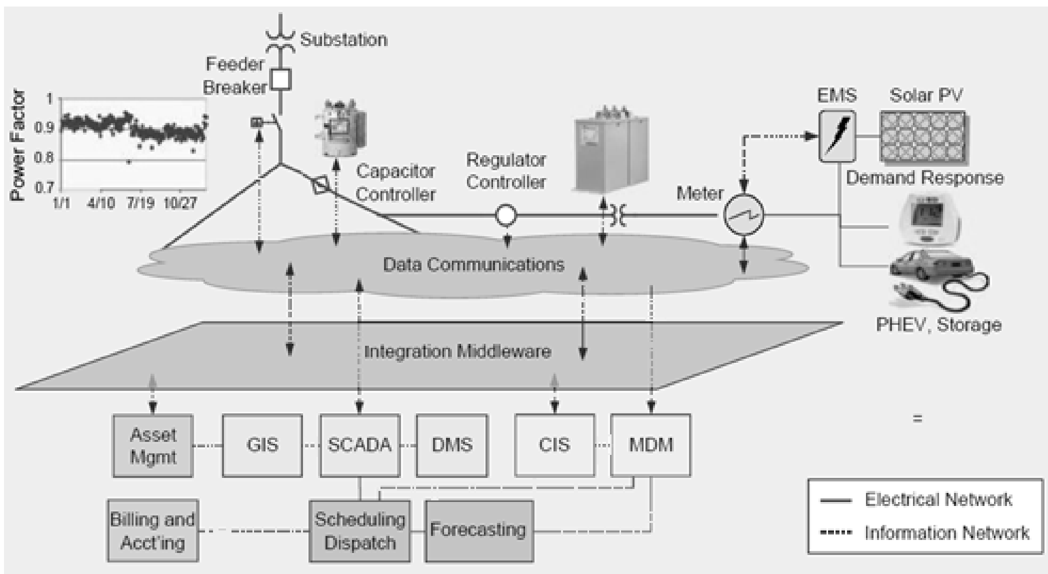

Fig. 3. Systems required to support the SMART GRID[4]

6. Conclusions

The traditional model-large remote power stations with central dispatch, long transmission lines, and a distribution system primarily designed to deliver power from transmission substations to load centers with established load profiles-may be evolving into a new approach. This new approach will accommodate greater levels of demand side management; generation and storage resources on the distribution system; generation closer to the loads; perhaps greater flexibility for islanding and micro-grids; and considerably higher levels of intermittent generation, especially on the transmission system. These changes not only require changes to the power system capacity and capabilities, but they also will have a significant impact on the protection and control systems (e.g. IEC 61850) needed to monitor and control the reliable operation of the power system in a most economical fashion. The modern protection and control systems impact is particularly significant for the distribution grid, where, traditionally, very limited sensors, automation, and information are available. These capabilities are the key to the smart grid.

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