Embedded power protection

Embedded applications in power system automation

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Since the infancy of electrification, more than 130 years ago, protecting assets from power failures has been a main objective. New embedded information technologies incorporated in power system automation are now handling protection aspects plus many additional dedicated applications. This evolution and its future trends are discussed in this overview article of power system automation, as applied to the generation, transmission and the distribution of electricity.

Power system automation has its origin in the protection of high- or medium-voltage equipment from damage in case of a power system failure. This equipment includes power switching devices, circuit breakers, and power lines, and also motors and generators. The first protective devices were developed more than 130 years ago at the time when the first electrification projects began. Protective devices at that time were built on electromechanical principles and their operation was mechanical. Even today, such electromechanical relays exist in large numbers in many power systems worldwide. As electronics and semiconductor technologies emerged, power system protection also took advantage of new possibilities and a second generation of protective devices was designed with electronic components. These solid-state relays enabled new applications, incorporating enhanced protection functions in addition to power measurements, alarm triggering and basic trending. Eventually, when microprocessors became commercially available in the early eighties, numerical protection emerged. Microprocessor technology has enabled a wealth of new functionality. These embedded numerical devices now deliver key benefits in protection, control, monitoring, and self-supervision, as well as in the field of data communication.

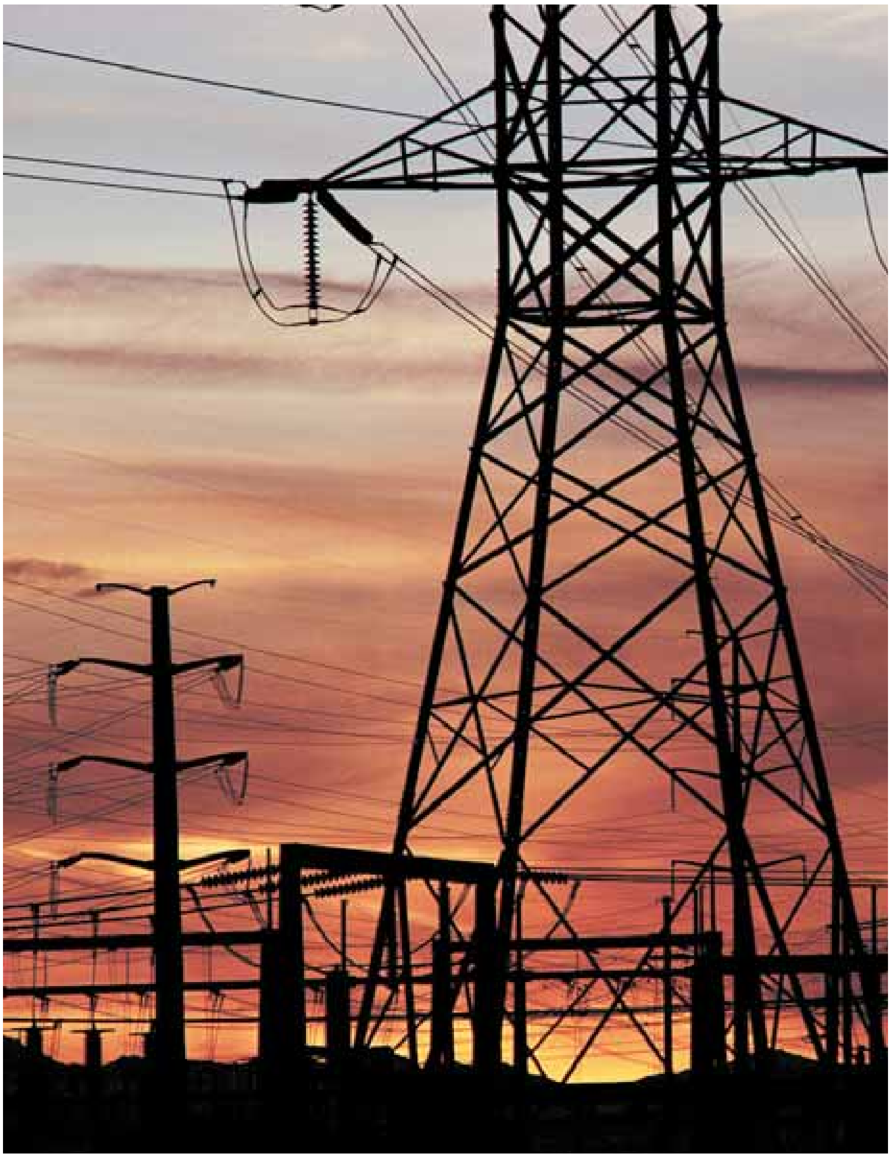
Power system automation business drivers

While in the past the sole purpose of a protective device was to protect high- and medium-voltage equipment, today's power transmission and distribution business environment imposes new requirements that call for new solutions. Technical considerations are complemented by a great number of new challenges. Electricity market deregulation, utilities' customer-focus, customer retention, power quality and reliability, value added service, financial performance, reduced operation and maintenance cost, and asset management are just a few of the challenges that drive the implementation of modern automation solutions in the power delivery process. Real-time data communication is a key feature and ubiquitous access to process information is key to reaping the benefits of advanced solutions.

Power system automation application areas

Power system automation is a distinct variant of general industrial automation. Due to the proximity of high- and medium-voltage equipment, power system automation solutions have more stringent requirements. Compared to industrial automation, the key differences include higher voltage signaling, high current and voltage sensing, system time synchronization of 1ms accuracy for event time tagging, short typical response time (in the range of some milliseconds) and more stringent EMC (electromagnetic compatibility) and EMI (electromagnetic interference) testing requirements. In the following section, some typical power system automation applications are introduced and characterized.

The number of embedded system components is increasing rapidly and these components with their varied tasks cover the entire chain of the electrical power delivery process from production to consumption. A key criterion for the characterization of an embedded system or system component is its ability to react to process events or conditions within a deterministic timeframe. Such real-time applications are typically executed cyclically. The cycle time determines the fastest response time and must therefore be designed specifically for the application. In general, applications closer to the power process require shorter cycle times than applications in remote locations such as network control centers. The title picture depicts a typical power delivery



structure involving several automation applications with different characteristics. In general, the basic functionality of power system automation includes protection of power system equipment, control of power flow, monitoring of the power process and condition monitoring of the equipment.

Power station

Industrial control is the predominant automation technology at the power station. However, higher voltage devices such as power generators utilize power system automation devices. Typical functionality includes:

- Generator protection and control
- Functions to verify synchronous operation (Synchrocheck), ensuring proper timing when the generator is connected to the power transmission network.
- Circuit breaker protection and control

Power system automation devices are usually integrated into the power plant automation system, enabling central control of the complete station.

Power transmission network

Substations are usually located at each end of a power line. The most typical application in the transmission network is the power line protection function, which is embedded as a dedicated task in the automation system that is installed in the substation. Line differential protection is built on two electronic devices that measure voltage and current at both ends of the line. Specialized communication links transmit these measurements, which under normal operating conditions would show zero differences. A difference in measured quantities would indicate a fault on the power line and circuit breakers would be operated (tripped) in a matter of a few milliseconds, disconnecting the line from the transmission network. Such faults can be temporary, as in the case of a lightning strike, or permanent, as in the case of a fallen tree. In the case of a temporary fault, automation functions will reconnect the line automatically.

Another common application is the line distance protection that performs a similar function but is based on the power line impedance rather than voltage or current differences. In the event of a line fault, the embedded device will not only disconnect the line, but it will provide some indication of how far from the substation the failure is thought to have occurred. Automation devices in a substation are generally connected to a remote communication terminal or gateway, which exchanges information with the network control center.

> Today's power transmission and distribution business environment imposes new requirements that call for new solutions.

While the transmission network operates at alternating current (AC), high voltage direct current (HVDC) is usually employed for very long distance power transmission. Power at both ends of the line needs to be converted from AC to DC and from DC to AC by thyristor controlled converters. These circuits require highly sophisticated and very powerful control and protection equipment, executing at cycle times as short as 100 ns.

Transmission substation

At the substation, large oil-insulated power transformers convert voltage levels from the transmission voltage, which might be 240 kV, to the distribution voltage, which might be 110 kV. Specific arrangements of circuit breakers enable reliable control of the power flow. Many embedded systems are installed for automation purposes. In general, one distinguishes between object protection functions, such as line protection, transformer protection, and breaker protection, and system protection functions, such as busbar protection. Short circuits in the substation can become as high as 100,000 Amps, so protective devices need to react in 10 to 20 ms by disconnecting the faulting part of the station.

For dependability reasons, separate embedded devices are used for protection and control. Thus, a substation will need many dozens of automation devices, and large stations can require several hundred. The automation devices are modular system components, which vary in their number of process inputs and outputs, as well as in their computing power.

Primary distribution substation

The primary distribution substation performs the same functions as a transmission substation but on lower voltage levels. Smaller power transformers convert voltage levels from, for example, 110 kV to 38 kV. At this level, protection and control are generally integrated in a single device, executing all functions concurrently. The energy involved in a fault is less critical than in a transmission system and thus, real-time response requirements are somewhat relaxed. However, operating times are still in the range of a few tens of milliseconds.

Secondary distribution substation

The secondary distribution substation is located closer to consumers and at lower voltage levels. It may or may not include a transformer and the complete arrangement is considerably less complex than in the primary substation.

Sophistication in automation is also very limited and most often reduced to simple protection functions. Devices are standardized and available at very low cost. Most often, no communication is employed at this level of the distribution network.

Distributed power generator station

The most common application of a distributed power generator is an emergency backup power supply for critical consumers, such as hospitals, industrial applications or mission-critical infrastructures. A key application in such stations is the transfer switch from the standard power source to the backup supply. Appropriate embedded automation functions ensure correct operation of all devices involved, including the ability to disconnect the power line, start the generator, and connect the generator to the critical consumer. In case the power supply needs to remain uninterrupted, as is commonly required in information server farms, large batteries or flywheel technology would be employed to overcome the generator startup delay. Complete fast transfer operations can be executed within a few milliseconds, leaving critical computer equipment uninterrupted.

Feeder automation

The application of protection and control devices outside the substation and on the power distribution line is called feeder automation. Typical functionality includes overcurrent protection, fault location, breaker reclosing. Smart and quick restoration of faulted distribution feeders are other good examples of advanced embedded automation functions.

Industry network

Large power consumers such as industrial parks, chemical plants and factories operate and maintain their own on-site power distribution network in order to power motors and other large equipment. A great number of devices are installed to perform protection, control and measurement functions.

These power system automation devices are typically integrated into the overall process control system.

Network control center

The network control center is the central location for network operation. Large supervisory control and data acquisition (SCADA) systems collect information from all substations and perform complex computations. At this level, energy management applications are executed, enabling proper and stable operation of the generators, transmission network and consumers. Complex power flow calculations are performed to monitor critical conditions and enable appropriate actions to be taken by network control personnel.

Due to the proximity of high- and medium-voltage equipment, power system automation solutions have more stringent requirements.

Embedded power system automation devices perform real-time-critical functions on all levels of the system and control hierarchy. The graph in 1 classifies the applications mentioned above according to their real-time response requirement.

Technology Trends

The future of embedded components in power system automation will be determined by three distinct technology trends:

Electronics integration

As integrated circuit technology advances, more and more functionality will be incorporated into single automation devices. Because of higher CPU clock speeds and increased memory, a single embedded device will be capable of executing new and additional functionality, which will need to be processed by multiple devices, or even off-line.

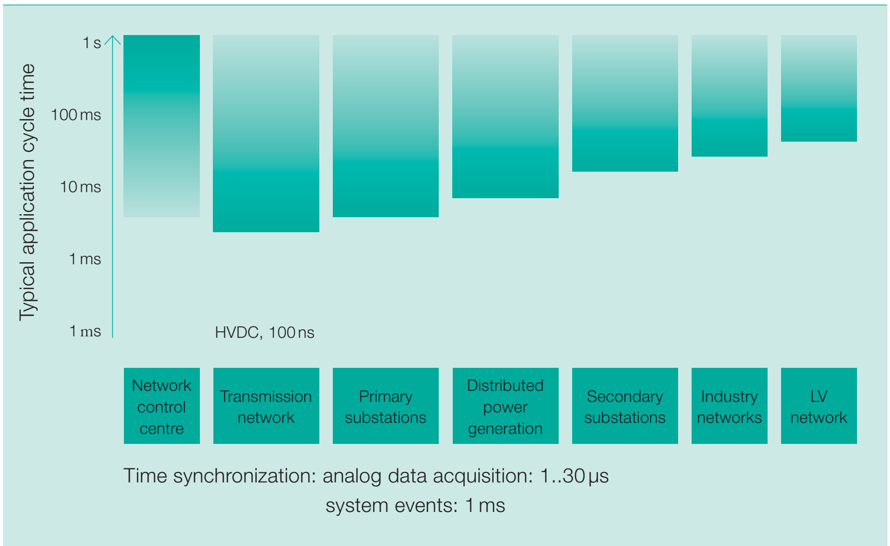
Substation automation technology

Early implementation of numerical power system protection and control devices used specialized digital signal processing (DSP) units. Today's implementations are leveraging the vast computing power available in general purpose central processing units (CPU). As such, PowerPC microcontrollers deliver high computing power at low power consumption and, therefore, low power dissipation. Random Access Memory (RAM) is utilized for the program execution memory and erasable read only memory (EPROM) stores program and configuration information. A typical configuration can include a 400 MHz PowerPC, 64 Mbytes of EPROM and 64 Mbytes of RAM. The CPU can be complemented with field programmable gate arrays (FPGA) that integrate logic and signal pre-processing functionality. An automation device usually includes a number of printed circuit board assemblies (PCBA), accommodating requirements for the diversity and number of different input and output circuitry. High-speed serial communication is built in for inter-module communication that enables the CPU to send and acquire data from the input and output modules. Application-specific circuits are designed to optimize overall technical and economical objectives. The picture below shows a sample of a high-performance CPU module, connected to a binary input and Ethernet communication module.

- a EPROM
- b Signal preprocessing FPGA
- c Device internal 100 bit/s serial communication
- d Power supply
- e Multi-port Ethernet switch with optical and electrical 100Mbits/s Ethernet media access
- f 18-300V binary inputs
- g Binary input processing ASIC
- h RAM
- i PowerPC micro-controller

Embedded system technologies

1 Real-time requirements for different embedded applications in a power system hierarchy



Moreover, modern system implementations are based on more generic electronics and software platforms, allowing for the most economical configuration of specific applications.

Switchgear integration

Embedded systems will also be integrated into the switchgear apparatus itself. Automation devices are currently mounted in switchgear panels and connected to the apparatus by extensive wiring.

Thus, the apparatus and its automation functionality represent a comprehensive functional unit that is also referred to as the intelligent apparatus. Hardware engineering activities, such as drafting and wiring will be substituted by software engineering and configuration.

Integrated electronics in low-voltage equipment is already well established and state-of-the-art. In medium voltage, the first intelligent circuit breakers have been launched and market acceptance is growing. On high-voltage levels, research is ongoing and market acceptance still needs to be established 2. However, what is common to all application areas is the continuous drive towards more integration.

It is only the rate of progress that differs.

Data communication

The strongest trend however, is towards more and higher-speed communication, which in general means Industrial Ethernet implementation. The new utility industry standard, IEC61850, is fostering inter-operability on all levels of power automation systems, boosting the benefits and the acceptance of base communication technology. Future devices will include integrated multi-port network functionality, such as routing and switching capabilities, as well as highly accurate time synchronization. Additionally, most of the commonly used protocols, such as Modbus and DNP (Distributed Network Protocol) will be extended for Ethernet networking, enabling the utilization of a multitude of standard protocols in a single Ethernet network.

Today's protection and control devices have the potential to become fully capable communication network nodes with automation functionality.

> Industrial control is the predominant automation technology at the power station.

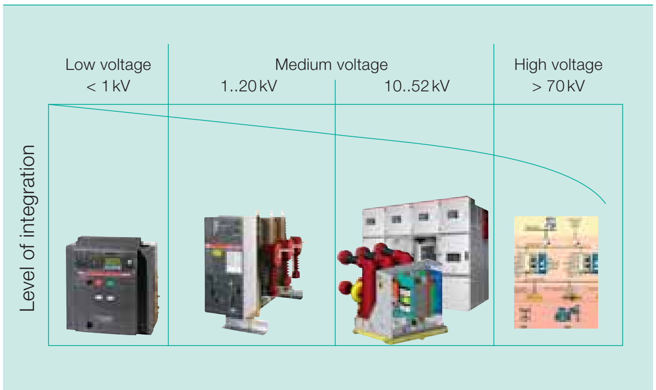
Future trends in embedded power protection technology

Highly sophisticated embedded systems are employed in great numbers in the electrical power delivery process at all levels. The main function of these systems is to protect the power system components, control the power flow, and monitor the process, as well as the condition of its equipment.

Power system automation devices are integrated in communication networks for the exchange of information between several such devices, as well as with supervisory systems.

Technology trends predict an even higher level of functional complexity per device and also deeper integration with medium- and high-voltage apparatus. The need to enhance automation and communication will continue to grow. To meet this demand of the future automation devices must be equipped with sophisticated data communication and networking capabilities.

2 Device integration related to voltage levels



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