Standards Based Smart Grid Power Distribution Systems

Author: Advantech

E-mail: eainfo@advantech.com

Power distribution grids are brittle. They were not designed; they were built and added on to, with disregard for safety, security, and robustness. This has been going on for more than 100 years. In many countries, power systems just barely operate. In North America, the grid is dangerously brittle and could be damaged easily. Power plants were large, in the beginning, and either nuclear, fossil fuel, or hydroelectric. They were counted on to put power into the grids in a consistent manner, which required little fine adjustment or control. The price of electricity changed annually.

This has changed, and changed dramatically.

In a modern power grid, there are many different types of power production systems. There are the conventional large generation plants using nuclear power and conventional fossil power plants and hydroelectric systems. There is also wind, geothermal, solar, and tidal generation systems. Smart grids are necessary for demand-response power production, and to manage the contribution of the non-conventional systems, which are not consistent power producers. The price of power can now change anywhere from every 15 minutes to every hour in a demand/response system. Much more visibility is necessary to deal with cost changes, power origination changes, and changeable grid reliability.

It is necessary to provide quality power for the 21st century, for the Internet of Things, and Manufacturing 4.0. It is equally necessary to produce a scalable and improvable grid in developing countries that need electrical power but have limited infrastructure. A new kind of grid needs to be designed and built to satisfy the requirements of this new century. For about a decade now, this has been called the Smart Grid.

The heart of the Smart Grid is a robust, integrated communications network with enough speed and bandwidth to produce near-instantaneous communications from any node on the grid to any node on the grid, and back.

The network supports the physical basis of smart electrical distribution: the Smart Transformer Station. The station must be capable of functioning as an intelligent grid node to enable demand/response production of electricity. The transformer station must be capable of using a unified information platform on the entire grid to perform required maintenance, to operate unattended and in automatic mode, to self-diagnose problems and correct them. Automated self-regulation for operational status and the ability for intelligent analysis and decision support are also needed to permit the transformer station to maximize its flexibility and responsiveness.

IEC 61850 and the Smart Grid

At the heart of the unified information platform and integrated communications network of the Smart Grid is an international standard from the International Electrotechnical Commission: IEC 61850. Originally entitled “Communications Networks and Systems in Substations,” the latest version of the standard is now called, “Communications Networks and Systems for Power Utility Automation.”

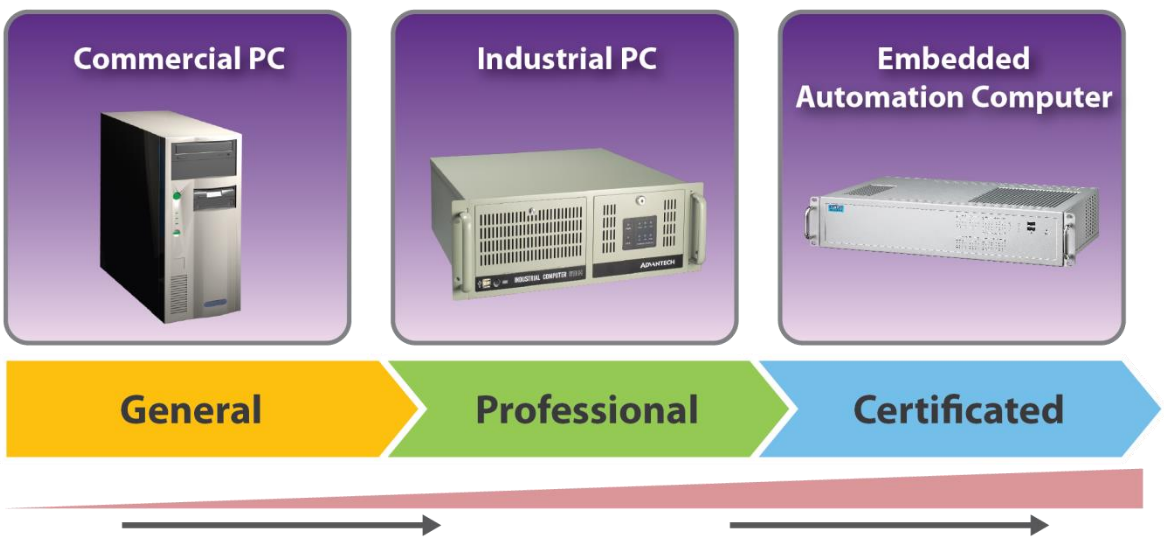
IEC 61850 defines the universal platform for communications and operations between devices in a power system. Utility workers can use devices of different manufacture, or located in different plants at the same time, and share the information, services and functions of these devices. IEC 61850 defines the interoperability between devices on the grid.

In fact, IEC61850 is not limited to power systems. IEC's TC65 technical committee further extended it to industrial measurement and control systems based on Ethernet networks. That would be nearly every DCS or SCADA system in existence.

The General Requirements section of the standard, IEC 61850-3, specifies that substations and transformer stations must conform to all the requirements of hardware design to meet IEC 61850.

IEC61850 Embedded Industrial PCs vs General Industrial PCs

Computer control has been expanding in industry and utility service since the early 1970s. Dick Morley, the inventor of the PLC, famously said, "It was always a computer. We called it a controller and used ladder logic so we wouldn't scare the operators and maintenance people." The advent of the personal computer also created a venue for simpler, less expensive control systems.



But the commercial PC is not robust enough for use in the industrial environment. Hardened, industrial personal computers, or IPCs, are used all the time for monitoring and controlling industrial processes as well as other commercial uses.

IPCs are stable, hardened, safe and secure. Embedded IPCs are even more so. For example, where a standard industrial PC uses housings made for rack mounting with main boards, backplanes and high-power power supplies, an embedded IPC uses a hardened aluminum casing with embedded main boards, no backplane and an external power supply with low power consumption. The aluminum case serves to act as a heatsink since the brightness of the case improves heat dissipation, and the Embedded IPC can be easily made fanless.

Embedded IPCs use a single, embedded main board, with CPU and peripherals, and use PCI104 or MINIPCI to expand. The standard PCI, ISA peripherals and buss controllers are integrated on the board for ruggedization and better maintenance. Other interfaces, such as DIO, audio, TV-OUT, network (Ethernet) ports, serial ports, USB ports are integrated into the main board. This reduces the amount of wiring and improves the vibration isolation of the embedded IPC.

Industrial PCs have been applied to substation and transformer station control for many years. In recent years, embedded IPCs have played an integral role in smart substation and transformer station design because they are high performance, have a compact, space-saving design, and are known for high stability and high reliability as well as high performance.

Companies such as Advantech provide Embedded IPCs that are certified to meet the design requirements of IEC61850 for use in substations in the Smart Grid environment.

Figure 1 - Advantech UNO-4683

These embedded IPCs can be used as an HMI/SCADA server, a terminal server, a protocol or communications gateway, a network security server, and many more critical Smart Grid functions. IPCs such as the UNO-4000 series conform to IEC 61000-4 requirements for EMI rejection, are designed for anti-shock, anti-vibration, and use a switching power supply for 90-250VAC/VDC-power input. Advantech's UNO-4000 series has multiple communication interfaces, Ethernet, USB interface, COM interface, PCI-104 expansion slots, and multiple I/O modules designed for the requirements of an IEC 61850 transformer station.

Based on IEC 61850, the intelligent transformer station or substation has a structure composed of three layers. The first is the station control layer. In the station control layer, IPCs can be used as the station's HMI/SCADA system, which can monitor and report on the status of the equipment in cabinets. The Advantech UNO-4000 series can provide IRIG-B time synchronization functions and integrates a UNOP module with TTL, fiber, serial, human machine interfaces to provide a complete HMI/SCADA solution.

The second layer in the substation structure is the spacer layer, where IPCs can be applied to the network analyzer functions. Equivalent in function to an airliner "black box" the network analyzer is used to record and analyze the performance of the network and its data processes. When an IED (Intelligent Electronic Device) malfunctions, a network analyzer is used to determine the process of failure and provide a sequence of events around the failure. Advantech's UNO-4000 series has high calculation performance, a fast data acquisition function, isochronous timestamp function, duplicate hard disk holders, and support for RAID to handle even large volumes of data swiftly and easily.

In the process layer, an embedded IPC like the UNO-4000 series can be applied to IED equipment. All of the basic components of a transformer station (transformer, circuit breaker, switching device, etc.) need to be monitored and controlled. The low-power CPU of embedded IPCs like the UNO-4000 series makes it an ideal hardware platform for IEDs. In some cases, embedded IPCs can be substituted for purpose built IEDs, thus reducing the cost of building and operating the automated transformer station or utility substation.

It is especially important that the IPC used in Smart Grid applications be certified to IEC 61850 standards and others.

The Specific Requirements of IEC 61850-3

IPC equipment that is manufactured to conform to IEC 61850-3 must conform to the following requirements. First, it must have a strong EMC design to prevent EMI effects on the IPC. Second, it must have a wide temperature range designed into it.

Power sources, I/O interfaces, electrical fast transient pulse rejection, static electricity and RF electromagnetic energy rejection are part of the requirements. Companies making IEC 61850-3 conforming devices generally certify their products to IEC TS 61000-6-5 for electromagnetic compatibility when used in power plant and transformer or substation environments.

IEC 61000-4 standards form the basic immunity standard for EMI/RFI rejection, fast transient rejection, power surge immunity, power supply ripple and voltage dips and sags, and conducted RFI immunity. Manufacturers of embedded IPCs used in substations and transformer stations like the Advantech UNO-4000 series must have passed the requirements of IEC 61850-3 to be able to work reliably, and be stable in Smart Grid automated systems in transformer stations.

In addition, requirements for working conditions and environmental conditions must be met in order for a product to be certified for conformance to IEC 61850-3.

The important tests for conformance are the Electrical Fast Transient (EFT) test, the Electrostatic Discharge (ESD) test, and the wire to wire and wire to ground surge test. Other tests include voltage sag testing, short duration power interruption tests, and electrical field and RF immunity testing. In order to qualify for IEC 61850 compliance, manufacturers of embedded IPCs must rigorously test their products for all these issues and design them to the highest level of immunity.

Electrical Fast Transient Test

Companies like Advantech test their IEC 61850-3 compliant devices, like the UNO-4000 for EFT. Electrical fast transient pulses are due to the breaking of the inductive load in the circuit. This interference features pulses appearing in groups, higher pulse repetition frequency, pulse waveforms with a short rising time, and with a single pulse with lower energy.

Some inductive loadings of a transformer station, such as relays, contactors, transformers, and other devices, will also exhibit this kind of transient interference, which will influence the normal operation of the device in a substation or transformer station.

Advantech tests the power supply, the I/O, and communication connection ports for EFT. Advantech's power supply design includes transient voltage suppression and protection devices, and I/O ports are designed to release EFT pulses to the casing and to ground to ensure the reliability of the equipment.

Electrostatic Discharge Test (ESD)

Static electricity is everywhere, and in the presence of powerful electrical fields, like in a substation or transformer station, static electric charges can build unless grounded and released. Static charges may damage chips and interrupt communications and data acquisition. It's important that the products used are rated for static discharge and provide the features needed to ensure the proper safety of all the equipment as well as employees.

Advantech tests its UNO-4000 series for static discharge to qualify for conformance to IEC 61850-3 certification, based on the requirements of the IEC 61000-4-2 standard. Based on the results of its testing, Advantech designed its communication ports to be sure that the system can run normally when exposed to static electricity by providing isolation in the transformers, power supply and optically coupling the communication ports.

Electromagnetic Radiation Test

RF energy is everywhere. This is especially true in transformer stations and substations, where there are large numbers of electronic devices all radiating RF energy for electromagnetic field radiation interference. IEC 61850 provides requirements for EMR and EMI immunity testing, and many countries specify that products must meet or exceed the European Community EMC Directive on electromagnetic interference. Conventional PCs have very low EMI and RFI immunity. In products destined for use in utility substations and transformer stations, the level of acceptable immunity is much higher. Embedded IPCs have very high noise immunity because of their integral design features.

Advantech simulates an actual test situation using a source of EMI and RFI. These fields are similar to the fields caused by voltages and currents generated by the equipment under test. Advantech runs the equipment full out, and performs the test under all sensitive operation modes. The device is tested for 80 to 3000 MHz, with a field intensity of 10 V/m. Under certain circumstances, the field intensity can be increased to 35 V/m. Because of this testing, Advantech designs its products to have rigid cases to minimize RF interference, and reserves a shielded line grounding interface for customer use.

Wire to Wire/Wire to Ground Surge Test

Surges can be caused by lightning striking around the equipment, or starting and stopping high power equipment, or circuit malfunction, switching or variable frequency power supplies and devices. They can be both voltage and current surges. Power surges have profound negative effects on electronic devices, and can cause failures, system faults, and stop system operations. Power surges and fast transients can damage IPC circuitry, yet not cause a complete system failure. This is a difficult and dangerous situation.

Advantech tests for both wire-to-wire and wire-to-ground surges in accordance with IEC 61000-4-5, and as a result of these tests, Advantech’s designs add effective protection devices to conform to IEC 61850.

Other tests including voltage sags and short interruption of power tests are run to conform to IEC 61850, and storage capacitors are added to both buffer the power into the device and keep voltage sags and short duration power interruption from affecting the operation of the devices.

Another test that Advantech runs to ensure IEC 61850 compliance is a power frequency magnetic field immunity test. This is especially important in utility substations and transformer stations, where magnetic fields are generated from AC transformers and other fields can be produced like the leakage magnetic flux of a damaged transformer. Power frequency magnetic fields are inevitable in utility applications. Advantech tests devices to conform to IEC 61000-4-8.

IEC 61000-4							
Testing items			Level 1	Level 2	Level 3	Level 4	Level 5
IEC 61000-4-2	Electrostatic discharge	Air Discharge: Contact discharge	2kv 2kv	4kv 4kv	6kv 8kv	8kv 15kv	
IEC 61000-4-3	Radiated electromagnetic disturbances	Frequency range: 80~1000MHz	1V/m	3V/m	10V/m	35V/m	
IEC 61000-4-4	Fast transients	Input port: Signal port	0.5kV (5kHz) 0.25kV (5kHz)	1kV (5kHz) 0.5kV (5kHz)	2kV (5kHz) 1kV (5kHz)	4kV (5kHz) 2Kv (2.5kHz)	
IEC 61000-4-5	Surges	Line to neutral: Line to Earth	0.5Kv	0.5Kv 1kV	1kV 2kV	2kV 4kV	
IEC 61000-4-6	Induced disturbances	E.M.F	1V	3V	10V	30	
IEC 61000-4-8	Power frequency magnetic field	Magnetic field strengthen	1A/m	3A/m	10A/m	30A/m	100A/m
IEC 61000-4-10	Damped oscillatory magnetic field	Magnetic field strengthen			10A/m	30A/m	100A/m
IEC 61000-4-11	Voltage dips, short interruptions And voltage variations	30% reduction(voltages dips), 1 period; 60% reduction(voltages dips),50 period 100% reduction(voltage interruptions),5 period; 100% reduction(voltage interruptions),50 period					
IEC 61000-4-16	Immunity to conducted, common mode disturbances	Frequency Range 15Hz~150Hz 150Hz~1.5kHz 1.5kHz~15kHz 15kHz~150kHz	1~0.1Vr.m.s 0.1Vr.m.s 0.1~1Vr.m.s 1Vr.m.s	3~0.3Vr.m.s 0.3Vr.m.s 0.3~3Vr.m.s 3Vr.m.s	10~1Vr.m.s 1Vr.m.s 1~10Vr.m.s 10Vr.m.s	30~3Vr.m.s 3Vr.m.s 3~30Vr.m.s 30Vr.m.s	
IEC 61000-4-17	Ripple on DC input power port immunity	% nominal DC voltage	2%	5%	10%	15%	
IEC 61000-4-29	Voltage dips, short interruptions and voltage variations on d.c input power port immunity	30% reduction(voltages dips), 0.1 sec; 60% reduction(voltages dips), 0.1 sec; 100% reduction(voltage interruptions),0.05 sec.					

Applications of Embedded Industrial Computers in Automating Intelligent Transformer Stations

Embedded IPCs are ideal for the many uses of computing devices in transformer stations and utility substations. IPCs, such as Advantech's UNO-4000 series devices, can be used in many of the nodes in substation networks. IPCs can be used as network servers, controllers, HMI and SCADA servers, data loggers, and provide IRIG-B time synchronization functions.

Using IPCs allows for high performance networking and unified threat management against intrusion by hackers. Using an IPC as a network record analyzer enables immediate analysis and maintenance of any IED in the station.

IPCs like the UNO-4000 series can be used for communications gateways, communications servers, and as the reliable calculation platform called for in IEC 61850-3. Using configurable IPCs makes system design simpler and easier. Using configurable IPCs means that the system can be replicated from substation to substation, without having to redesign the system, devices, and network from scratch.

Using configurable IPCs for many different functions in a substation can reduce the time and cost of maintenance, too.

The intelligent IEC 61850-certified embedded Industrial Personal Computer is an integral part of the architecture of smart grids, and will lead to better and more agile power distribution systems in the next decade.

Application Example

A typical smart substation consists of three levels. The substation level, which is located in a shielded control room, provides an overview of the whole network by using a workstation, master and backup computers, and GPS receiver.

The intermediate layer (bay level) conducts maintenance work to link upper and lower levels as well as controlling IEDs (Intelligent Electronic Devices) and transducers in the process level.

The process level is close to the switchyard equipment and is responsible for data acquisition. Based on this multi-tier architecture, a system integrator planned to upgrade its original monitoring system to a smart substation. Therefore, the new computer for the substation automation system needed to offer various serial ports and network interfaces to meet the special requirements of the IED acquisition and support the Linux operating system upon which the system integrator’s acquisition software is installed, as well as complying with the international standards and gaining the certifications that are required.

Two types of open embedded computers for substation automation were needed. Chosen were Advantech’s UNO-4673A and the UNO-4671A, which allowed the system integrator to design the most optimal solution for the control and monitoring systems. These substation computers featured a high-performance CPU, a wide range of communication interfaces such as isolated serial port, LAN port, and PCI-104 extension slot.

They also are compliant with the international IEC 61850-3 and IEEE 1613 standards.

Using these computers provides an excellent gateway, controller or protocol server at substations.