DISTRIBUTED BUS PROTECTION APPLICATION IN A PLATFORM FOR PROCESS BUS DEPLOYMENT IN THE SMARTSUSBSTATION

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SUMMARY

Bus protection is typically a station-wide protection function, as it uses the majority of the high voltage (HV) electrical signals available in a substation. All current measurements that define the bus zone of protection are needed. Voltages may be included in bus protection relays, as the number of voltages is relatively low, so little additional investment is not needed to integrate them into the protection system.

This special circumstance, where all HV electrical signals are connected to a single device, allows defining a bus protection scheme as the basic structure for the implementation of a complete Protection, Control and Monitoring System in a HV Substation.

Bus protection is not presently defined as a complete Protection, Control and Monitoring System due to the challenges of data collection. All HV electrical signals, equipment status signals, and equipment control signals, must be physically wired to the bus protection system, and must be further wired to other devices for other zones of protection. Distributed bus protection was developed to partially address this challenge of data collection. Bay units are installed in individual line bays to simplify the field wiring necessary for data collection by collecting the HV electrical signals, equipment status signals, and equipment control signals locally. However, the bay units are still dedicated to a single zone of protection, that of bus protection and the bay units are wired in conjunction with other devices.

This paper presents a new Distributed Bus Protection System that represents a step forward in the concept of a Smart Substation solution. This Distributed Bus Protection System has been conceived

not only as a protection system, but as a platform that incorporates the data collection from the HV equipment in an IEC 61850 process bus scheme. This new bus protection system is still a distributed bus protection solution. As opposed to dedicated bay units, this system uses IEC 61850 process interface units (that combine both merging units and contact I/O) for data collection.

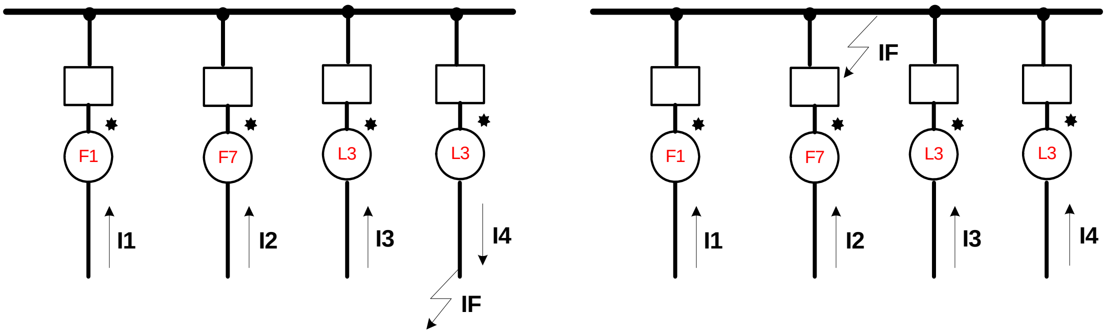
The main advantage then, is that as the bus protection is deployed, it is also deploying the platform to do data collection for other protection, control, and monitoring functions needed in the substation, such as line, transformer, and feeder. By installing the data collection pieces, this provides for the simplification of engineering tasks, and substantial savings in wiring, number of components, cabinets, installation, and commissioning. In this way the new bus protection system is the gateway to process bus, as opposed to an add-on to a process bus system. The paper analyzes and describes the new Bus Protection System as a new conceptual design for a Smart Substation, highlighting the advantages in a vision that comprises not only a single element, but the entire installation.

Keywords: Distributed Bus Protection, Process Bus, Process Interface Unit (PIU), IEC 61850

BUSBAR PROTECTION OPERATING PRINCIPLE

Khirchoff's current law states that the sum of the currents entering a given node must be equal to the currents leaving that node. It applies to ac current for instantaneous values. Thus, the sum of the currents in all feeders of a busbar plus any bus fault current must be zero at any instant in time. The sum of the feeder currents alone therefore equals the bus fault current.

Consider the two situations demonstrated for the simple bus shown in **Error! Reference source not found.**.



$$I_F = I4 = I1 + I2 + I3$$
$$\sum i = 0$$

a) External Fault or Load Flow

$$I_F = I1 + I2 + I3 + I4$$
$$\sum i \neq 0$$

b) Internal Fault

Figure 1: Bus Protection Operating Principle

In case of an external fault, the current leaving the bus is equal to the sum of all of the currents entering the bus, and the total summation is zero. The same would be true when considering load flow. On the other hand, in case of an internal fault, the sum of all of the currents entering the bus is equal to the total fault current (summation of feeder currents is not zero). An ideal differential relaying system takes advantage of the fact that the sum of the feeder currents will be zero for external faults or load flow, whereas the sum will be equal to the total fault current for internal faults. Unfortunately, there are problems introduced wherein the ideal cannot always be obtained, and steps must be taken to insure that the differential relaying system works properly, even under non-ideal conditions.

BUS PROTECTION SYSTEMS

Bus protection systems must be suitable for application on any of the busbar arrangements as described. Beyond the standard protection requirements of reliability (both dependability and security for all fault events) and high speed (to limit the impact of a bus fault on the power system), bus protection systems need to be selective. This requires that a bus protection system only trip the feeder breakers that are actually connected to a faulted bus. For a single busbar system or a breaker-and-a-half busbar system, this requirement is easily met, as all breakers can only connect to one bus. However, for more complex arrangements, such as the double busbar system, this requirement for selectivity is more difficult to meet. This sets the following requirements for bus protection systems:

- Providing independent protection zones with independent protection settings for each bus segment.
- Monitoring which bus segment each feeder or source to the bus is connected to.
- Tripping only the breakers connected to a faulted bus segment.
- Dynamically change each bus protection zone based on which feeders are connected.

The first requirement is straightforward to meet for numerical bus protection systems. The second and third requirements are essentially wiring and I/O point count requirements. The status of each circuit breaker and each isolator switch (that determines which bus segment the feeder is connected to) must be brought to the bus protection system. Trip contacts for each circuit breaker must be supplied by the bus protection system. A typical feeder connected to the double busbar system of **Error! Reference source not found.** is going to require at least 6 status inputs (2 for the circuit breaker, 2 each for the isolator switches) and 1 contact output. Many more I/O points may be required based on actual arrangements and individual utility practices.

The fourth requirement is for a dynamic bus replica, that tracks which feeder is connected to which bus protection zone, through the status of isolators and circuit breakers, and issues trip commands to only the circuit breakers connected to a faulted bus.

PROCESS BUS AS PART OF THE SMART SUBSTATION

One possible definition of a “Smart Substation” is a substation that supports the ability to acquire the data necessary to support intelligent applications, and the ability to rapidly deploy intelligent applications as they are developed. A Smart Substation then supports more robust data acquisition, improved communications between access levels inside the substation, and more robust application platforms. Some goals and proposed solutions for the Smart Substation can be described as follows:

1. Reduce the use of copper wiring and the project execution time to a minimum by moving field labour to the factory.
2. Reduce the time of data collection to SCADA from the current typical time of 1 second to 1 power cycle, providing an effective real time system.
3. Implement one communication protocol for access levels.
4. Facilitate the data access for an easy asset management implementation.

“Process bus” is nothing more than the ability to communicate currents, voltages, equipment status, and equipment control commands between primary system equipment (the “process level”) and application devices at the bay or station level. It is clear that process bus is a key piece of the Smart Substation. A process interface unit (PIU), installed at primary equipment at the switchyard, publishes sampled values of currents and voltages along with equipment status, and subscribes to equipment control commands via IEC 61850 message formats. This clearly replaces much field wiring, and makes data from the primary equipment available for all applications.

More formally, the design of new substations shall not only have the objective of reducing the initial investments and application suitability of devices but also minimising the cost of long term maintenance and future refurbishments. The amount of corrective maintenance actions on the secondary copper wiring between the primary apparatus and protection and control IEDs as well on all copper connections at IEDs I/O boards can be significantly reduced. Therefore the concept of process bus permits the lifecycle view of design of electrical substations. Standardisation of interfaces between primary equipment and secondary systems, reduction of the number of copper cables and the use of pre-connected cables permits the refurbishment to be done with less effort.

Furthermore, process bus supports the development of a protection, control and monitoring system (PC&M) approached from the utility enterprise perspective that recognises and addresses needs, such as cost reduction and speed of deployment, while remaining at the same time reliable and secure. The process bus system originates from the following enterprise objectives:

- Achieving cost savings
- Reducing project duration and outage windows
- Shifting cost from labour to pre-fabricated material
- Targeting copper wiring as main area for cost optimisation
- Limiting skill set requirements
- Supporting optimum work execution
- Improving system performance and safety
- Using open standard communications

NEW DISTRIBUTED BUS PROTECTION USING PROCESS BUS

The goal of this new system is to start to meet the needs of the Smart Substation. The new system uses a central relaying unit for all protection and control functions, uses PIUs to acquire all signals from and provide control of primary equipment, and uses IEC 61850 communications between the central relaying unit and the PIU. The central relaying unit, in addition, collects all related and necessary data in one device. So this new Distributed Bus Protection System addresses the Smart Substation goals of reducing field wiring, implementing one communications protocol for all access levels, and starts on facilitating easy data access. In addition, this system can be a future platform for further applications for station-wide data.

Solving the Cost of Field Wiring

As previously described, bus protection for large bus architectures is costly due to the time to design, install and commission all of the associated field wiring. Every source in a bus protection zone requires extensive field wiring for the relay to acquire the current measurements and equipment status, and to issue control commands. Every signal used by bus protection requires a pair of copper wires. Every one of these wires between the primary equipment and the relay, and the terminations of these wires, must be designed, installed and commissioned for the specific project. Every one of these wires will be wired in series or parallel to protective relays associated with the zones of protection for the source, so this effort will be duplicated. This process is exceedingly labor-intensive, with most of the labor requirements being on-site manual labor. The end result is a very intensive and error-prone process that adds significant time and cost to every project and makes long term maintenance costly, and changes difficult to implement. This effort is very much the same if the project is installing a new bus protection system, or simply adding an additional source to an existing system.

The new Distributed Bus Protection System changes the focus of bus protection to that of application by replacing most of the field wiring with distributed I/O and fiber optic cables. The protection system consists of a distributed process interface (data acquisition and tripping) architecture using PIUs as bay units, with centralized processing performed by a single IED.

- All copper field wiring is between primary equipment in the switchyard and PIUs, which ideally should be located at the primary equipment in the switchyard. Fiber optic cables connect PIUs to the central bus protection unit.

- For all applications, the installation is then identical: the physical interface consists of PIUs connected to a fiber optic cable. A single IED is mounted in a relay cabinet, with the process cards in the unit patched to the fiber optic cables coming from the PIUs. The size of the IED, and the fact that there only fiber optic connections to the IED (with no field wiring) simplifies the relay panel, Therefore the relay panel design for all busbar arrangements and bus protection schemes is identical: one central relaying unit mounted in a relay panel, along with fiber optic patch panels.

As previously described, the new Distributed Bus Protection system uses PIUs as bay units, that both samples currents and voltages, and provides contact I/O for equipment status and control. Once a PIU is installed in a Bus Protection system, the PIU can interface with any other device that supports sampled value messages as per the IEC 61850 standard implemented with the correct profile. Rather than duplicate field wiring from the bus source for a feeder zone of protection, simply patch any compliant family to the fiber optic cable from the PIU to add acquire the same signals.

Protection

The central relaying unit of new Distributed Bus Protection system provides robust and reliable protection for all bus protection applications. Highlights of the protection functions related to bus protection include:

- Multi-zone differential protection with both restrained (dual-slope percent or biased) and unrestrained (unbiased or instantaneous) functions incorporated. Differential protection is fast (typical response time: 1 power system cycle) and secure. Security is achieved by using a fast and reliable CT saturation detection algorithm and a phase comparison operating principle. Security is further enhanced by support for redundant process interface units (Bricks). Supports both three-phase tripping and individual phase tripping.
- Dynamic bus replica functionality and multi-zone protection (up to 6 zones) is supported
- Check-zone functionality configured by programming one of the differential zones to enclose the entire bus.
- Additional bus protection functions including end fault protection, breaker fail and overcurrent protection for each bus source, with CT trouble monitoring for each bus zone

All protection and control functions are implemented in the central relaying unit, including breaker failure. The PIU is intended to be a device located at primary equipment in the switchyard, and as such, is only a simple I/O device, and has no sophisticated processing. Sophisticated processing and application functions are best utilized in the central relaying unit.

Quickly Expand the Protection System through Process Bus

The Bus Protection System is intended to operate as a standalone, distributed bus protection system. The bay units for this system are PIUs, part of an IEC 61850 process bus solution. Once the PIUs for the Bus Protection are installed, process bus data is available for use for any other zone of protection. The PIUs, then, are a distributed I/O interface for all protection functions and zones, not just the Bus Protection

With the Bus Protection in place, installing line protection or feeder protection is a simple process: mount the relays in a panel, and patch to the fiber optic cable from the appropriate PIUs. The only requirement is the relays must implement the appropriate IEC 61850 profile to interface successfully with the PIUs.

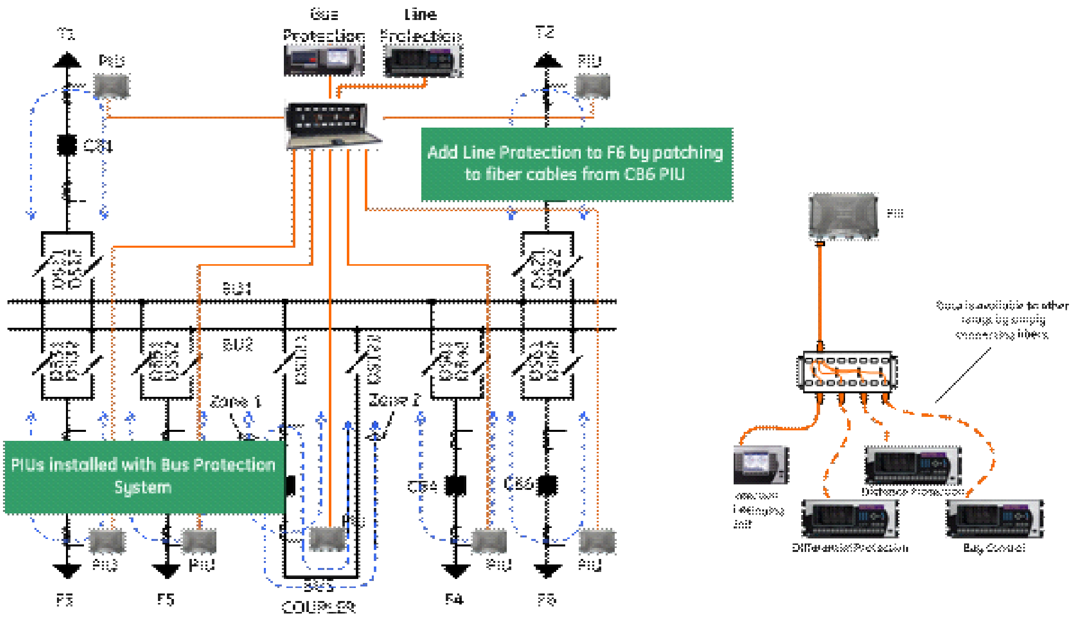


Figure 2: Easy Protection Expansion

Cyber Security and Process Bus

Process bus systems can introduce challenges related to cyber security, especially in North America. NERC Critical Infrastructure Protection rules will define merging units or PIUs as critical cyber assets, and subject to implementing appropriate cyber security protection. This new Distributed Bus Protection System is designed specifically to address the cyber security problem. The communications architecture is a point-to-point architecture, with no remote access to the communications between the Protection central unit and the PIUs. The messaging between the relay and the PIUs is completely, physically sealed from the outside world, so there are no special concerns with regards to cyber security.

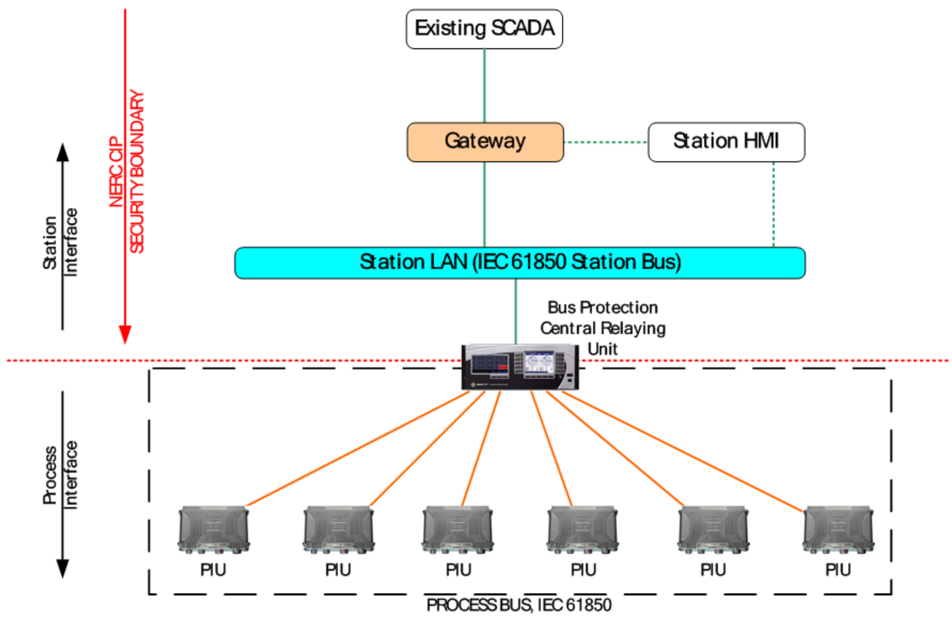


Figure 3: Natural Cyber-security Barrier

THE DISTRIBUTED BUS PROTECTION SYSTEM AS PART OF THE SMARTSUBSTATION

The new Distributed Bus Protection System described in this paper starts to meet the goals of the Smart Substation. The use of process bus and process interface units (PIUs) as bay units reduces the use of copper wiring and project execution time to a minimum. Communications between the central relaying unit and PIUs uses the common communications protocol of IEC 61850. The system also facilitates the acquisition of data from across the substation for presentation to other devices, station control, and traditional SCADA services. The new system supports the rapid development of other station-wide functions, and has started the implementation of a station-wide fault recorder. And finally, installing this system is a low-risk and cost-effective way to start the installation of process bus protection systems. For the same cost as a traditional distributed bus protection system, easy expansion of other protection systems is nothing more than an add-on function.

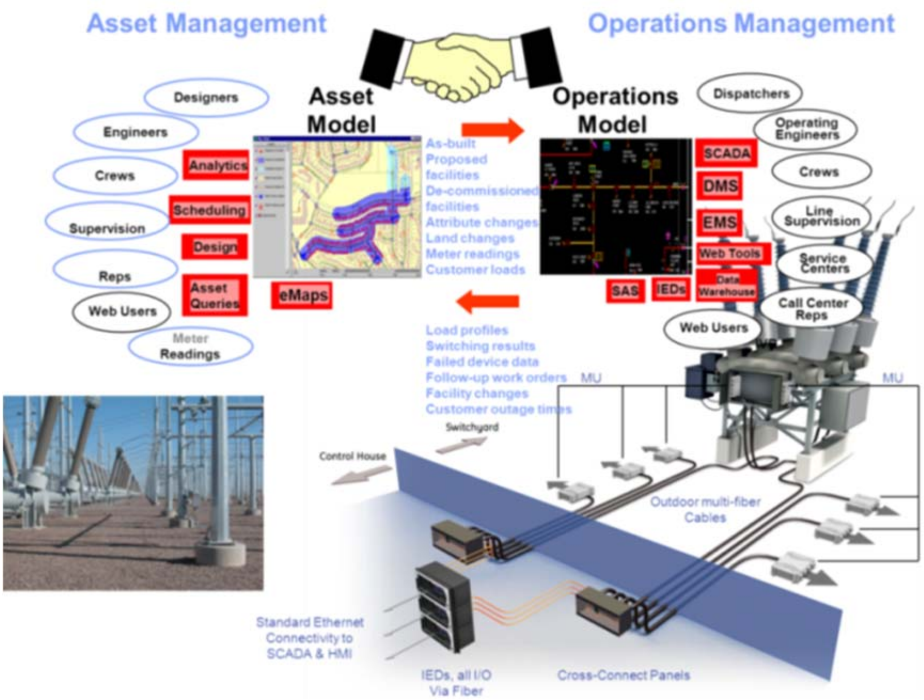


Figure 4: Vision of the Smart Substation

References

1. IEEE Publication 76 CH 1130-4 PWR, “Transient Response of Current Transformers”.
2. GE publication GET-6455, “Application of PVD Relays Using Different Ratio Current Transformers”.
3. “IEEE C37.97-1979 (1990) Guide for Protective Relay Applications to Power System Buses”.
4. C. Russell Mason, “The Art and Science of Protective Relaying”.
5. J. Lewis Blackburn. “Protective Relaying, Principles and Applications”.
6. UR GE Instruction Manual. GEK-113200, “B90 Bus Differential relay”.
7. J.G. Andrichak, Jorge Cardenas, October 1995 “Bus Differential Protection”, Spokane Washington. GE Protection & Control.
8. Jorge Cardenas, John Garrity “High Impedance Differential Protection in the MIB relay”. GE Publication GET- 8495.
9. J. Cárdenas, A. López De Viñaspre, R. Argandoña, C. De Arriba, H. Farooqui, 2012 “The next generation of Smart Substations. Challenges and Possibilities”,. CIGRE Paris.