

HYBRID PROTECTION AND CONTROL SYSTEM FOR THE PETROLEUM & CHEMICAL INDUSTRY

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Bruno de Oliveira e Sousa
ABB Oy
Vaasa
Finland

Ganesh Kulathu
ABB India Limited
Vadodara
India

Jani Valtari
ABB Oy
Tampere
Finland

Janne Starck
ABB Oy
Vaasa
Finland

Abstract - This paper describes a hybrid protection and control (HPC) secondary substation system for Petroleum and Chemical industry applications. The developed HPC system is based on the partial or entire shift of the bay level functions from the bay level to the substation level via a highly-available and fast Ethernet network based on the IEC 61850 standard. The HPC architecture integrates centralized protection and control units, performing backup and high-complexity functions, to the existing substation secondary system, in which performs the basic protection and control functions at process level, via a redundant Ethernet network. In combination, this results in a functionality-redundant system. This approach is developed to improve system reliability, flexibility and availability and to enable centralized-based protection and control functionality. The approach can be well implemented in both greenfield and brownfield projects. In order to demonstrate this concept, this paper describes: (i) the hybrid protection and control concept and its benefits; (ii) the main technologies; and (iii) the benefits to the Petroleum and Chemical industry. The main results show that the HPC system aggregates benefits from both centralized and decentralized architectures with moderate changes in the secondary system. In addition, the hybrid approach offers benefits from dividing protection and control functions into the station and bay levels, according to their criticality and complexity, and includes state-of-the-art substation communication features.

Index Terms — centralized protection and control, IEC 61850, intelligent merging unit, hybrid architecture, redundancy.

I. INTRODUCTION

In these challenging times for oil and gas exploration, extraction, refining and petroleum production and ever-growing demands on carbon footprint reduction combined with a steady decrease in experienced personnel, the challenges faced by Petroleum and Chemical (P&C) industry are multidimensional. These changes call for a serious reconsideration of the currently deployed technologies across different process operational areas in the production chain. This may require some changes in the approaches to be in tune with the immediate future. It is paramount to ensure that these new approaches integrally comply with the expectations of the P&C industry, such as high system availability and reliability.

Substation protection and control philosophy [1], [2] is currently implemented through dedicated numerical relays for every feeder in medium voltage substations. This is

irrespective of the criticality of the process load that the feeder supplies power to. The back-up protection is available only in the incoming feeder that has to cover for any failure of an outgoing feeder relay unit. When back-up protection operates to clear a downstream fault, the entire substation loses power supply. Therefore, the degree of discrimination of feeder protection is quite low mainly due to lack of functional and/or physical redundancies at bay level. The relays at the bay level are connected to the process level via hardwiring and to the substation level via optical fiber or galvanic Ethernet. Consequently, an alternative to this philosophy is the hybrid protection and control (HPC) system.

The HPC system is a secondary substation architecture that is based on a flexible distribution or replication of feeder protection and control functions between bay and substation levels via fast highly-available IEC 61850-compliant Ethernet network. The required levels of functional or physical redundancy is determined according to the relative criticality of the feeders in the substation. This implies also on the possibility of the total concentration of bay level functions at the substation level, performed by the centralized protection and control (CPC) unit [3], [4]. The HPC system integrates the contemporary, *i.e.*, decentralized, substation secondary system and CPC units connected to a redundant IEC 61850 network. In addition to perform bay level functions for all feeders, the CPC unit supports advanced substation-wide functions and applications. In the scenarios in which all functions are concentrated in the CPC unit, the process level inputs and outputs are handled by process input-output (PIO) units. Combined, these principles result in a functionally and physically redundant protection and control system, which is exceptional to medium voltage systems.

Upcoming greenfield projects or small to medium scale brownfield installations, going for system expansion, in the lower hierarchy of the production chain could be the early candidates for deployment of an HPC system. The P&C industry has steadily embraced devices, configuration tools and communication protocols conforming to the IEC 61850 substation communication standard, since its inception in 2004 [5]. Advantages offered for multi-vendor secondary equipment interoperability based on the IEC 61850 MMS (manufacturing message specification) and GOOSE (generic object oriented substation event) communication profiles have greatly influenced this industry. Furthermore, the usage of the IEC 61850 SAV (sampled analog value) communication profile could provide new benefits and optimization to this industry.

This paper is divided into four sections. After Section I, the introduction, Section II describes the hybrid protection and control system and its features; Section III shows the current practices in the P&C industry; and Section IV contains the conclusion.

II. HYBRID PROTECTION AND CONTROL SECONDARY SUBSTATION SYSTEM

The idea of a centralized architecture for substation secondary systems is not a new concept [3]. Its implementation, nevertheless, has just recently brought attention to the industry with pilot projects [6] and the possibility of new functions concentrated in a single unit and based on the IEC 61850 standard.

This section describes the HPC system and highlights the benefits and features from the decentralized systems. Additionally, it details the main functions that benefit from a centralized protection philosophy.

A. Principles

The centralized architecture in the secondary system refers to an architecture, where the protection and control functions performed in the relays at the bay level are reallocated to a CPC unit [3]. In this architecture, there are no protection components, *i.e.*, relays, installed to the bay level, instead the process level include intelligent merging units (IMU) and PIO equipment for exchanging the information with the CPC unit. The HPC, however, is a combination between centralized and decentralized architectures. This combination relies on that fact that protection and control functions can be performed either at the bay level, in the relays, or at the substation level, in the CPC unit in parallel or coordinated manner.

In the HPC systems, the bay-level functions are partially moved to the substation level. These functions are grouped, according to criticality: the most critical functions are maintained at the bay level and duplicated to the substation level. This ensures system availability. In case of failure at the station level, the bay level relays can still perform protection and control functions. In case of failure at a bay or at the process level, the functionality is covered by the CPC unit and other bay protection units or IMUs. Functions that demand a higher computational performance and centralized information from the other bays are located at the CPC unit. This architecture propitiates a redundant functionality system.

Fig. 1 schematizes a simplified HPC architecture. In this scheme, the secondary system runs according to IEC 61850-8-1 and IEC 61850-9-2 and suggests a redundant communication network. Two possible solutions emerge from the HPC architecture. They are:

- Combination of bay protection and control relays and a single CPC unit;
- Combination of IMUs and redundant units.

It also includes other system components, such as time synchronization server station gateway, control center system and a possibility of connectivity with the service cloud. The decentralized system deployed in substations today can be migrated to an HPC system with the addition of CPC units. System extension decisions involving the inclusion of new feeders or bays can be based on the relative hierarchy between feeders. High-priority feeders can consist of a bay protection relay while

low-priority feeders can execute functionality using IMU and PIO units.

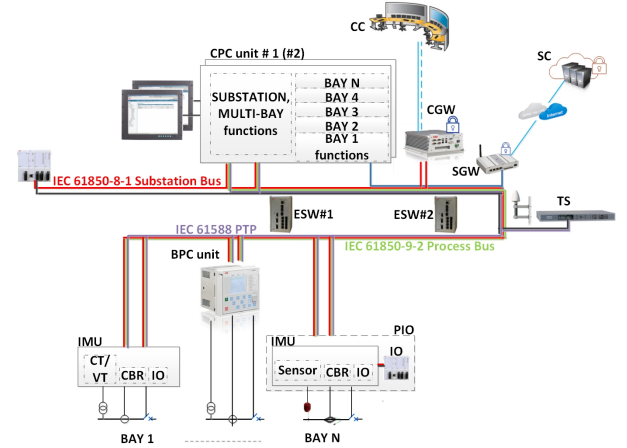


Fig. 1 Hybrid protection and control architecture.

The IMU generates current and/or voltage samples via the IEC 61850-9-2 traffic all feeders in the substation. The CPC unit, after processing all samples, performs the protection, control, monitoring and measurement functionality for all bays in the substation. It can execute from basic overcurrent protection up to the most complex functions for all bays within a substation. Certain functions are multi-feeder functions, *i.e.*, involving single, multiple or all bays in the substation.

Through the IEC 61850-8-1 communication network, the CPC unit can detect fault conditions and initiate trip action using GOOSE messaging to trip the circuit breaker from the faulty bay. Moreover, measurements, alarms and report status are also sent upstream to the substation gateway or HMI using this communication network.

B. Technology Involved

The HPC concept includes recently developed technologies that provide advancement in communication through protocols, time synchronization and measurement (sensors) [4]. These advancements have enabled protection and control applications in the CPC unit at the same effectiveness and performance rate of a bay level protection relay.

1) IEC 61850 Standard

Certainly, the aspect that has contributed the most to the development of centralized architectures is the IEC 61850 standard. Its increasing acceptance has favored the utilization of fast and standardized Ethernet-based communication networks [7]. Firstly, the station bus (IEC 61850-8-1 bus) allows the replacement of copper wiring between relays on a horizontal level, *i.e.*, relay-to-relay communication. Secondly, the process bus (IEC 61850-9-2 bus) enables the digitized measurement information from instrument transformers available in a standardized way to other devices.

These aspects have enabled the concept of location transparency. This concept is based on the shift of protection and control functions to whichever part of the system, as long as sufficient communication performance can be deterministically guaranteed. This implies on the division of the functions between different relays or shifting all functions to a single device, as, for instance, at

the substation level. This is the core principle of the hybrid protection and control architecture.

2) Intelligent Merging Unit

The intelligent merging unit is, by definition, a piece of equipment that acquires signal from electronic low power instrument transformers (sensor system unit) or conventional instrument transformers and transmits digitalized high frequency samples to the subscribing upper level unit. In addition, it can also send and receive binary information using IEC 61850 GOOSE.

According to the principles of location transparency, the PIO and the measurement interfaces must be segregated from the application logic. In the IEC 61850 standard, this occurs with the concept of intelligent merging unit. The IMU combines the standard functionality of a merging unit, working in accordance with the IEC 61850-9-2, with basic protection, such as circuit breaker failure, and supervision functions. The IEC 61850 9-2 LE (Light Edition) and IEC 61869-9 define a sampling rate of 4 kHz (in 50 Hz networks) and 4.8 kHz (in 60 Hz networks) for raw measurement values to be sent to subscribers (CPC unit or relays, in some cases).

The IMU contains all functions needed for digitizing both measurements and other input or output signals. It can also receive trip, open or close signals from an external unit, e.g., CPC unit, and extend the same to operate the circuit breaker. In the context of the centralized systems, the IMU can perform protection and control functionality in case of loss of the communication network at the substation level, and it embodies the combination of a relay and of a merging unit.

3) IEC 61588 Ed 2 or IEEE 1588 Precision Time Protocol

The IMUs, CPC units and relays in a HPC architecture are all connected to the process bus and therefore must be able to publish off or subscribe to the IEC 61850 9-2 LE samples. These devices require high-accuracy and high-resolution time synchronization and their system clocks must be synchronized according to IEEE 1588 V2 Precision Time Protocol (PTP) with power profile. This ensures high accuracy time synchronization of 1 μ s and a time stamp resolution up to 4 μ s.

4) PRP & HSR Protocols

The IEC 61850 standard and the location transparency concept increase the importance of communication within a substation. When Ethernet-based communication is employed for mission-critical protection functionality, the reliability of the communication must be reinforced with redundant systems. The IEC 61850 standard defines two methods for achieving redundancy: the parallel redundant protocol (PRP); and the high-availability seamless ring (HSR) [8]. The first can be described as a double-star topology (Fig. 2), while the latter is characterized as a ring-based topology (Fig. 3).

Either PRP or HSR must be embraced and installed in the Ethernet-network topology in order to convey and high level of availability. Both HSR and PRP based Ethernet network arrangement ensure and facilitate requirements of the process bus and high-precision time synchronization. Either PRP or HSR must be adopted to ensure a highly available and reliable HPC system.

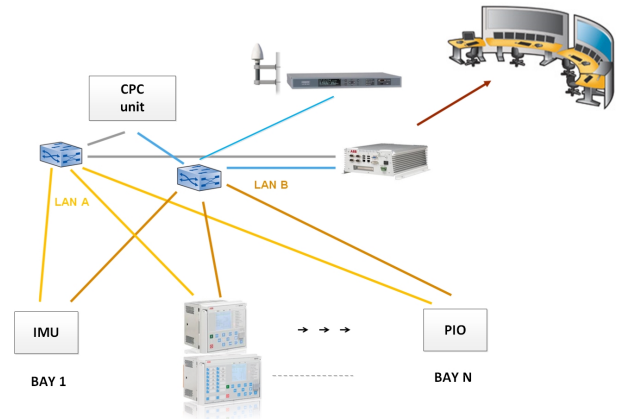


Fig. 2 Ethernet-based communication network using the parallel redundant protocol (PRP).

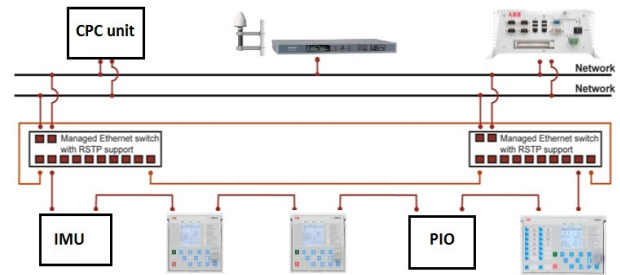


Fig. 3 Ethernet-based communication network using the high-availability seamless redundancy (HSR) protocol.

C. Benefits of HPC Systems

The centralized architecture has emerged as a realistic solution and a number of benefits can be listed. The capital cost of this system can be reduced, when all calculation intensive operations can be performed in a single unit, and the bay level devices can be simplified and cost-optimized. In addition, this system improves the processes associated to the deployment, commissioning, maintenance and update of the secondary system. This can be attributed to the fact that these processes are focused on a single device, the CPC unit, not on a large number of components spread throughout the substation. As a consequence, the cost of these processes can be drastically reduced.

In order to fulfill the N-1 criterion, redundancy in the HPC system can achieve a similar level of reliability at reduced costs than the decentralized duplicated systems at a considerably smaller number of components and decreased wiring. The reliability of both primary and secondary systems is improved by employing a CPC unit in comparison to the typical decentralized architectures.

The main benefits and functions attributed to the HPC system are:

- Improvement of substation protection and control functions and applications over time with increased system availability;
- Possibility to locate protection and control functionality across the process, bay and substation levels, thus bringing more flexibility, as required for the substation, thus bringing better value proposition;

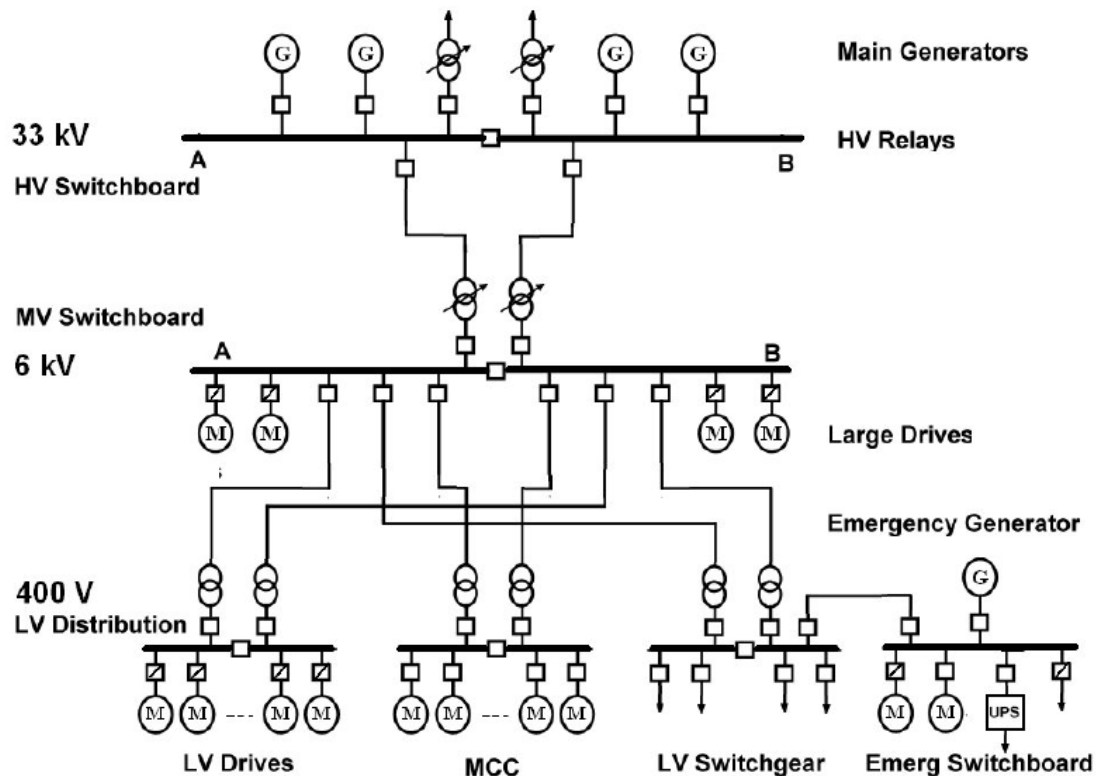


Fig. 4 Example of a typical distribution system in an oil and gas plant and its typical bays [9].

- Flexibility for different protection philosophies for each feeder, depending on requirements (e.g., criticality, availability and others);
- Utilization of substation automation technologies that also safeguard investment;
- Decrease of complexity during system extension, for instance, during the inclusion of new feeders into the substation in comparison to substation based on dedicated bay level infrastructure. When a merging unit with fixed configuration is installed at the process level, the additional bay functionality can be easily performed at the substation level in the CPC unit. This decreases wiring, engineering and maintenance efforts and costs;
- The HPC system promotes further interoperability between the CPC units and the components at the bay and process levels, e.g., bay protection relays, IMUs and PIOs, from different vendors. This is facilitated by the IEC 61850-based communication network;
- Functional and physical redundancy for the secondary system to operate during failure scenarios at process, bay and station level equipment;
- Advanced functions from the improvement of the higher calculation performance in the CPC unit enhance the protection and control efficiency through a more selective and accurate protection logic;
- New protection and control functions developed for high-end applications are easier and faster to update in the CPC unit. For instance, high-impedance earth fault function can be reliably implemented by collecting data from all the bays in the substation [9];
- Elimination of the use of copper wiring, thus being replaced for optical fibers [10].

The present instantaneous overcurrent protection does not greatly benefit from system centralization, whatsoever. It requires measurements only from one location and the basic logic of the algorithm is not expected to be frequently updated. Conversely, the possibility for more sensitive protection such as high-impedance earth fault protection clearly benefits from protection and control centralization. Moreover, other functions such as interlocking and busbar differential protection benefit from centralization due to the need to receive data from multiple points in the system.

III. CURRENT PRACTICES IN THE P&C INDUSTRY

Regardless of the operation of a refinery, an offshore platform, pipeline or even a floating LNG plant, some of the core processes involved in the Petroleum & Chemical industry are strongly dependent on reliable and uninterruptable electrical power supply. The unavailability of power supply can drastically reduce plant production capabilities that leads to enormous financial impact. In addition to that, during extreme conditions, such as blackouts or storms, the safety of working staff and property can be jeopardized [11].

Hence, it is not difficult to understand why it is a top priority to keep core production processes up and running under any circumstances. One essential pre-requisite for the uninterrupted operation of these production processes is the reliable supply of electricity.

Depending on location of the production site and also on the availability of the connection to the power supply, the production plants are usually equipped with interconnections to the public grid and/or own power generation plants. In some cases exclusively own operated power plants are providing the necessary electrical energy. Electricity is further distributed to the process plant at medium voltage (MV) and low voltage

(LV) levels with MV and LV switchgears installed at different sites within the plant location.

The present industry practice is to use multifunction microprocessor-based relays and objective of the protective relaying system is to provide personnel protection and to protect electrical equipment from overloads and faults on the power system. The applicable reference standards for multifunction microprocessor-based relays are IEC 60255 and IEEE C37.90.

It is a common practice to utilize a primary and backup approach for a relay scheme. With multifunction relays, each necessary protective functions, the primary and backup functions, are concentrated into the same device. There is an element of risk combining all the functions into one device. For critical, non-spared applications, redundant relaying approaches should be considered.

Some of the Petroleum & Chemical industry customers specify that for overcurrent applications, each multifunction relay shall protect no more than one circuit breaker. Furthermore, relays that protect and control more than one circuit breaker are not permitted.

Relaying schemes using multifunction relays must be simple and only those functions that provide adequate and desired protections should be enabled. The following items take precedence above others when specifying protection and control requirements MV and LV switchgears:

- Redundancy;
- Back-up;
- Self-diagnostic.

For communication to the SCADA system and also process control system, open protocols such as Modbus, DNP3, OPC, IEC 61850 are preferred.

Typical MV & LV feeder types are:

- Cable feeder;
- Overhead lines;
- Transformer (<500 kVA, <1500 kVA);
- Induction motor (LV: <150 kW; MV: <1500 kW);
- Synchronous motor;
- Generator;
- Auto-transfer;
- Tie lines;
- Capacitor banks;
- Bus section.

Moreover, islanding and load shedding functions are often required in which are either implemented at process control level or also at power automation level.

The current economic environment of this sector, in particular due to low oil prices, are facing demands for strong prioritization in investments in electrical assets upgrade. Installed base may be several decades old, not anymore supported by the original manufacturer and with questionable reliability due to the inexistence of spare parts and overall obsolescence. Safety aspects of older switchgear and other equipment are often not up to date with the current standards [12].

Consequently, companies in the field are constantly focusing on asset optimization through operating and maintenance cost reduction, while demanding increased reliability and utilization performance. In this context, the HPC system emerges as a possible solution.

The hybrid approach supports reliability of the electricity supply and allows the coupling of the CPC units into the secondary system. The CPC units can process

information using discrete and consolidated information, such as disturbance records assimilated from the various bay and IMU units. This information can be used for performing analytic functions such as condition monitoring within the substation or remotely. The basic protection and control functions, nevertheless, still remain in the bay relay.

IV. CONCLUSION

This paper detailed the concept of hybrid protection and control architecture for secondary systems in substations. It also introduced the hybrid approach in which consists of a combination of both the decentralized and the centralized systems, thus including functions and features intrinsic from both.

This solution ensures high levels of secondary system availability and reliability realized by virtue of multiple levels of redundancy possibilities at functional, physical units and communication network. The HPC infrastructure also opens up possibilities for remote system configuration management, upgrades and analytics.

In the context of the Petroleum and Chemical industry, the hybrid architecture emerges as a possible solution, given its high availability, flexibility from the communication possibilities and integration in the case of an existing secondary system (brownfield projects). It is essential to highlight that for the HPC system, a number of alternatives for the architecture and allocation of protection and control functions are available. The correct sizing and allocation of components depend on several factors, including the size of the substation, number of bays involved, type of redundancy and, most importantly, the project specifications.

V. ACKNOWLEDGEMENT

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VIII. VITA

Bruno de Oliveira e Sousa graduated from Aalto University, Finland, in 2012 and 2015 with a M.Sc. and a D.Sc. degree, respectively, in Power Systems and High Voltage Engineering. He is currently working in the Product Management team at ABB Medium Voltage Products and has authored about 15 papers in journals and international conferences. Bruno is currently a member of the IEEE. His interests include reliability and protection & control of power systems.

bruno.sousa@fi.abb.com

Ganesh Kulathu graduated from the University of Kolhapur, India in 1993 with a BE (Electrical) degree. He also has a MS degree in Software Systems from Birla Institute of Technology and Science, Pilani – India. He has been with ABB since 1996 in project execution, management roles involving R&D projects, people and products. He also has about 12 patent filings and has 6 granted patents.

ganesh.kulathu@in.abb.com

Janne Starck has Master of Science (telecommunication) degree from University of Oulu 2000, Finland. He has been working for 20 years at ABB, being the last 8 years as product manager of distribution automation solutions. Janne is member of IEC 61850 standardization work in TC57, WG10 and also has been member of several CIGRE B5 working groups.

janne.starck@fi.abb.com

Jani Valtari graduated from the Tampere University of Technology in 2005 with MSc degree, and in 2013 with PhD degree. He has been working for ABB Oy since 2004, and is currently acting as an R&D Program Manager.

jani.valtari@fi.abb.com