Integrated Substation Protection and Control

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Abstract

Traditionally, electrical power substations have used static (electronic) and electromechanical devices for power system protection, supervisory control and metering. Each device independently acquires and processes the power system data from corresponding instrumentation transformers, circuit breakers, disconnects, tap changers, etc. This approach has two limitations. First is the cost associated with each device acquiring power system signals independently that includes lots of copper wire cost and labor cost for these wiring. Secondly, each device has only the local information from corresponding connections.

Modern microprocessor based processing technology and fibre optic based communication technology has provided an opportunity to acquire and process electrical power system information in very effective ways. This way microprocessor based technology has opened up the new era of integrated substation protection and control. The advantages and challenges of integrated substation are addressed in this report. Further, the case study on Hydro-one experiences with integrated substation functions is also described. Advancement in current practices for substation protection and control integration is explained with help of recent US patent filed by SEL. Finally, the features of IEC 61850 based substation function integration are illustrated and it has been shown that these features enhance the integration in substation protection and control.
Table of Contents

Abstract ........................................................................................................................................... 1
Table of Contents ............................................................................................................................ 2
List of Figures ................................................................................................................................. 2
1. Introduction .................................................................................................................................. 3
   1.1 Literature Review .................................................................................................................. 3
   1.2 Report Organization ............................................................................................................. 3
2. Impact of Integration on Substation Protection and Control ......................................................... 4
   2.1 Advantages of Integrated Substation Protection and Control .............................................. 4
   2.2 Challenges for Integrating Protection and Control Functions in Substation ..................... 5
   2.3 Reliability of Integrated Protection and Control of Substation ......................................... 5
   3.1 Case Study: Integrated Protection and Control System (IPACS) of Hydro-One ............... 6
   3.2 US Patent on Integrated Substation Protection and Control by SEL ................................. 6
   3.3 Future of IEC 61850 based Integrated Substation Protection and Control ...................... 8
      3.3.1 Functions of IEC 61850 based power substation ......................................................... 9
      3.3.2 Features of IEC 61850 to enhance integration of protection and control ................... 9
4. Summary ...................................................................................................................................... 10
References ...................................................................................................................................... 10

List of Figures

Figure 2 IEC 61850 based substation communication network ...................................................... 8
1. Introduction
Current protection and control practice in power substations is to provide the hard wire copper connections from the various power equipment devices (in the switchyard) to the individual protective relays in the control house. Each protection/control function requires a separate wire and a separate physical connection to the appropriate relay. This arrangement has certain disadvantages such as material cost of plenty of long copper wires, labour cost of complex wiring, maintenance and testing expenses of this mesh wiring, etc. Because of the complexity and expense of the system, it is very difficult to provide redundancy in substation connection. Failure at any one point in the substation can have significant consequences on the power system, in the absence of a redundant/backup system. Hence, it would be desirable to have a simpler arrangement which makes less use of hardwire connections while providing fast, convenient, redundant protection which would increase reliability of the protection and control system at a substation [1].

After developments in the area of digital technologies, functions that were previously implemented by electromechanical or electronic equipment can now be implemented by software in digital microprocessors. This opens up completely new possibilities in terms of function implementation leading to the concepts of functional coordination and integration. Using microprocessor based relay, it is possible to accommodate several protection and control functions in a single relay. Therefore, it is interesting to evaluate the substation system with integrated protection and control functions.

1.1 Literature Review
Microprocessor based relaying has open up the new era of substation automation i.e. Integrated substation protection and control. The benefits of integrated substation relaying and control are described in [1]. Design criteria and merits-demerits of substation protection and control integration are discussed in [2, 3]. In reference [4], the impact of substation function integration on reliability of substation system is evaluated in detail. The substation function integration experience of Hydro-one (formerly Ontario hydro) is described in [5]. Reference [6] discusses the US patent on integrated protection and control system for a power system substation. Finally, the communication based substation integration system is standardized in [7].

1.2 Report Organization
Chapter 2 discusses the advantages and issues with integration in substation protection and control. Chapter 3 describes case study on Hydro-one experience on substation protection and control integration. Further, it also elaborates US patent on integrated substation protection and control. The effect IEC 61850 based substation communication is highlighted in the same chapter. Finally, chapter 4 summarizes the project report.
2. Impact of Integration on Substation Protection and Control

The employment of microprocessor technology to substation has led to new era of integrated substation protection and control. The major architectural changes, which microprocessor technology brings in substation control systems, are listed as follows:

1. Primary plant analogue information can be converted to digital format and multiplexed into fibre optical based links which is connected to several IEDs.
2. Digital sampled values are processed in microprocessor, and decisions are taken according to protection and control algorithms at bay level. Several protection and control algorithm can be implemented in single relay (or IED).
3. All protection and control function of IEDs can exchange the information over a common communication link.

In short, potentially all information can easily be made available to any substation protection and control function, if the complete substation system has the same digital language. As a consequence information exchange between functions became comparatively easier through high speed serial digital communication link. Protection and control functions can therefore, share information and be coordinated in ways not possible in the past. This results in improved protection and control capabilities and is the driving force behind integrated substation protection and control systems.

At microprocessor based bay level, the functionality is differentiated by software (or protection algorithms), rather than hardware. The hardware is based on general purpose processing platforms, which tend to be very similar from protection to protection. Furthermore, the processing power of these platforms allows the implementation of several protection and control functions in a single microcomputer, i.e. several protection and control algorithms running on the same processor or on the same microcomputer containing several processors [2].

2.1 Advantages of Integrated Substation Protection and Control

There are several advantages offered by integrated substation protection and control are discussed as follows [1-5]:

1) Cost reduction is one of the benefits expected from the move towards the digital technology and it is the main driving force behind integration of substation protection and control functions. Early comparisons between the cost of digital, with or without functional integration, and conventional substation systems did not indicate a clear cost advantage of systems based on digital technology due to lack of cost effective VLSI technology. Nowadays, there is an indisputable trend for easier access to low cost digital and microprocessor-based technology. This technology is not specific of power systems applications and therefore benefits from the reduced costs associated with mass production of general purpose microprocessors.

2) Due to substation functions integration, the reduction of the panel sizes and cubicle space required for the equipment, which can translate into savings in civil engineering costs.

3) The existence of a process level communication system allows the multiuse of inputs, i.e. primary plant data is obtained via a single data acquisition module and made available, in digital format, to all functions requiring it. This would eliminate extensive point-to-point copper wire and more importantly wiring labour costs.
In an integrated protection and control system, potentially all information can be made available to all functions - a substation-wide information system (communication bus at station level) - offering novel opportunities for improving overall system performance.

Modem multifunctional feeder protection relays that, in addition to their main protection function, implement a variety of control functions, such as synchronising, auto-reclosure and fault recording are an example of functional integration. The addition of control functions to the protection relay does not normally require additional hardware or inputs from primary plant, since the protection and the control functions use common information.

The availability of comprehensive information concerning operating conditions allows the implementation of enhanced system-wide operation-support tools and increases operator awareness. The operator is then in a position to make better use of the system, by operating it closer to its limits.

The self-testing capability of digital equipment provides the possibility of performing condition-based maintenance.

### 2.2 Challenges for Integrating Protection and Control Functions in Substation

1. Reliability of substation protection and control due to integration of functions from different vendors
2. Digital hardware fast obsolescence: high speed latest technology keeps coming in to the market.
3. Software upgradation may require at the time of substation system expansion and to cover new devices features of different vendor
4. Newly enhanced function interference with existing integrated functions from different vendor

### 2.3 Reliability of Integrated Protection and Control of Substation

Perhaps the most important concern raised by functional integration, particularly at transmission levels, is one of reliability. In conventional systems, where functions are implemented by segregated devices, functional independence is inherently guaranteed. In integrated systems, failure of a single device is more likely to cause loss of several functions. The utility must therefore decide which functions should retain their independence and must not be integrated.

The impact of functional integration on the reliability of protection and control systems has been quantified in reference [4]. The results of the analysis show that judicious integration of protection and control functions leads to reliability gains, afforded by hardware rationalization. The independence of protection is the most common concern amongst utilities. The danger of a single failure may lead to the unwanted tripping of several circuit breakers. In this context, the implementation of serial communication links must be carefully designed. Some reports argue that high levels of integration may be acceptable if self-testing facilities are effective. The integration of protection is therefore not detrimental to the reliability indices of the system. Furthermore, it achieves considerable hardware reduction. The robustness of the conclusions presented in [4], and proved by performing analysis, which measures the sensitivity of the system’s reliability to variations in the availability of the hardware modules. Further, with integrated simple architecture, it is possible to provide redundant system for certain critical functions.

This chapter describes the current integration practices in substation using case study of Hydro-one utility and US patent. Further, it also discusses the future scope of substation integration using standardized communication protocol for substation, IEC 61850.

3.1 Case Study: Integrated Protection and Control System (IPACS) of Hydro-One

The Integrated Protection and Control System (IPACS) was first practical integrated substation system of Hydro-one (formerly Ontario Hydro). This system integrates the acquisition and processing of power system potentials, currents and equipment status. The ability of the IPACS system to successfully perform all of its functions is contingent on providing each function with power system information in real time. IPACS is divided in three different levels, 1) Measurement and protection level; 2) Control and substation monitoring; 3) Data analysis and archiving. Data is available at the highest rate in the first (Measurement and protection) level, lower in second level (Control and substation monitoring) and lowest in the third level (Data analysis and archiving).

First level is measurement and protection function. The current and voltage values to first level are obtained from instrument transformers through fibre optic link. As the protection functions need to be fastest, the data rate of this link should be high enough. The control and substation monitoring functions are implemented in the second level of the architecture. Status and analog values are passed to the control and substation monitoring general purpose microprocessor. The control functions include: opening and closing breakers, automatic and manual tap changer control, enabling and disabling reclosure, and acknowledging alarms. A modem, connected to a leased communication facility, provides communications to the supervisory master in the control centre. Substation monitoring includes: trip and sustained alarm logging, sequence of events recording, and digital fault recording. The data analysis and archiving functions are implemented in the third level. Power system data is stored in a data based and is updated each time there is a power system event occurs [5].

3.2 US Patent on Integrated Substation Protection and Control by SEL

Schweitzer Engineering Laboratories (SEL) has patented “Integrated protection and control system for a power system substation” in 2006. As mentioned before, conventional substation has point-to-point hard wire copper connections between the protective relays and related devices within the control house. The protective relays/devices oversee all of the status/power system condition information concerning the various bus lines, transfer lines, transformers and circuit breakers at the substation and provide alarms and circuit breaker trip control signals when such power system equipment is indicated to be outside of specified operating limits. Alarm signals are also generated by the power system equipment, including alarms from the circuit breakers and the transformers if the condition/operation of the equipment is outside selected limits. This could include, for example, a low pressure alarm from a circuit breaker or a particular physical aspect of a transformer. Other alarms are also possible, even substation yard intrusion alarms. All of this information is provided to the protective relays in the central control house by hardwire connections.
The notations in Fig. 1 are described as follows:
10 – Overall patented substation system; 16 – Fibre optic communication link; 18 – Control house; 21- serial communication link; 26- copper hard wire link;

As shown in Fig. 1, the present invention includes a substation control system, responsive to a plurality of inputs from power system assemblies in the substation, comprising: at least one remote input/output module having a fibre-optic transceiver capability; wire connections, for providing status indications from selected status points in the power system assemblies to input contacts of the input/output module. At least one logic processor connected to a fibre-optic line from the input-output module and responsive to signals thereon for communication thereof to protective relay devices; a fibre-optic communication line connecting the remote input/output module and the logic processor. And at least one protective relay responsive to signals from the logic processor to perform protection functions and to produce corresponding control [6].

The I/O module includes a fibre-optic transceiver which converts the input signals into a form for use on a fibre-optic communication line. The fibre-optic line has the advantage of eliminating long hardwire connections, specifically, in the embodiment shown, the hardwire connections from the power system equipment to the I/O modules are short, with the remaining distance to the control house being fibre-optic connections. The use of the I/O module, with a fibre-optic
transceiver, makes this possible. It reduces significantly the possibility of interference, induction and voltage use, to which wire connections are susceptible. Various I/O devices can be used. However, the remote input-output module must convert the signals on multiple input wires to a fibre-optical output. Thus, it simplifies the wiring arrangements in the overall system significantly.

In the present invention, due to the combination of the short hardwire connections, the fibre line/link which covers most of the distance between the I/O modules and the logic processors, and the basic arrangement of I/O modules, logic processors and protective relays, in the hierarchy shown, the overall system is efficient, and makes maximum use of the capability of the individual elements of the system, particularly the protective relays, which can be quite sophisticated. Further, the present system uses dual, i.e. redundant protection/control systems and a comparison capability to ensure the accuracy of the overall system and to quickly identify and correct malfunctions. In some situation, the logic processors can be eliminated, although in most cases, they will be necessary for the proper and efficient overall function of the system of the present invention [6].

3.3 Future of IEC 61850 based Integrated Substation Protection and Control

IEC working group TC 57 has published new standard IEC 61850 for substation automation in 2003 [7]. This standard provides interoperability between two devices of different manufacturer in the same substation. In addition to this, the communication network proposed by this standard would replace lot of complex substation component wiring, and would improve the flexibility for the information sharing. IEC 61850 standard is divided into total 10 parts, which covers not only how to communicate but also what to communicate. The most important part of the substation automation is Intelligent Electronic Devices (IEDs), which are micro-processor, based logical devices for protection, control and monitoring purpose. As shown in Fig. 2, these IEDs are connected to a common communication network, mainly divided in two levels: 1) Station Level, 2) Bay level, and 3) Process Level.

![Figure 2 IEC 61850 based substation communication network.](image-url)
3.3.1 Functions of IEC 61850 based power substation

A complex substation protection, control, monitoring and recording system has a hierarchical structure. The three levels in the functional hierarchy are defined as follows:

1. **Process level:** This includes the communication between protection and control IED to the process (the primary equipment in the substation), such as analog signals, binary status signals or binary control signals.

2. **Bay level:** Bay level is between Process bus and station bus, which includes protection and control IEDs of different bays. All integrated protection and control in IEDs at bay level are connected to the corresponding process bus. Process bus segments of different bay may be connected through communication devices such as Hub or Bridge.

3. **Station level:** At this level the functions are related to the overall operation of equipment in the substation. The functions using the data of more than one bay or of the complete substation are implemented at this level. For example, the triggering of a breaker failure relay by a protection device, or tripping multiple breakers by the breaker failure relay through the trip outputs of a bus differential protection.

3.3.2 Features of IEC 61850 to enhance integration of protection and control

IEC 61850 has standardized not only how to communicate but also what to communicate. This enhances the integration of protection and control as listed follows:

1. Interoperability between different vendors allows complete integration of bay functions within one or two IEDs.

2. Free allocation of substation functions (logical nodes): Any possible number of substation protection and control functions can be integrated at bay level IED.

3. High speed communication links: It is possible to communicate among bay level and/or process level IEDs from multi-vendors with integrated different substation protection and control functions.

4. Common Substation Configuration Language (SCL) throughout the substation: All IEDs configure and communicates with all devices in common language, hence, functions can be integrated among bay and/ or process level IEDs.

5. Self-describing devices: It allows the complex integration of substation functions throughout the substation.

6. Simple architecture: As the plenty of point-to-point copper wires are reduced to just communication links, it is possible to integrate many critical functions in an IED and also have redundant IED connected to corresponding communication bus.
4. Summary

The integration of protection and control functions in a substation is possible with the help of microprocessor based relay. Integrated substation protection and control provides significant reduction in wiring and labour costs, reduced panel size, self-testing capability, etc. Using case study of Hydro-one, the integrated substation function is discussed. Further, from the recent US patent on integrated protection and control of power substation is illustrated in detail. However, there are certain issues related to reliability and digital (hardware, software) technology with the current substation integration practices. Finally, IEC 61850 based substation function integration is introduced to address some of the current integration challenges. The discussed IEC 61850 features definitely improve the integration of protection and control functions in power substation and would change the future architecture of power substation.

References