

Protection — Evolution, Technologies and Trends

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Abstract

Industrial growth with increased automation has made electricity as the key resource for the modern society. Electric power in today's context has assumed importance as necessity of life next to food, shelter and clothes. This also implies that all elements of entire chain of power generation, transmission and distribution needs to offer fail safe performance at all instance of time, and in case of any unforeseen faults, are required not only to provide effective protection to power system elements and isolate the fault but also ensure continuity of electric supply for rest of network, by ensuring very minimal region/loads over faulted section remains without power. Power system protection hence remains one of the most complex discipline in electrical engineering. Protective relays are the decision-making devices in the protection scheme. These relays have undergone, through more than a century, important changes in their architecture, functionalities and technologies. In this paper, after giving insight on the evolution of protective relays from onset of electrical energy to current deployment, emerging trends are also touched upon. Specific emphasis on very recent deployment of Centralized Protection and Control solution is then described. Finally, future trends are also highlighted at the end.

Keywords: Centralized Protection and Control, Electromechanical, Numerical, Relay, Solid-State, IEC61850

1. Introduction

Having uninterrupted 24 x 7 x 365 good quality reliable power supply has become basic need of modern society. CTs, VTs, Circuit breaker as Apparatus and Switchgears, along-with protective relays forms the backbone of power system. However, to deliver uninterrupted supply-protective relays plays the critical role. The IEEE defines protective relays as: “relays whose function is to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action”. Relays detect and locate faults by measuring electrical quantities in the power system which are different during normal and intolerable conditions. The most important role of protective relays is to first protect individuals, and second to protect equipment. In the second case, their task is to minimize the damage and expense caused by insulation breakdowns which (above overloads) are called ‘faults’. These faults could occur as a result from insulation deterioration or unforeseen events, for example, lighting strikes or trips due to contact with trees and foliage. Relays are not required to operate during normal operation but

must immediately activate to handle intolerable system conditions. This immediate availability criterion is necessary to avoid serious outages and damages to parts of or the entire power network¹. In any case, considering the criticality of power supply availability, the power network needs to be designed in such a way that during such events smallest possible region containing faulted element sees power disruption while other part of network should continue to have uninterrupted power.

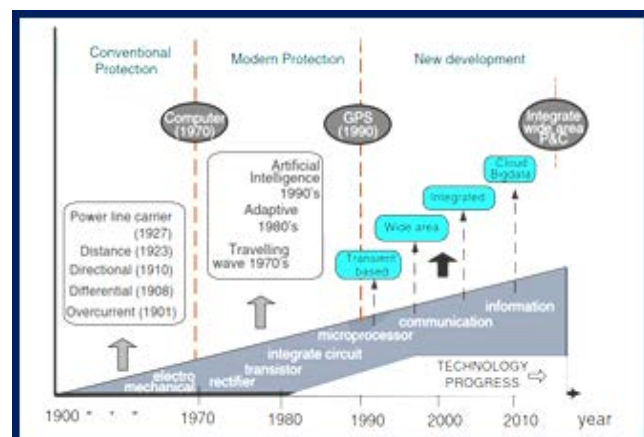


Figure 1. History of power system protection.

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2. Historical Background

Power system protection emerged at the beginning of the last century, with the application of the first electro-mechanical overcurrent relay. Most of the protection principles currently employed in protection relays were developed within the first three decades of the last century, such as overcurrent, directional, distance and differential protection, as shown in Figure 1. The development of modern science and technology, especially electronic, computer, information and communication technology promoted the development of relay technology, this further supported through innovation in materials and components (Rogowski coil, Graphical displays, Optical interface etc.) along with manufacturing process of the hardware structure, help create innovative relay protection device. At the same time, great theoretical progress had been made in the relay protection software, algorithms, etc. As shown in Figure 1, the progress in modern technology stimulates the development in power system protection.

3. Technological Evolution

Let's look retrospectively about different technologies which shaped the evolution of protective relays. Originally, around 1909 electromechanical relays were used to protect power systems. Most relays used either electromagnetic attraction or electromagnetic induction principle for their operation. All relays developed till 1960s were electromechanical relays.

When solid-state/ static technology was introduced, amplitude and phase comparison were implemented using discrete components including vacuum tubes. In early 1960's, advances in the integration of electronic circuits made this technology suitable for use in relays. The major advantage of these relays was that no moving parts were needed for performing their intended functions. The operating speeds of these relays were also more than the speed of their electromechanical counterparts and their reset times were less than the reset times of their electromechanical counterparts. In addition to these benefits, the solid-state relays could be set more precisely and needed less maintenance.

Early 1970's with first microprocessors being available, followed by the advances in the Very Large Scale

Integrated (VLSI) technology and software techniques led to the development of microprocessor-based (also referred as Digital / Numeric) relays, which were first offered as commercial devices in 1979. Early designs used the fundamental approaches that were previously used in the electromechanical and solid-state relays.

Microprocessor-based/Numeric relays in 1980s performed basic functions, took advantage of the hybrid analog and digital techniques, and offered good economical solution. Continuous advances in electronics, combined with extensive research conducted in microprocessor technologies, led to applications in which multiple functions were performed by a microprocessor relay. Multifunction relays were introduced in the market in the late 1980s. These devices reduced the product and installation costs drastically. This trend has continued until now and has converted microprocessor/micro controller/Digital signal processor-based relays to powerful tools in the modern substations².

Table 1. Provides the comparative outlook for these generation of relays³.

Table1: Comparison between the different generations of protective relays			
Relay type feature	Electromechanical	Solid state	Microprocessor / Digital / Numeric
Accuracy & sensitivity	Good	Very good	Excellent
Lifetime	Long	Short	Short
Undesired operating	Almost never	Possible	Possible
Reliability	High	Good	Moderate
Discrimination capability	Low level	Good	Excellent
Condition monitoring	No	No	Yes
Multifunction	No	Limited	Yes
Data communications	No	No	Yes
Remote operation	No	No	Yes
Disturbances immunity	High	Low	Very Low
CT burden	High	Low	Low
Parameters setting	Difficult	Easy	Very easy
Range of settings	Limited	Wide	Very wide
Self-diagnostics	No	No	Yes
Metering	No	No	Yes
Event archiving	No	No	Yes
Size	Bulky	Small	Compact
Visual indication	Flags	LEDs	LCD

4. Technological Advancements

Last two decade saw emergence of IEC61850 based protection devices and increasing deployment of communication protocol based interface layers, changing the topology of conventional substation to digital substation gaining from availability of high performance-multi thread digital core (Microprocessors/ Microcontroller/ DSPs) and thereby reducing hard wired connections by exploiting high speed communication interfaces and thereby offering flexibility in operation, maintenance and control⁴.

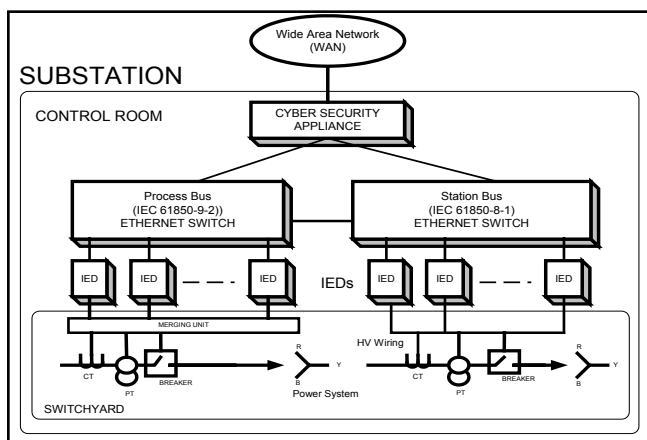


Figure 2. IEC 61850 enabled digital substation.

Digital substations thus are seen to offer following benefits:

- Safety
- Reduced substation footprint
- Interoperability
- Reduces copper cabling
- Ease of configuration
- Maximum reliability and availability
- Real-time performance
- Smart Grid communications capabilities
- Reduces cost of ownership

During last two decade, several new trends also have emerged. These include common hardware platforms, configuring the software to perform different functions, integrating protection with substation control, and substituting cables carrying voltages and currents with fiber optic lines carrying signals in the form of polarized light.

On the software side, artificial intelligence techniques, such as neural networks, and adaptive protection are some of the fields that are being applied in protection practices. Recent work includes feedback systems in which relays monitor the operating state of the power system and automatically reconfigure themselves for providing optimal protection.

However, in recent times one such big shift which has emerged in protection context is deployment of centralized substation protection system solution. The concept basically considers of an overall integrated protection where the protection package would not only oversee individual units of a plant but also a section of the network. This concept even though was in discussion in previous decades, very recently solutions and installations

now are coming up with product solution level maturity coming through advancements in computer hardware/software and communication technologies.

5. Need for Centralized Protection and Control

Recent report of the Intergovernmental Panel on Climate Change (IPCC) emphasizing that, to fight climate change, our energy system needs to be completely reshaped at an unprecedented speed, leading to new renewable and intermittent energy resources getting connected to the energy system and consumption being managed with demand responses, and along with new storage devices getting deployed and used. It is important to note that, all this needs to happen without risking the security of the power supply. It means that the protection and control functionality of our power networks must be enabled to manage continuous changes during the lifetime of devices. This is a tremendous challenge to the protection and control system, which needs to become more flexible and be able to reconfigure faster.

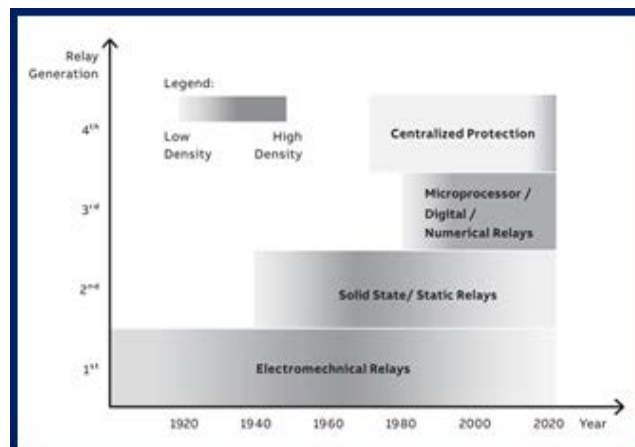


Figure 3. Different eras of protective relays.

The requirement for increased flexibility creates a need to also evaluate substation protection and control architectures with different design principles. In computer science, Separation of concern (SoC) is a design principle which simplifies development and maintenance by splitting the overall functionality into individual sections, which can be reused, as well as developed and updated individually. One of the key benefits is the ability to improve or modify without having to know the details of other sections, and without having to make corresponding

changes to those sections. Conventionally the sections in substation automation architectures have been physically separated to different protection and control relays. However, the availability of Centralized Protection and Control (CPC) units makes software managed sections available too, with the aim of increased flexibility and more reliable and quicker deployment of protection and control systems. Figure 4 depicts SoC design principle with CPC concept.

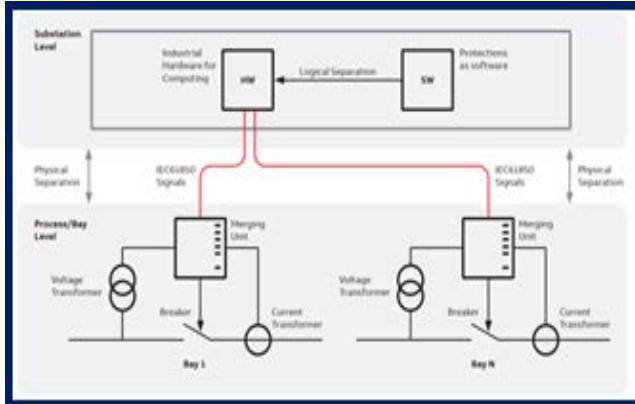


Figure 4. SoC design principle with CPC concept.

6. Enablers for CPC

Electrical substations play a major role in building a reliable power network. Their basic functions have remained unchanged for years. There is a need to monitor, control and protect different elements of a distribution network. The technical solutions on the other side are constantly changing e.g., the technology for data processing and communication. The key technical enablers supporting the emergence of Centralized Protection and Control (CPC) are

6.1 IEC 61850 Station and Process Bus

IEC 61850 standard have made fast and standardized Ethernet-based communication more available. The station bus as defined in IEC 61850-8-1 allows for the elimination of copper wires between Numerical Protection Relay (NPR) units on the horizontal level i.e., relay-to-relay communications. The process bus as defined in IEC 61850-9-2 allows sharing of digitized information from instrument transformers or sensors in a standardized way to other relays and/or CPC units. This has enabled shifting of protection and control functions.

6.2 Merging Unit

The interface of the instrument transformers (both conventional and non-conventional) with a relay and CPC unit is through a device called Merging Unit (MU). Intelligent Merging Unit (IMU) has also been proposed as a general term for relay with MU capabilities. MU is defined in IEC 61850-9-1 as interface unit that accepts Current Transformer (CT)/Voltage Transformer (VT) and Binary Inputs (BI) and produces multiple time synchronized digital outputs to provide data communication via the logical interfaces. between different relays and/or CPC units at the substation level.

6.3 Substation Time Synchronization

With Ethernet-based technology it is possible to achieve software-based time synchronization with an accuracy of 1 ms quite easily, and without any help from HW. This is also what the IEC 61850 standard refers to as the basic time synchronization accuracy class (T1).

6.4 Communication Redundancy

High availability and high reliability of a communication network are two very important parameters for architectures utilizing a CPC system. IEC 61850 standard recognizes this need, and specifically defines in IEC 61850-5 the tolerated delay for application recovery and the required communication recovery times for different applications and services. The tolerated application recovery time ranges from 800 ms for SCADA, to 40 μ sec for sampled values. The required communication recovery time ranges from 400 ms for SCADA, to 0 for sampled values.

7. CPC Deployment Options

Deciding on the conventional protection and control architecture, or CPC architecture for a substation project depends upon many parameters, including but not limited to substation protection philosophy, defined specifications, time critical applications for protection and control, redundancy requirement at the physical, functional or communication level, flexibility to adapt the changes our power distribution grid is facing today, etc.

Traditionally the protection has been distributed in multiple different Numerical Protection Relays (NPR), as shown in 'Decentralized' – Figure 5a but in CPC all

the safety critical intelligence is in one device as shown in centralized- Figure 5b.

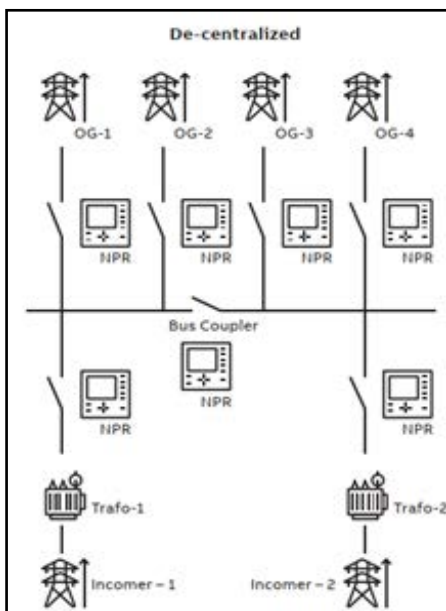


Figure 5. Conventional – Decentralized scheme.

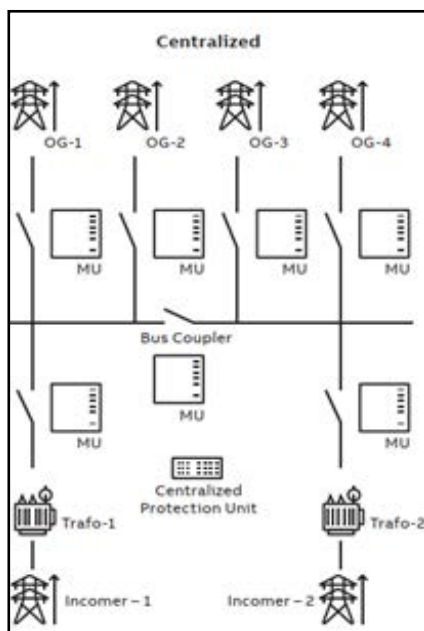


Figure 6. Latest– Centralized scheme.

For risk mitigation, it is extremely important to consider possibilities for redundancy. possibility is to combine both approaches by using bay level backup protection with the CPC unit. This approach is shown in Figure 5c as ‘Hybrid’.

The idea of the combined solution is to use simplified protection at the bay level and all the substation-wide and advanced protection in the central device. The protection system still has the flexibility of central protection and the control concept, as new functionalities and extensions can be updated in a single location. The hybrid solution is also a possibility for existing installations since adding just the central device can introduce new functionalities for the complete substation. Furthermore, since the bay level relays contain protection functionality, the n-1 criteria can be fulfilled without redundant CPC units and without redundant communication.



Figure 7. Hybrid scheme.

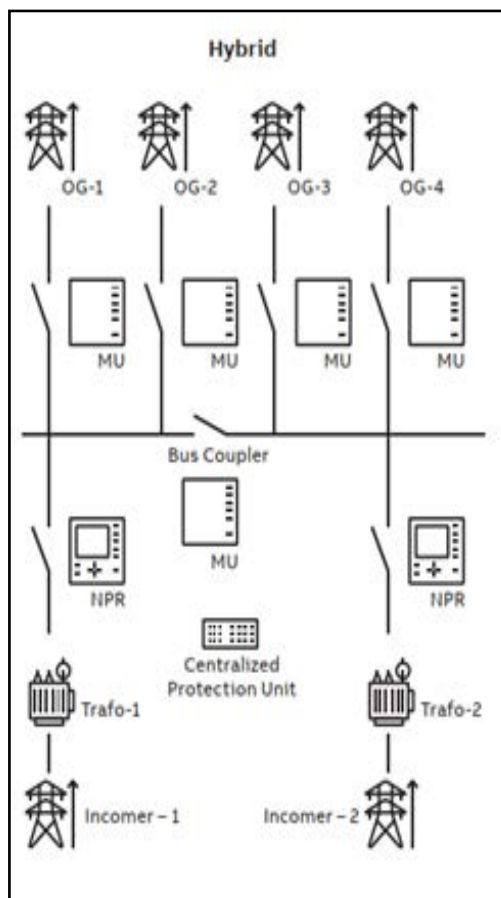


Figure 8. ABB SSC600: Smart substation controller for realizing centralized protection and control.

8. Cyber Security

With increased dependency on communications and network connectivity, cyber threats due to technological misuse and abuse remains a concern. The CPC system's key equipment such as relays, MUs and CPC units are not exceptions when it comes to cyber threats. Increased awareness and cyber security advancements to safeguard electric grids against such cyber-attacks can be implemented by authentication and authorization, auditability and logging as well as product and system hardening. Firewalls, intrusion detection or prevention systems, or VPN technology should help to protect the CPC system's key equipment. Verified malware prevention software can protect central computers against attacks and viruses. Another possibility to protect the central computer is application white listing, which can provide a heightened degree of security for the CPC system configuration.

9. CPC Installation based on Hybrid Architecture

The pilot for the CPC with hybrid architecture was realized during 2017-2018 and was implemented in the substation of Noormarkku – 110kV/20kV substation with double bus-bar and one power transformer in Finland³.

In India, very recently (In Q4 2019) Tata Power DDL (New Delhi) to improve their network, with focus on safety, reliability and flexibility for future needs have chosen to pilot smart substation control and protection device type SSC600.

10. CPC Solutions

SSC600 - smart substation control and protection device, offers extended capabilities by incorporating merging units and Relion protection and control functionality to form a custom protection and control solution⁶. This helps in moving from traditional substation protection control and measurement to smart substation control and protection.

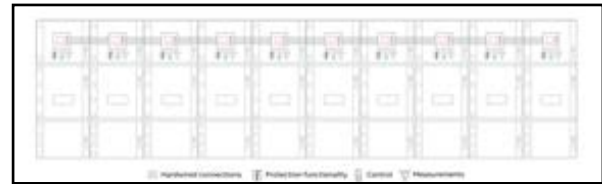


Figure 9. Traditional substation protection, control and measurement.

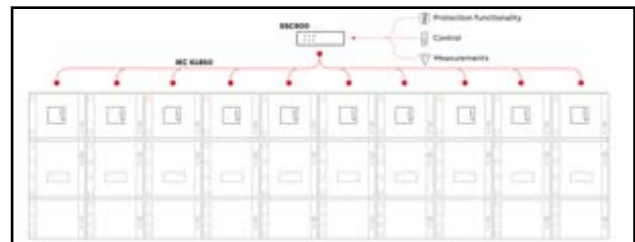


Figure 10. Smart substation control and protection SSC600.

11. Concluding Remarks

Traditionally, protection relays were always seen as CAPEX driven components of the power system. With the SoC design principle for protection and control schemes and technology advancement in data processing, computing and substation communication, the dividing lines between the relay, as we know today, and the CPC system are likely to get blurred, implying that a more software-oriented approach to protection and control solutions will be enforced. This technological shift can bring fundamental change in a way the protection and control relay business model exists today. It is possible that new revenue streams like Software as a Service (SaaS), Infrastructure as a Service (IaaS), Cloud-based services, Big Data and analytics-based services, Digital Twin based simulation services, etc., will be introduced for protection and control of distribution grid and substations.

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