Simplicity in Relay Protection System design; is it still a valid element?

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Abstract— Simplicity is one of the key elements of a good Relay Protection System design together with Reliability, Selectivity and Speed. However, with the evolution of the protection relays, protection schemes have evolved in a way that they can be described to be anything but simple. This paper analyzes the evolution of protection system design and the advantages and disadvantages of the current approach.

Index Terms— Simplicity, Protection System, Bulk Electric System, Relay evolution Reliability, Regulatory Agencies, NERC, Remedial Action Scheme (RAS).

I. INTRODUCTION

SIMPLICITY is of paramount importance when designing and laying out protective relay circuits. These circuits are called upon to operate so infrequently that they should be more reliable than the apparatus or lines they protect. Certain limiting conditions and requirements requested by circuit designers generally cause false tripping and make the circuits less reliable. A simple protective system with all the extra devices left out operates so satisfactorily that the reasons for its good operation are often forgotten. [1]

II. WHAT IS SIMPLICITY

In the 20th century, Albert Einstein asserted that “our experience hitherto justifies us in believing that nature is the realization of the simplest conceivable mathematical ideas” [4].

In the early 21st century, it is typically just equated with the general maxim that simpler theories are “better” than more complex ones, other things being equal. [4]. This is known as “Ockham’s Razor” principle.

Nature does nothing in vain, and more causes are in vain when fewer will suffice. For Nature is simple and does not indulge in the luxury of superfluous causes. [4]

Simplicity in Protection System design is defined by Blackburn as the “minimum protective equipment and associated circuitry to achieve the protection objectives.” [2]

A protective relay system should be kept as simple and straightforward as possible while still accomplishing its intended goals. Each added unit or component, which may offer enhancement of the protection but is not necessarily basic to the protection requirements, should be considered very carefully. [2]

The modern microprocessor relays are multifunction devices. For some reason some protection engineers believe that every single function available should be enabled.

The engineer responsible to design the protection system must do a multitude of choices. The protection system is chosen after the client (particular specifications, preferences, equipment already available), voltage level, the weight of the plant, the location since protective equipment is subject to the rigor of physical changes such as, internal or external transients, temperature, humidity, vibration (earthquakes or others), human activity, flora and fauna, the possibility to have back-up functions, distribution of current faults and system grounding and last but not least, the technical capacity available in house.

Many of the decisions are made based on personal experience of the design engineer.

The choices are also affected by the customs, the authorities and the economic situation. The system is chosen to fulfill the requirements on the plant and to give the lowest possible “Life Cycle Cost”. [3]

III. PROTECTION SYSTEM DEFINITION

According with the document “Glossary of Terms Used in Reliability Standards, Protections System is defined as “Protective relays, associated communication systems, voltage and current sensing devices, station batteries and DC control circuitry”.

Fig. 1
IV. HOW PROTECTIVE RELAYS HAVE EVOLVED AND HOW THIS IMPACT PROTECTION SYSTEM DESIGN?

The evolution of protection devices can be divided in several stages; the first stage was the era of electromechanical relays, which started early in the 1900’s. The next era was static or solid state relays, which were introduced in the 1960s. The era of microprocessor based relays started in the 1980s, where microprocessor performed the logics, but the filtering was analogue. The first fully numerical relay was introduced 1986. The era of integrated control and protection started in mid1990’s.

In the past, using electromechanical technology, a combination of standalone single function protection devices were used to accomplish desired degree of protection. There was a well-defined line between protection, control and communication.

The concept was simple and based on single contingency event. For transmission systems normally you had Primary and Secondary protection. The standard rule was they should be of different protection principle and different manufacturer in order to avoid common mode failure. The following combination were typical:

- Primary Phase comparison relay
- Secondary Pilot distance relay.
- Primary: Distance relay
- Secondary Directional overcurrent + directional earth fault relay

For distribution protection there were normally 4 relays; an overcurrent protection device per phase and one ground relay. This combination of 4 single phase overcurrent devices allowed one relay to be removed from maintenance without jeopardizing the reliability of the protection system. It was simple and only need 2 settings to be defined: TAP and Dial.

The system could also be implemented using only two CT’s in phases A and C and using only 3 relay however without providing the same degree of protection when one of the relays were removed.

Overcurrent relays installed in the main breakers did not have instantaneous elements in order to avoid racing with the instantaneous elements installed at the feeders.

Buses were normally protected by different means like differentially connected overcurrent relays or Partial Differential schemes taking into account the known limitations of each scheme. Bus differential relays were seldom used.

Relays have evolved from being single phase, single function protection only devices to multifunction microprocessor protection, control and communication devices.

For EM relays designs, the scheme functionality was possible to be deduced from the schematic diagrams. This is no longer the case with integrated microprocessor relay designs where the relay has become a black box, performing multiple protection, automation and control functions. [7]

Nowadays, besides the schematic drawings, depending on the application will be also required to take a look on the logic diagrams. This logic diagrams can contain several pages of logic. In order to be properly understood, logic diagrams should be accompanied with the specification explaining how the scheme is expected to behave.

Have you ever tried to find out expected system operation from a Logic Diagram alone? This is like trying to put yourself into someone else’s mind. Good Luck.

We have gained a lot in terms of monitoring, diagnostic and adaptivity but need to pay in return complexity. Standard schemes based on single contingency have evolved to adaptive systems based on specific conditions of the system at a given time.

40 years ago, market was dominated by two players. Protection & control schemes were all contained in a couple of books widely known by any person working on system protection. Protection systems were designed based on them. Now the possibilities are endless.

I have seen Utilities using up to 3 microprocessor devices to protect a single distribution relay. Each relay has hundreds of settings to be defined depending on the application like for example measuring mode and reset mode that were inherently embedded in the relays before.

In average, an electromechanical relay manual was 15 pages long and includes all the necessary information to install, connect, set, test, troubleshoot and repair the device.

Nowadays, depending on the device and the manufacturer, there might be tens of manuals associated with the device like Technical manual, application manual, Operation manual, installation manual, engineering manual, connection diagram, communication manual, etc. each one of them averaging between hundred to thousands of pages each, this without taking into account the application notes issued to clarify applications not clearly explained in the technical manuals.

Modern microprocessor relays provides the user with a flexibility in design to levels that were not even dreamed with electromechanical relays; in the words of Walter Elmore “…Changing technology – from electromechanical to discrete semiconductor, to integrated circuits, to microprocessor techniques – has enhanced the ability to solve old gnawing problems and it is in itself a fascinating study …”. However, it is need to be understood that flexibility comes hand to hand with complexity as Flexibility and Simplicity are mutually
exclusive concepts. The same way you cannot have a system that it 100% dependable and 100% secure, you cannot have a system that is 100% flexible and 100% simple.

NERC has been tracking misoperations for several years and the data indicates that the greatest causes of misoperations are:

- Incorrect settings, logic and design errors
- Relay Failures
- Communication Failures

MP relays are 5 times more likely to cause misoperations that EM relays.[7]

A large utility tracked work procedure errors over the last few years this utility has over a 1000 buses and over 30,000 relays. It was found that among human failures, incorrect settings were the largest cause of relay misoperations.[7]

IV. REGULATORY ENTITIES AND THEIR IMPACT IN PROTECTION SYSTEM DESIGN

The existence of regulatory entities is not a phenomenon present only in US but worldwide. Once different utilities needs to be interconnected to increase power system reliability, there is the need of an entity that defines and regulate the critical path for power transmission also called Bulk Electric System or Transmission Backbone Network.

This regulatory entities are not meant to change the technical and practical aspect that relates to the application of power system protection but they do have an impact on the manner in which the protection process is carried out. [2]

The most widely known of the regulatory entities is the North American Electric Reliability Corporation aka NERC.

NERC vision is a highly reliable and secure North American bulk power system. [5] NERC mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid. [5]

Bulk Electric System (BES) definition includes all Transmission Elements operated at 100 kV or higher and Real Power and Reactive Power resources connected at 100 kV or higher. This does not include facilities used in the local distribution of electric energy. [6]

In summary all Elements and Facilities necessary for the reliable operation and planning of the Interconnected bulk power system will be included as BES elements.

NERC relies in 8 regional entities that covers all USA areas

One example of the impact of the Regulatory entities is the so called Special Protection Systems also known as Remedial Action Schemes.

A Special Protection System was defined by the NERC Glossary Terms as “…an automatic protection system designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability. Such action may include changes in demand, generation (MW and Mvar), or system configuration to maintain system stability, acceptable voltage, or power flows. An SPS does not include (a) under frequency or under voltage load shedding or (b) fault conditions that must be isolated or (c) out-of-step relaying (not designed as an integral part of an SPS). Also called Remedial Action Scheme…” [8]

This definition was later found to “lacks clarity and specificity necessary for consistent identification and classification of protection schemes as SPS or RAS across the eight NERC Regions, leading to inconsistent application of the related NERC Reliability Standards.”[9].

The term Special Protection System was eliminated and the term RAS adopted to eliminate the confusion associated with the two defined terms.

The new definition for RAS is “A scheme designed to detect predetermined System conditions and automatically take corrective actions that may include, but are not limited to, curtailing or tripping generation or other sources, curtailing or tripping load, or reconfiguring a System(s).

RAS accomplish one or more of the following objectives:

- Meet requirements identified in the NERC Reliability Standards;
- Maintain System stability;
- Maintain acceptable System voltages;
- Maintain acceptable power flows;
- Limit the impact of Cascading; or
- Address other Bulk Electric System (BES) reliability concerns.

These schemes are not Protection Systems; however, they may share components with Protection Systems. [9]
V. RELIABILITY STANDARDS AND THEIR IMPACT IN PROTECTION SYSTEM DESIGN

As of June 18, 2007, the Federal Energy Regulatory Commission (FERC) granted NERC the legal authority to enforce Reliability Standards with all U.S. users, owners, and operators of the BPS and made compliance with those standards mandatory and enforceable.

Currently there are 21 reliability standards related to protection and control subject to enforcement in United States that have impact on protective relaying. Additionally there are 11 Cybersecurity Standards. They are not covered as part of this paper.

VI. OTHER ASPECTS THAT HAVE AN IMPACT PROTECTION SYSTEM DESIGN

During the first ¾ of 20th century, the design bases for protection system design did not change. However since then the speed of the changes has increased dramatically.

Substation design changed from hardwired to communication based.

Power System design changed as it moved from unidirectional power flow to Bidirectional power flow.

Personal profile for relay design has changed from protection engineers to code writers.

Life Cycle of the protection devices changed from 60 + years in electromechanical relays to 10 – 20 years in the case of Microprocessor relays which means the several generations of relay will need to coexist.

New constrains like environmental do not allow the construction of new infrastructure at the same speed the load need grows, therefore, there is a need to do more with the existing infrastructure. Disperse generation is one of the consequences and this of course has also impacted the way protection systems are designed.

The replacement of hard generation by renewables.

The evolution of communication and communication protocols like IEC61850 has also driven more and more communication based protection systems.

An example of this is the so called Wide Area Protection or Wide Area Monitoring which is based on PMU’s measurements or Synchrophasors.

PMU’s were the answer to improve situational awareness. Applications based on PMU measurements have been developed since then like Angle Differential since Phase Angle is strongly correlated to active power transfer and system topology. [10]

All of the above have of course impact in the relay protection design.

VII. CONCLUSIONS

Simplicity is still a valid element of a good protection system design; Simplicity is applicable in every aspect of protection system design.

Protection engineer should focus on the application when selecting relay protection settings and protection functions to be enabled.

Flexibility and simplicity are mutually exclusive concepts. The same way you cannot have a system that it 100% dependable and 100% secure, you cannot have a system that is 100% flexible and 100% simple.

Relay evolution has allowed a level of flexibility in terms of monitoring, diagnostic and adaptivity but all this comes with complexity.

In the words of Walter Elmore, “…Protective relaying is a constantly changing and expanding science that challenges even those who are deeply and totally involved with it…” therefore we should expect protection system design will continue changing and it is up to the protection engineers to find the adequate balance of simplicity and complexity.

REFERENCES

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