Multifunctional Protection IEDs – How Much Functionality is Too Much?

Presented to
Western Protective Relaying Conference

16-18 October, 2012

Prepared by

Charles F Henville, Henville Consulting Inc.

Multifunctional Protection IEDs – How Much Functionality is Too Much?

Abstract: This paper will examine the factors that affect the limits of functional integration of protection, automation and control (PAC) systems embedded in a common intelligent electronic device (IED) when applied to electric power systems. We look at factors as they are impacted by past, present, and possible future technology. These factors must be considered in the context of operating and maintaining power systems being stretched with increasing dependence on PAC to minimize investment in primary equipment. In this paper we consider the impact of functional integration on planning, design, installation, operating, and maintaining:

- Protection systems for a single piece of primary equipment
- Protection systems for multiple pieces of primary equipment
- System Integrity Protection Schemes (SIPS)
- Protection, control and monitoring systems.

1. Introduction

"All the eggs in one basket"… a refrain familiar to protection engineers world wide. Few protection engineers would tolerate dependence on a single basket with severe common mode failure results. Might we then consider "All the eggs in two baskets" that would mitigate a common mode failure concern? With ever increasing functional capabilities of intelligent electronic devices, pressure increases to concentrate more and more functions in fewer and fewer devices. On the one hand as functions are integrated, PAC system interconnections are decreased, along with hardware and maintenance costs. On the other hand system complexities and interdependencies increase along with more complete integration.

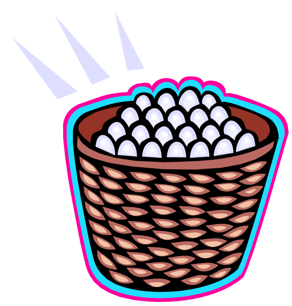

Figure 1 - All eggs in one basket

In this paper the impact of functional integration on various processes involved in planning, designing and operating power systems are reviewed to help the reader understand the limiting factors. This conference paper gives only an overview of the issues associated with functional integration, for more in depth understanding of the general issues, the reader is encouraged to study References 1 and 2. Other information on the various levels of acceptable functional integration of specific utilities in a variety of countries, may be found in Reference 3 and specifically for the UK in Reference 4.

Some ancillary functions naturally fit with computer based protection systems and enhance their performance. These include self monitoring, peer to peer communications, event recording, fault location and analogue disturbance recording. These functions are expected extensions of the digital protection system, and are usually, (though not necessarily exclusively) applied in modern multifunction protection systems. Extended functionality that simply enhances basic performance of protection systems is not considered in this paper, as it is considered that there are few impediments to extending functionality to improve basic performance.

The qualitative nature of the discussion in this paper does not allow for quantitative analysis of the impact of functional integration on PAC system reliability. Reference 5 is an example of quantitative analysis of such impact in a specific example for alternative degrees of integration of feeder protection and bay controls.

The means of achieving functional integration are outside the scope of this paper, though different means might have different levels of acceptability. For instance a greater degree of physical integration might be acceptable if ways of operating and maintaining the different functions independently can be achieved. One example could a single IED including both protection and control functions, but with separate configuration files for the protection function from the configuration files for control functions. The impact of this separation of files is discussed in Section 5.3 of this document.

2. Planning

Power system planning engineers try to meet the system performance requirements at minimum lifetime costs. They consider performance in terms of functional specification, reliability, and flexibility from an overall power system point of view. In addition to meeting immediate requirements, they also have to look forward to possible additional requirements for the foreseeable future.

An example might be consideration of how much functionality can be integrated into a single device in a transmission line protection refurbishment project. Modern transmission line protection systems (see devices 11-1 and 11-2 in Figure 2) may include some, all, or more than the following functions:

a) Multiple zones of phase and ground distance protection (function 21 in Figure 2)
b) Out of step tripping and blocking functions (function 78 in Figure 2)
c) Multiple levels of time and instantaneous directional phase and ground overcurrent protection (functions 50L and 67N in Figure 2)
d) Over and under voltage functions (function 27/59 in Figure 2)
e) Breaker failure protection (function 50BF in Figure 2)
f) Automatic reclosing (function 79 in Figure 2) with, or without synchronizing or synchronism check functions (function 25 in Figure 2)
g) Metering functions
h) Alarm functions eg breaker monitoring such as functions 50/51 in Figure 2 or line overload such as function 50L in Figure 2
i) Functions and logic suitable for SIPS
j) Functions for control of breakers and disconnect switches

Initial cost will be minimized if as many functions as possible are integrated into a single device, but too much integration also has its price. If the single multifunction device is forced or taken out of service, not only the transmission line protection will be removed, but also all the auxiliary functions inside the device will be taken out of service.

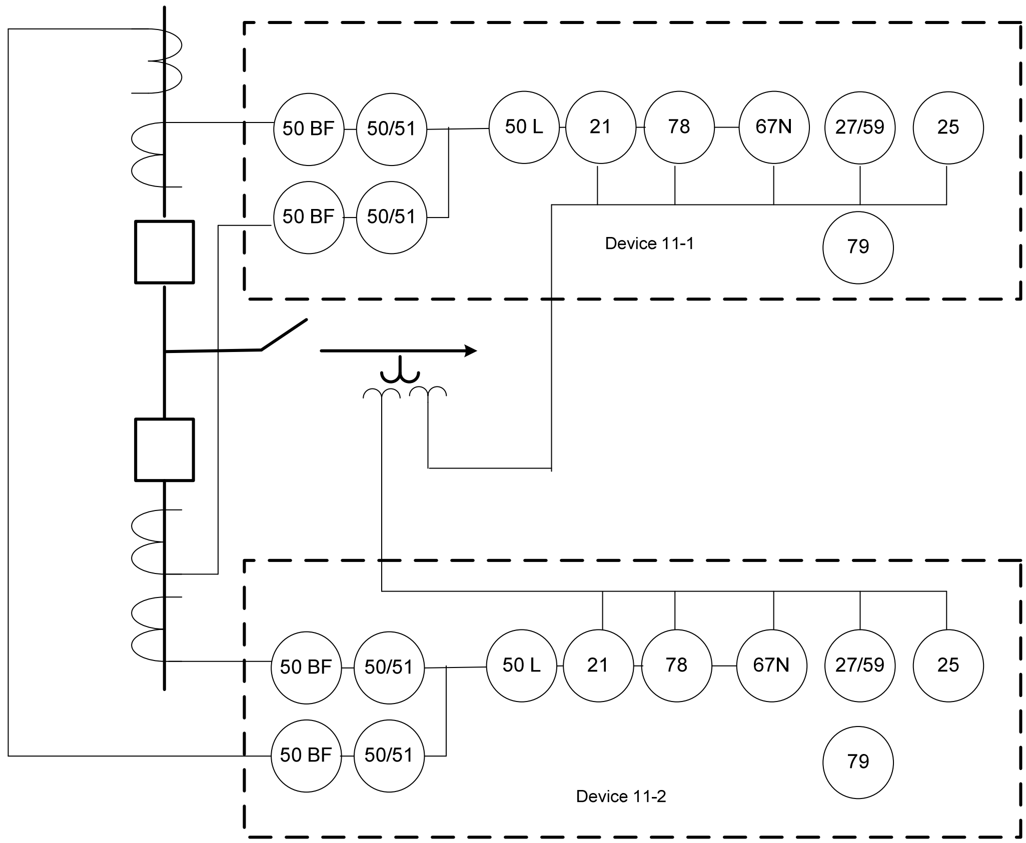

Figure 2 - Example Multifunction Transmission Line Protection Devices

Most transmission line protection systems will be redundant for improved dependability, but some features are not redundant. For instance, some users do not want to apply simultaneously operating redundant automatic reclosing (function 79 in Figure 2). This is because of a concern that one automatic recloser might not be adequately coordinated with the other. If automatic reclosing functionality is enabled in only one of a redundant pair of systems, then loss of the system incorporating the reclosing will unnecessarily make reclosing unavailable. There are techniques for overcoming this problem, but they need communications between the redundant line protection systems, with the associated increase in complexity. The increase in complexity is even greater when single phase tripping and reclosing is applied.

The planning engineer has to decide whether to enable automatic reclosing in both redundant systems or to enable in only one, and accept the added complexity of communications between the two systems. Design and operational and maintenance staff will have input as to the impact of the added complexity issue.

Similar concerns arise in other areas of functionality where taking one multifunction device out of service might not always be optimum for non duplicated functions that it includes.

3. Design

The designer implements the planning intent. This individual makes the major decisions regarding the means of implementing the specified functionality. The designer will specifically identify the specific constraints limiting functional integration and the specific initial cost benefits of increasing integration.

It is at the design stage that space and wiring constraints are identified. If there are not significant savings to be achieved by integration, the savings may not justify the increased complexities that increased functional interdependencies introduce.

On the other hand, if space or wiring constraints increase the value of integration, the designer may propose integrations to significantly reduce overall project costs. For instance if a single multifunctional bay protection device can provide all the functionality of more than one discrete equipment protection system, the designer may propose such implementation to achieve the cost savings. It is at the design stage that specific limitations due to protection and control interdependencies can be identified along with specific impacts on project costs and operation and maintenance requirements.

In some cases, even though the cost savings of functional integration are significant, the added complexity prohibits excessive integration beyond the levels which the stakeholders can accept. For example, relay to relay communications systems now include multiple channels that offer protection grade reliability that provide multiple opportunities for teleprotection applications without the cost of dedicated teleprotection systems. However in the case of transmission line protection systems teleprotection facilities may be limited to facilities required or dependent on the operation of the transmission line itself. Thus when the transmission line is taken out of service, the protection facilities may also be removed without impacting any other power system protection systems. For instance, transmission line relay to relay communications could be used for teleprotection associated with:

- Breaker failure protection for the associated line terminal circuit breakers
- Transformer or reactor protection for transformers directly connected to the line terminal without a fault interrupting circuit breaker.
- SIPS using the line status as an input (with caution) or affecting the line status as an output.

These associated teleprotection functions will not be required when the line is out of service. Therefore disabling the transmission line protection systems (which can be safely done if the line is out of service) with their associated relay to relay communication systems will not adversely affect equipment or system protection functions which will not be required when the line is out of service.

However, if the relay to relay communications were used for other teleprotection applications that were required whether or not the line was in service, then an operational trap arises. That is, the transmission line protection systems could be removed from service (which is normally a safe operation if the line is out of service) and the teleprotection functions would also be unintentionally removed even though they might still be required for other protection functions.

Therefore at least one utility has specified an application limit for relay to relay communications whereby they may not be used for any function that is not directly related to the line status.

4. Installation and Commissioning

Installation and commissioning processes may significantly impact the degree of acceptable functional integration. The impacts depend to a large extent on whether the station equipment is new (greenfield) or operating. Most modern protection projects involve expansion or refurbishment of operating stations. In an operating station, primary equipment outage availability is severely limited. Usually it is difficult or impossible to obtain a simultaneous outage of more than one piece of primary equipment in an operating station. Also, installation and commissioning of new protection and control equipment will normally require outage of the associated primary equipment. Outage requirements during installation are among the most significant limiting factors on the degree of acceptable functional integration.

Functional integration issues are different if new equipment is stand alone or has to co-exist or even partially or fully replace existing PAC equipment in an operating station. For instance, a bus protection device may have to connect to current transformers on several pieces of equipment. All connections have to be made and tested before the bus protection system can be put into operation. If other functions in the same IED are used to protect or control other pieces of equipment, the sequence of outages together with conversion of protection and control functions must be carefully managed.

5. Maintenance

5.1 Taking equipment out of service

Preventative and corrective maintenance often include temporary removal of protection and control equipment from service. Functional integration is a key component that affects how much functionality is removed during maintenance. The greater the number of functions in a single device, the greater the impact of removal of the device to an operating station.

Most primary equipments have redundant or main and backup protection systems that allow one of the protection systems to be disabled while the primary equipment remains in service. Protection redundancy or backup maximizes the availability of the primary equipment while facilitating temporary removal of the secondary equipment (i.e., protection).

For instance in the days of single function electromechanical relays, three phase and one ground time overcurrent relay might have been used to protect a distribution feeder. These four discrete relays backed each other up since at least two relays would respond to any type of fault. For instance one phase and the ground relay could operate for a single line to ground fault (accepting somewhat lower sensitivity of the phase overcurrent device). Also, at least two phase relays would operate for any type of multiphase short circuit. Thus any single overcurrent relay could be taken out of service for maintenance, repair, or adjustment without taking the primary feeder out of service.

With modern multifunction relays, all three phase overcurrent and the ground overcurrent function would normally be integrated into a single device. Two options are available for backup protection.

1. Apply two multifunction devices to each feeder. This option increases the cost of the installation, but avoids common mode failure.

2. Apply a single multifunction device, but rely on backup protection for feeder faults by the bus overcurrent protections. This option is attractive from a cost point of view, but could result in trip of the complete bus and unfaulted feeders in the event of a feeder fault at the same time as its non-redundant protection was unavailable.

Increased complexities associated with functional integration also increase possibilities for human error during maintenance. Integration may help diagnosis of problems (through disturbance records providing coordinated information on the performance of many functions) or hinder diagnosis (through increased complexity and interaction of functions).

5.2 Updating software

Having too many functions in a single device complicates software updates. It may become desirable or necessary to update software because of limitations or problems with a single function. However depending on the confidence of the user in the IED manufacturer, updating the software for one function may require testing of all or many other functions. Thus the cost and difficulty of updating software of a highly integrated IED may reach far beyond the cost and difficulty of updating software of one component of a more functionally distributed system.

This issue of ease of updating software is an important factor in the consideration of the optimum degree of functional integration. It is sometimes not considered in evaluating the overall life cycle cost of PAC systems.

5.3 Settings maintenance and documentation

Protection settings are usually carefully documented and not changed without complete engineering review. This is because the impact of failure to trip or over-tripping on the power system is significant. Many utilities have strict processes which must be adhered to before and after protection settings are changed. These processes may include:

- Specially formatted settings sheets and associated configuration file management
- Engineering review of the need to change settings
- System operators’ review of the need to remove primary or secondary equipment from service during the settings change
- Testing of the relays after the settings are changed
- Recording of changes and formal updating of setting sheets and associated configuration files

On the contrary, the processes used to change settings of control, metering and alarm equipments are significantly more relaxed. This is because the impact of improper setting or unavailability of such equipment is much lower. Such equipment is usually part of a manual operation or delayed automatic control loop, so the power system is more tolerant of improper adjustment of control equipment. For instance thresholds for alarms, or labeling or scaling of metering are often adjusted to suit operational requirements with minimal procedural controls.

The different processes used to govern protection changes and control changes are a major concern for integration of protection and control functions in a single IED. The IED configuration files are often shared and the change processes cannot be easily separated between protection and control functions. This is especially of concern in the case of using common IEC 61850 files for protection and control purposes.

6. Operation

Complexity resulting from integration hinders full understanding of the impact of PAC maintenance on power system operation. Power system operators interact with maintenance staff to determine the impact of maintenance activities on system operation. As the primary system reliability increasingly depends on availability of PAC equipment, large scale functional integration increasingly affects overall reliability. As noted in previous sections, primary assets are difficult to take out of service. PAC equipment associated with some primary equipment may be redundant or backed up sufficiently to allow the IEDs to be temporarily removed from service without significantly affecting power system reliability. However, not all PAC functionality is redundant or backed up. If heavily functionally integrated IEDs are to be removed from service, even temporarily, power system operators must fully understand all functions that will become unavailable before allowing such IED(s) to be removed from service.

Shorthand methods of identifying functionality of PAC equipment for the convenience of users have arisen over many years and have been standardized in at least one standards making organization [6].

With limited functionality of electromechanical protective relays, the shorthand method of identification is quite simple. A time overcurrent relay with a built-in instantaneous element could be identified as “50/51”. As the functionality of computer based relays increased, so did the difficulty of using a shorthand method identifying what they did. The 1996 version of Reference [6] included a single device number (11) for a multifunctional device. However, as functionality increased even further, it was found that a single number was often not sufficient for users. The 2008 version therefore allows for a list box method to describe the key functions of a device number 11. This list box then becomes a group of functions provided by a common device.

7. Conclusion

Different and sometimes conflicting objectives affect the degree of acceptable functional integration. Key factors include:

- Lifetime cost should be considered, not just initial installed cost. Higher levels of integration often reduce initial installed cost, but increase complexity and associated operation and maintenance costs
- Relative availability of primary and secondary equipment must be considered when secondary equipment affects more than one item of primary equipment.
- Good understanding of the impact of the integration on achieving the objectives helps arrive at the optimal solution.
- Once a certain degree of functional implementation is decided upon, clear identification of all functions and interdependencies must be made available to operation and maintenance staff. This issue is of special importance for functions that are not duplicated. Such identification allows them to be fully aware of the impact of outages of the multifunction device.

When all the above issues are recognized and accounted for, the optimum level of integration will usually reveal itself.

8. References

1 CIGRE Study Committee B5, WG B5.13, "Acceptable Functional Integration in HV Substations", Technical Brochure 404 -WG B5.13, summarized in CIGRE Electra February 2010

2 IEEE Power Sytem Relaying Committee Report, "Ancillary Protective and Control Functions Common to Multiple Protective Relays", available on line from: http://www.pes-psrc.org/Reports/Ancillary_PC_Functions_Common_to_Multiple_Protective_Relays_10.1.pdf

3 CIGRE SC B5, Special Report for Preferential Subject No.2 "Acceptable Functional Integration for P&C for Transmission System", Study Committee B5 Colloquium, 2007 October 15-20, Madrid, Spain

4 Adams, R.J., McTaggart, C., Fitch, J., "Functional Integration Protection and Control Practices in the United Kingdom", Presented to Study Committee B5 Colloquium, 2007 October 15-20, Madrid, Spain

5 Ferreira, L.F.C, Crossley, P.A., Allan, R. N., Downes, J., "The Impact of Functional Integration on the Reliability of Substation Protection and Control systems", IEEE Transactions on Power Delivery, Vol. 16, No. 1, January 2001, p.p. 83-88

6 IEEE Standard C37.2 – 2008 "Standard Electrical Power System Device Function Numbers, Acronyms and Contact Designations"