# Flexible IED solution

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*Abstract*-- **This paper explains the customer benefits from using multifunctional IEDs that are flexible to configure, both to the customer's requirements and to the technical demands of the system. It also exemplifies the cost-effectiveness of solutions based on functional integration in modern IEDs, while offering increased availability.**

**In the first example, the significance of flexibility in modern IEDs will be demonstrated. Here, one protection device is used to protect a transmission overhead line from one line end, connected to two bays – in the same substation – with different CT ratios. One of the bays is used as main bay, while the other bay is used for emergency operating conditions. The operating philosophy demanded that both bays not be in operation at the same time. This challenging application was resolved by using modern IEDs with the capability for the necessary functional integration and logic design, fulfilling all of the technical requirements, in a cost-effective way.**

**In the second example, the paper looks at a protection and control solution applied on a combination of a 110/10 kV step-up transformer and a 110 kV overhead line. It will be shown that using this smart-solution, the same number of protection and control functions can be achieved using a fewer number of devices (IEDs) relative to a conventional solution.**

**Both examples are successfully tested and commissioned for the end-customers in Mongolia.**

***Index Terms*— control, cost effective, differential protection, functional integration, IED, line protection, protection, relay, transformer protection**

## I. Introduction

One of the main requirements in the modern power system protection engineering practice, which is applicable to modern engineering practice in general, is to create solutions that can satisfy all functional and safety requirements, while maintaining cost effectiveness at the same time.

Cost effectiveness has always been challenging for power system protection - also known as protection relaying - due to the importance of safety; both safety of persons that could be exposed to power system failures, as well as the safety of equipment.

At the same time there are important functional requirements, such as the availability of the power system, as in the case of incorrect behavior of the protective and automation equipment power system stability would be impacted, eventually causing loss of electricity supply to consumers.

An overview of these requirements can be summed up, so that the practical examples can be valued against them [1, 2, 3]:

- **Dependability** is a measure of certainty that the relay will operate correctly. In other words, it is a degree of certainty that a relay will trip when there is a fault.
- **Security** is a measure of certainty that the relay will not operate incorrectly. In other words, it is a degree of certainty that a relay will not trip when there is no fault.
- **Reliability** is the combination of dependability and security.
- **Redundancy** is the existence of more than one means for performing a given function.
- **Availability** denotes the amount of operational time of the relay within a given period.
- **Sensitivity** is the capability of relay to operate correctly even when the operational value is marginally within the defined conditions.
- **Selectivity** is the capability of the relay to operate only for those conditions for which it was meant to operate.
- **Speed** or **operating time** is the capability of the relay to operate in acceptable margins of the time it was meant to operate.
- **Value** of a relay, or relay protection system, defines that it shall have a reasonable **cost**, relative to the value and importance of the primary object that is protected.

It has been shown, in several works, what the advantages are of numerical relays as opposed to electro-mechanical and static relays. Therefore, this shall not be further discussed in this paper.

Functional requirements, such as sensitivity, selectivity and speed (or operating time) depend on the algorithm and hardware performance of a numerical relay, and the philosophy of applying multifunction or single-function numerical relays doesn´t significantly impact these requirements.

On the other hand, requirements such as dependability, security, availability, and redundancy are substantially dependent on the choice of a multifunction or single-function principle approach, and therefore they will be analyzed on the mentioned practical cases.

But foremost, the idea of this paper is to show benefits of functional integration in modern protective relays.

## II. Functional integration

### A. History

With multi-functionality is meant the collection of several different functionalities in the same physical device. For power system protection relays, this has been a trend ever since numerical relays with microprocessor technology were introduced and it has always been closely tied to the application requirements. It became possible to design a protection relay specialized for a certain application, containing the main protection functions for that particular application, and some additional backup and protection related functions.

Later, as microprocessor technology advanced and processing capacity increased, the capabilities of multi-functional protection relays were extended to user programmable logic, monitoring functions and more advanced event and disturbance recorders.

For example, if we consider a modern line distance protection, a multipurpose line distance protection relay now generally consists of a line distance protection function, backup protection functions such as overcurrent and earth fault protection, monitoring functionality, programmable logic and a disturbance recorder. All of the mentioned functionalities are closely related to the application.

Another example of a multi-functional protective device could be a transformer protection relay, incorporating transformer differential and restricted earthfault protection as main protection functions, as well as voltage and current based backup protection functions, monitoring functionality, programmable logic and a disturbance recorder.

### B. Multi-functionality and functional integration

Functional integration is a collection of different functionalities in a device that is able to cover more than one application area. In other words, functional integration is multi-functionality brought to the next level, where functions in a protective relay, or in a bay control unit (BCU), are applicable beyond a single application area. In addition to this, functional integration is the capability of the device to be applicable on more than one object.

Since one device can cover different application areas and since it can replace several different devices with a single piece of equipment, it is easier to call them IEDs – Intelligent Electronic Devices.

The first example of functional integration – covering more than one application area – would be a protective relay that includes apparatus control capabilities. In this case, the same device is used for protection and for control applications. Such devices, containing mostly simple current and voltage based protection functions, as well as apparatus control for one bay, have been used by distribution utilities for more than 25 years. These are also known as ´feeder protection and control devices´.

Further development of communication technologies and CPU capabilities made it possible to integrate more advanced communication possibilities into the IEDs. This evolution made it possible to avoid using external communication devices for exchanging e.g. binary signals for line distance protection, or analog signals for line differential protection. The devices could now communicate directly, which opened the door for further functional integration. On the other hand, the same evolution has led to the IEC 61850 standard, which combined with the evolution of measurement technologies enables the concept of Digital Substations.

More powerful CPUs in modern IEDs are also capable of handling not only the integration of simple protection functions with apparatus control functions, such as in feeder protection IEDs. They have the capability of combining CPU-demanding functions, such as line and transformer differential protection or line distance protection in the same device, together with apparatus control functions, automatic voltage regulation and tap changer control, various communication interfaces, monitoring functions such as PMU functionality, programmable logic and disturbance recorder functionality.

### C. Multi-object integration

The majority of the utilities today have embraced technology with numerical IEDs.

On the distribution level, especially on lower voltages, the trend is for control and protection functions to be integrated in the same device as mentioned. However it is not common to see IEDs applied on multiple objects.

On the transmission level, the majority of the power system utilities have the philosophy to separate bay control unit IEDs from protection IEDs. And the protection functions are usually distributed in two protection IEDs, commonly known as Main 1 and Main 2 or Main and Backup.

This means that despite the fact that – functionality wise – everything can be achieved in one single device, utilities are generally still choosing solutions with three dedicated IEDs: one BCU, and two protection devices. The reason for having two separate protection IEDs and a separate bay control unit IED is to avoid the impact of a single point of failure, improve maintainability and to increase the overall (perceived) reliability and availability of the protection system.

However it has already been proven [3] that a reduced number of IEDs doesn´t lead to a lower availability and reliability of the protection system, as long as a substantial amount of backup devices is engaged. Additionally, BCU functionality can also be made completely redundant when applying devices with functional integration [4], something that is still relatively uncommon today.

As a result, many utilities around the world are changing their philosophies, and are moving towards using solutions with two IEDs, where typically one IED is used as protection Main 1 and as the BCU, while the other IED is used as Main 2.

It is of utmost importance that in any case, the demands on the power system protection explained in the introduction are always satisfied.

### D. *Practical examples*

The philosophy of using modern flexible IEDs – based on the functional integration principle – to achieve the required number of protection and control functions in less devices relative to conventional solutions (as explained in ´C´), is not commonplace. It will be explained that these solutions fulfill and improve upon all basic requirements for power system protection, listed in the introduction.

There are substations that are successfully commissioned as ´totally integrated power and control systems´ [5], meaning that all of the protection and control functionalities are performed on one central computer. The main drawback of such a solution is the impact of a single point of failure. This impact can be diminished by introducing redundancy.

#### 1) *Differential protection of a line connected to two separate bays*

The first example will show how the multi-object capability of a modern numeric flexible IEDs can be applied to protect a 110 kV overhead line (OHL) that is connected to two bays: the main bay, and the emergency bay. In this case, there is only one protected object – the overhead line. The main challenge is the fact that the line can be connected to two different bays with different characteristics.

During normal operating conditions the OHL is connected to the 110 kV bus via the main bay, which has a CT with a ratio of 500/5 A. In the case of failure of the apparatus or during maintenance works in the main bay, the line is supplied from the emergency bay, which has a CT with a ratio of 600/5 A, as shown on the image below.

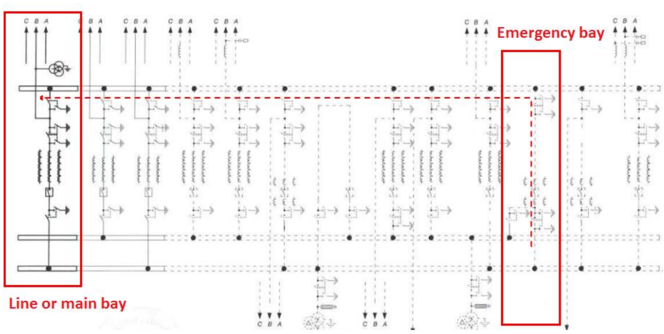


Fig. 1 - SLD of the station where the line can be supplied from the main bay, with the CT ratio 500/5 A, or from the emergency bay, with the CT ratio 600/5 A. Due to different CT ratios for the protected object, this represents a challenge for most protection IEDs

This is not a typical situation, as in most common cases the OHL CT is positioned on the line side with all the apparatus being in between the CT and the busbar. In such cases, if the station has an auxiliary busbar with a bypass bay (called emergency bay in this case), it makes no difference for the line protection, as it always receives current measurements from the same CT.

As explained in [2], redundancy is improved by the usage of a Main 1 / Main 2 solution, thereby increasing the reliability of the system [3]. But increasing the number of IEDs reduces the availability of the system, reducing the reliability again.

In case the IED applied for the situation from Fig. 1 doesn´t have the flexibility to handle more bays at the same time, up to 4 protection devices must be used to solve the application to the functional requirements defined in the introduction, which would add significant cost.

With the multi-object integration as explained in this chapter, two devices (protection Main 1 and Main 2) capable of protecting multiple objects in parallel are used instead of four (two devices when main line bay is used, and two applied for the emergency bay), which significantly reduces the cost, while fulfilling all other functional requirements, and improving availability.

Experience from on-site testing and commission have shown that, as expected, less time is spent on testing IED functionalities and related wiring, because functions and the wiring for all operating modes (main bay / emergency bay) are integrated in the same device. This means that one instance of line differential protection is used, not two, and therefore less time is spent for the functional testing of IED performance. Functional integration leads to less hard-wiring [2] and less point-to-point testing, which significantly reduces the commissioning time.

On the system level, since more functions are integrated in fewer devices, experience has shown much more efficient testing of the IEDs reporting to SCADA.

#### 2) *Protection and apparatus control for a line and a transformer with fewer devices*

The second example shows that the required functionality of line and transformer differential protection, backup protection and apparatus control, can be achieved by using fewer devices compared to conventional solutions, while keeping the required level of reliability of the system by using multi-object integration.

The diameter to be protected consists of one 110/10 kV step-up transformer, connecting a solar power plant to a 110 kV transmission system via a 110 kV overhead line, as shown in Fig. 2.

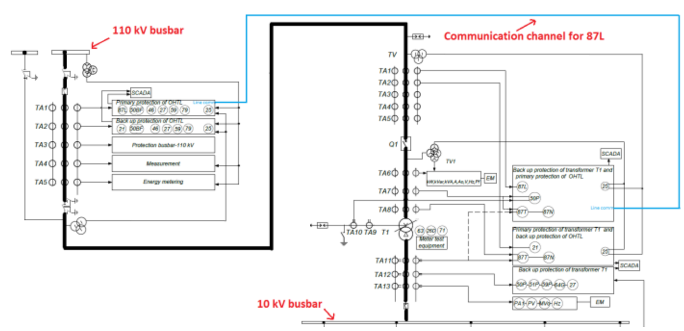


Fig. 2 – SLD diagram showing the 110/10 kV step-up transformer connecting the solar power-plant to the 110 kV system

In the case of a conventional solution for Main 1 protection, two devices are required for line differential protection, and one additional device for transformer differential protection. If Main 2 protection is considered, at least two additional devices are required for distance protection on the overhead line and impedance protection for the step-up transformer. Together with dedicated BCUs this will result in a total of 7 devices/IEDs.

Instead, advantage is taken from the fact that modern numerical IEDs based on functional integration can be used beyond the level of a single application. In this case, the transformer protection device used as Main 2 will at the same time send current measurements from its high-voltage winding to the line differential device on the remote line end. This is possible because the transformer protection device is equipped with a communication module, enabling it to be part of line differential protection scheme, while simultaneously serving as Main 2 protection for the transformer.

At the same time, the Main 1 transformer protection serves as the BCU, as it integrates all main transformer protection functions (differential protection and restricted earth fault protection), together with the apparatus control.

On the remote line end, the mentioned line differential IED protects the line as Main 1, while the line distance IED serves as Main 2, and at the same time acting as a BCU.

In this way, in the case of failure of any of the devices, the complete topology is still covered by the protection scheme, making sure that reliability of the system is at the required level. Since the BCUs are integrated in the protection IEDs, the cost of the IEDs is significantly reduced.

By using functional integration the total number of required IEDs is reduced from 7 to 4, with no impact to redundancy and improving availability.

As explained in the previous example, there are several benefits that come as a result of such functional integration: cost reduction because of fewer IEDs, less time for functional testing, less wiring, less point-to-point testing, and faster SCADA testing and commissioning, while keeping the required levels for the power system protection requirements.

### *E. Conclusion*

Modern numerical IEDs have the possibility of application in more than one application area at the same time, for more than one object. Using the capability of multi-object protection and control, and combining different application areas in the same device has proven a cost effective solution. Not only for the direct cost of purchasing fewer IEDs, but also taking into account the reduction in time required for wiring, testing and commissioning. It is also important to emphasize the reduced time spent in the substation by the personnel, reducing the exposure to dangerous voltages, thereby improving the safety aspect.

What the optimal level of functional integration is in order to have the most satisfactory results depends on the application in question and is beyond the scope of this paper, and an interesting topic for further discussions.

## III. REFERENCES


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## IV. BIOGRAPHIES

**Marko Kovacic** received his BSc diploma in 2009, and MSc diploma in 2011 from the Faculty of Electrical Engineering and Computing, University of Zagreb, both in electrical engineering.
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