



Acceptable Function Integration of Protection and Control at Bay level

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Summary

The well-known trend to reduce the number of IEDs in a bay or for a feeder by higher integration of functions is analyzed. Some examples show which functions are integrated today in bay level IEDs for protection or control. In order to determine the maximum acceptable integration, fundamental rules governing overall reliability are listed. For transmission bays or feeders the limit of two IEDs per bay or feeder may be reached. It is shown how IEC 61850 facilitates the integration of functions in less and less IEDs.

The acceptance to integration level of Protection and Control functions into IEDs depends not only on the technical options given but also on rules arising from the philosophy of the users.

Keywords

Substations, Substation Automation, Protection, Control, Monitoring, Bay Level, Reliability, Redundancy, IEC 61850

1 Introduction

With the advent of numerical technology, it has become possible to integrate functionalities in protection and control IEDs (Intelligent Electronic Devices), thanks to powerful microprocessors and high memory CPUs. The driving force is always the cost reduction resulting from a reduced number of IEDs, from lower number of IED failures, and from decrease of the needed space needed for the secondary equipment by increasing compactness.

In the past, during the days of electromechanical and static devices, it was common to provide one function per hardware device. Integration of functions gained momentum with the introduction of digital processors and as of to date, there has been a continuous rise in function integration capabilities with numerical technology in a 220/60 kV substation (see Figure 1).

The content of this paper is limited to Bay level in Protection and Control of Transmission substations if not specifically stated otherwise. The term *bay* is mainly used for a line or a transformer to a single / double / triple busbar arrangement, the term *feeder* mainly for a line or a transformer to a 1 ½ breaker arrangement. IEC 61850 is in favor of the term *bay* for both cases.

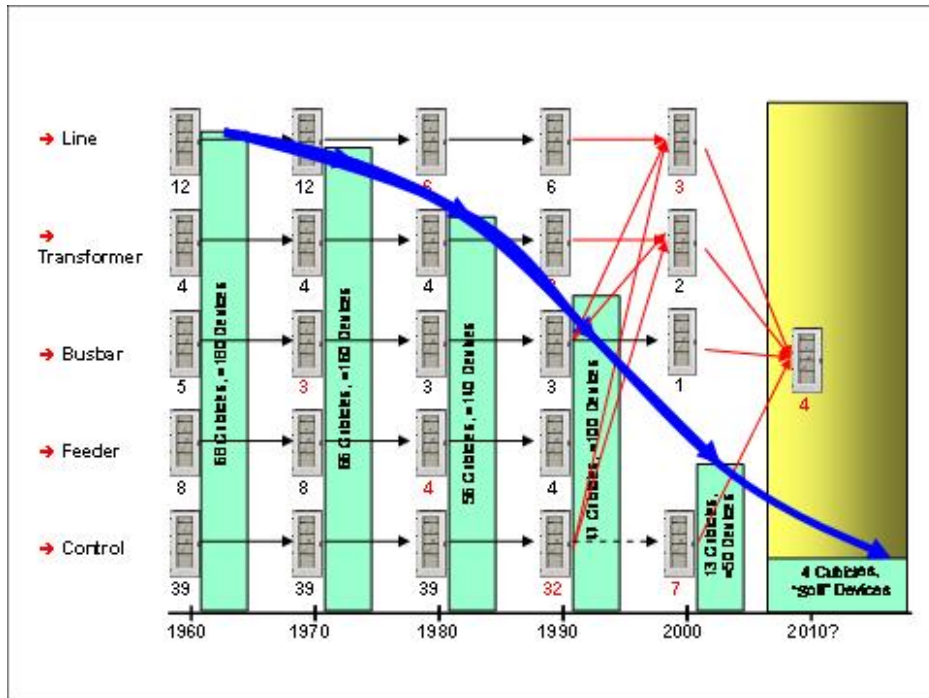


Figure 1 – The trend for function integration in SA and at bay level

2 Today's Practice

As a result of integration, there has already been a substantial reduction in hardware in comparison with the one device per function approach of the past. A vast majority of utilities have accepted the advantages of function integration. In transmission, the highest accepted level of integration today is 3 or 4 IEDs for a typical Double Bus bay, namely one (1) for controlling and two (2) for feeder protection, i.e. one each for Main 1 and Main 2, and may be a fourth one (1) for De-Centralized busbar protection or other functions needed.

Generally, the functions can be classified as follows:

- Feeder Protection functions
- Busbar Protection
- Protection related functions (e.g. Synchrocheck, Autoreclosure)
- Control functions
- Logics and Monitoring functions

Considering the secondary technique as a whole, i.e. protection, control and monitoring, more synergy and a higher level of functional integration can be reached in the bay or also beyond the bay without losing necessary reliability or security.

2.1 Feeder Protection

Protection functions of a feeder are classified as either Main or Back-up type. A Main protection function normally comprises of a group of associated functions (e.g. Power Swing detection) housed in the same IED. Examples for Distance and Differential Protection are listed in Table 1. Back-up functions are time delayed and generally derived either from current or voltage.

Lines and Cables Feeders are invariably protected by redundant main protections (Main1 and Main2) in two independent IEDs. What functions are included depends on the exact type of feeder to be protected and controlled referring to e.g. a short line, long line, etc. Back-up functions if required are allocated to both IEDs.

Transformer and reactor feeders are protected by complementary groups of functions in two separate IEDs. Combinations of Main (e.g. Differential) and Back-up (e.g. Time delayed Overcurrent) functions may be found in both IEDs.

TABLE 1	IEEE	Lines		Cables		Trafo		Reactors	
		Main	B/up	Main	B/up	Main	B/up	Main	B/up
Feeder Protection Functions									
Distance & Associated functions	21	x	x				x		
Measuring elements, 3 to 5 zones		x	x				x		
Phase Selection		x	x				x		
Directionality		x	x				x		
Load Compensation		x	x						
Load Encroachment		x	x						
Power Swing Block		x	x						
Pole Slip Trip		x							
Series Compensation		x							
Switch onto Fault		x	x				x		
Fuse Fail Supervision	47	x	x				x		
Communication schemes & Logics	85	x							
Longitudinal Differential	87L	x		x					
Phase Segregated Biased		x		x					
Negative Sequence comparison		x		x					
Charging Current Compensation		x		x					
Current Circuit Supervision		x		x					
Analog/Digital Communication		x		x					
Time Synchronization		x		x					
Directional Comparison	21	x		x					
Phase Comparison	78	x		x					
Low Impedance Differential	87T					x		x	
Phase segregated, biased, multi CT sets						x		x	
Harmonic and Waveform Restraint						x		x	
Negative Sequence comparison						x		x	
Restricted Earth Fault	87N					x			x
High Impedance Differential	87T					x		x	
Phase segregated						x		x	
Restricted Earth Fault	87N					x			x
Current functions			x		x		x	x	x
Phase instantaneous	50		x		x		x	x	x
Phase Time delayed, multi-stage	51		x		x		x	x	x
Residual instantaneous	50N		x		x		x	x	x
Residual Time delayed, multi-stage	51N		x		x		x	x	x
Thermal Overload	49		x		x		x	x	x
Voltage functions			x				x		
Phase Undervoltage, multi-stage	27		x				x		
Phase Overvoltage, multistage	59		x				x		
Residual Overvoltage, multistage	59N		x				x		
Overexcitation	24						x		
Current/Voltage functions			x				x		
Directional Phase Overcurrent, multistage	67		x				x		
Directional Residual Overcurrent, multi-stage	67N	x					x		
Communication schemes & Logics	85	x							
Frequency functions							x		
Underfrequency, multi-stage	81						x		
Overfrequency, multi-stage	81						x		
Rate of change, frequency	81						x		
Back-up Control			x		x		x		x

2.2 Protection related Functions

The protection related functions, namely Autorecloser and Synchrocheck are ideally integrated into the Bay Control IED or both Main protection IEDs in Double Busbar schemes. In 1-1/2 Breaker schemes, these functions are ideally located in the Bay Control IED on per-breaker basis. It is also possible to allocate these in the Main protection IED. However, it has to be mentioned that co-ordination between multiple instances of the same Autorecloser function in different IEDs has to be ensured which could result in complex engineering. This effort depends to a large extent on the type of diameter, whether Line-Line or Line-Transformer.

The protection related Breaker Failure function is discussed together with the Busbar protection below.

A typical example of protection function integration and application in a Double Busbar Bay for a Line feeder is shown in Figure 2 .

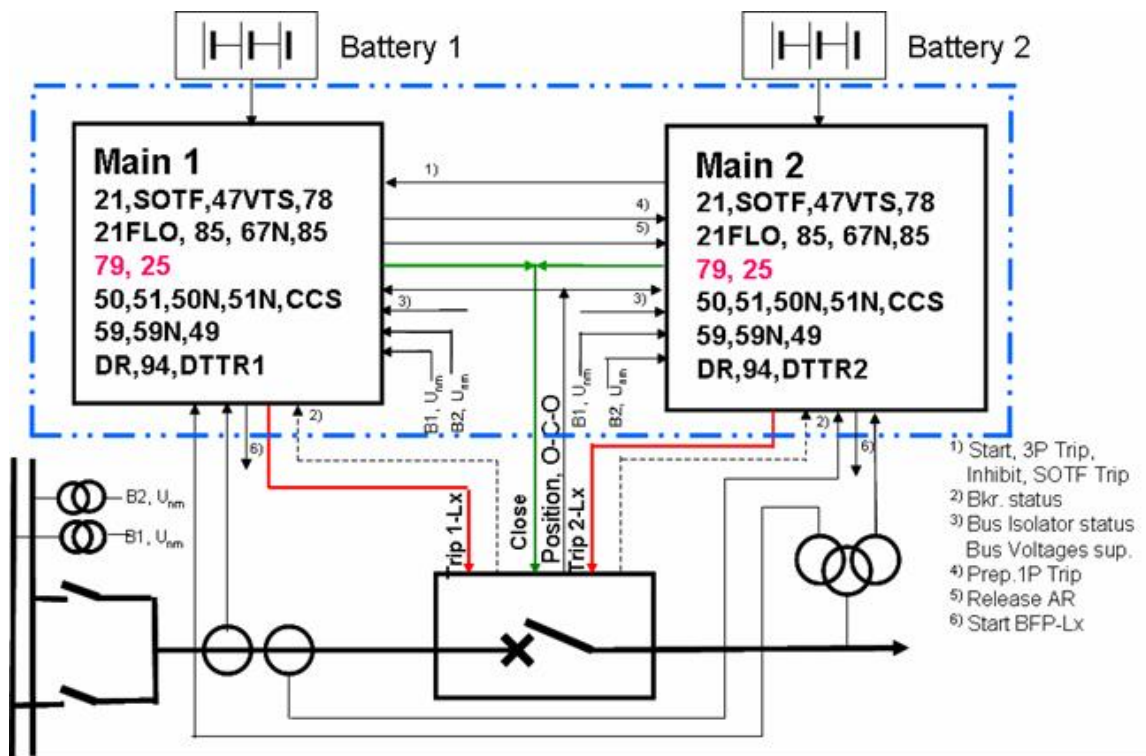


Figure 2 – Protection of a line feeder by Main 1 and Main 2 (example)

2.3 Busbar Protection

Station level equipment like the Busbar is normally protected by only one Main protection system, centralized or de-centralized with independent hardware. Only in rare cases the complete busbar protection is duplicated. In the *decentralized* arrangement, a significant achievement has been made by integrating one of the Feeder Main protection functionality into the bay unit used for Busbar protection thus reducing further the number of IEDs. In order to get the benefit of common tripping arrangements based on busbar topology, the Switchgear protection functions like Breaker Failure and End Fault Protection are conveniently integrated into the Bus protection IEDs also. In a *centralized* busbar protection arrangement, it is also possible to house the Breaker Failure and End Fault Protection in the Feeder Protection IED or the Control IED for Re-trip and recommended to have the topology-aided trip of the neighboring breakers from the Busbar Protection IED for more reliability.

Table 2 summarizes the Busbar and protection related functions and indicates the possibilities for integration.

TABLE 2	IEEE	Bus Prot		1-Bkr		2-Bkr	
		Central Unit	Bay Units	Fdr. Prot Main 1 & 2	Contr	Fdr. Prot Main 1 & 2	Contr
Busbar Protection and Protection related Functions							
Centralized Low Impedance Differential	87B	X					
Phase segregated, biased		X					
CT Saturation Compensation		X					
Check Zone		X					
Sensitive Differential		X					
Directional Comparison		X					
CT and Isolator Contact Supervision		X					
Undervoltage release		X					
Breaker Fail	50/ 62BF	X		X	X	X	X
End Fault	50/ 62EFP	X		X	X	X	X
De-Centralized Low Impedance Differential	87B	X					
Phase segregated, biased		X					
CT Saturation Compensation		X					
Check Zone		X					
Directional Comparison		X					
CT and Isolator Contact Supervision		X	X				
Undervoltage release		X					
Breaker Fail	50/ 62BF	X	X	X	X	X	X
End Fault	50/ 62EFP	X	X	X	X	X	X
Apparatus Control incl. Interlocking					X		X
Switchgear							
Autorecloser	79			X	X	X	X
Synchrocheck	25			X	X	X	X
Pole Discrepancy	61			X	X	X	X

A typical example of Protection arrangements in a Double Busbar arrangement with de-centralized Bus protection and redundant Feeder protection is shown in Figure 3.

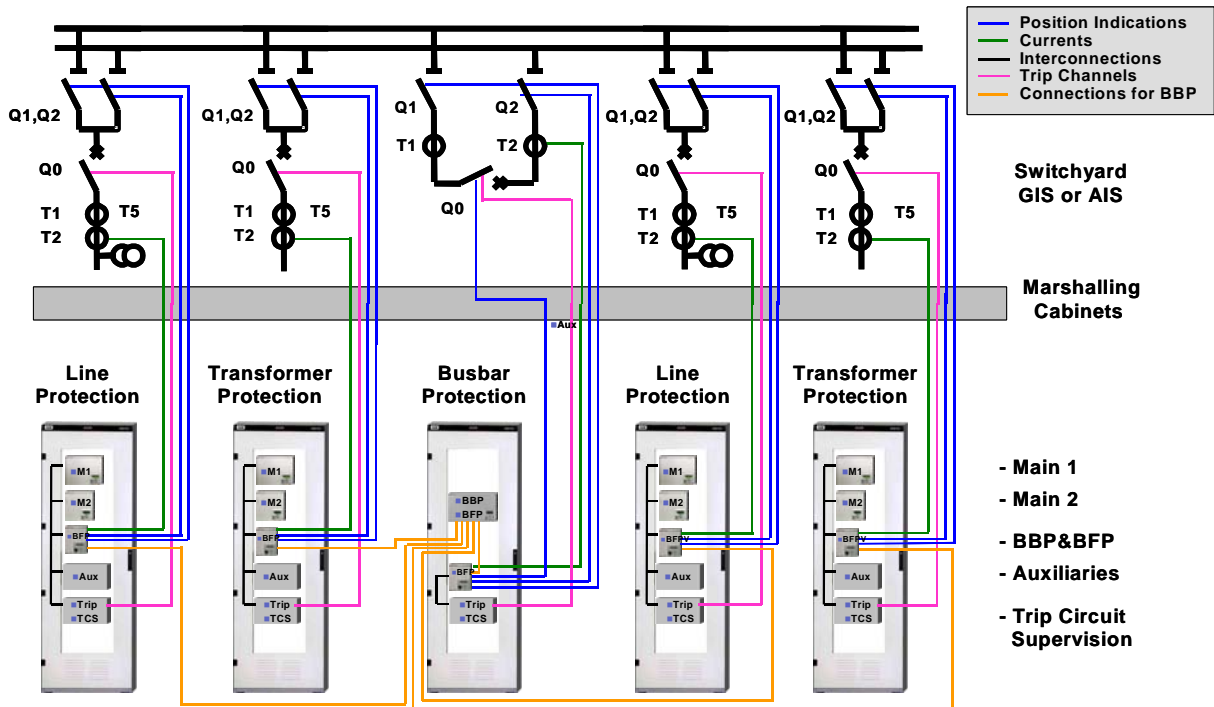


Figure 3 – Decentralized busbar protection and redundant feeder protection for a double busbar scheme

2.4 Bay Control

The bay control function is mainly receiving the remote commands from station or network level HMI and delivering feedback of the switchgear position to these HMIs. A bay level HMI may also be provided or supported. To the control functions belong also interlocking of the switchgear operations. Different command modes like Select-before-Operate are provided. In any case, Synchrocheck and Interlocking conditions are checked by the bay control function before the command is issued to the switchgear.

A limited Back-up protection function may be integrated in the bay control IED. A limited Back-up control function is in rare cases integrated in the Main protection IEDs at least for emergency purposes. This indicates the beginning of acceptance in having protection and control functions in the same IEDs also at transmission level as already accepted for a long time at distribution level (one common protection-control device per bay).

2.5 Logics and Monitoring functions

A significant reduction in hardware is also achieved by integrating features such as Tripping and Lockout arrangements, Mechanical protection trip schemes etc. into the Feeder numerical IEDs, by using Logic Gates, Timers, Flip-flops etc and with the necessary quantity of Binary inputs and outputs. Logics today mean in nearly all cases a signal interconnection by SW functions in all relevant IEDs. Monitoring functions such as Disturbance and Event Recorder and Measurement functions can be integrated into the IEDs also. All this integration makes it possible to skip a lot of auxiliary contacts needed for signal multiplication.

Table 3 summarizes the integration possibilities of the above logics and functions.

TABLE 3	IEEE	Lines		Cables		Trafo		Reactors	
		Prot	Contr	Prot	Contr	Prot	Contr	Prot	Contr
Logics and Monitoring Functions									
Trip arrangements		X		X		X		X	
Direct trip		X		X		X		X	
Start BFP		X		X		X		X	
Intertrip Receive		X		X		X		X	
Lockout		X		X		X		X	
Trafo Mechanical Prot						X			
Immunity against stray pick-up						X			
Seal-in						X			
Trip						X			
Alarms						X			
Logic Gates		X		X		X		X	
AND, OR, Timers, etc.		X		X		X		X	
Summator Blocks, analog		X		X		X		X	
Multi-purpose Function Blocks		X	X	X	X	X	X	X	X
Monitoring & Metering		X	X	X	X	X	X	X	X
Measurements		X	X	X	X	X	X	X	X
Event Counters		X	X	X	X	X	X	X	X
Disturbance Recorder		X		X		X		X	
Fault Locator		X							
Pulse Counters			X		X		X		X

3 Basic Requirements for Protection and Control

Conventional practice in protection dictates the requirements that failures of any object in the network do not lead to danger, limits damage to the faulty object and keeps to a minimum the disturbance on consumer-level. Further, *selectivity* shall be so designed that for a primary fault, the faulty object will be isolated and no other object is tripped.

The above requirement leads to the (n-1) principle as follows: Even in case that one of the secondary equipment is out of operation (under test, component failure, blocked), tripping in due time and with acceptable selectivity shall be possible. This also applies to a certain extent to CTs, VTs and CBs. Since current/voltage transformers and circuit breakers are expensive, these are not duplicated. Instead, redundant cores and trip coils are made available.

The above principle implies that if one of the elements in a substation has failed, all other elements in the substation remain healthy and ready to operate. If one of the protective schemes of a feeder fails, the other operates correctly.

In Transmission, from primary switchgear, battery systems and reliability perspectives, there are always redundant trip coils and DC supplies which in turn, together with the above (n-1) requirement emphasises the need for redundant feeder protection IEDs with galvanic and electrical separation. Busbar protection, traditionally, has always been with one protection system since *security* is considered more important than *reliability*. Breaker failure protection with Busbar protection constitutes one stand-alone system but if integrated with feeder protection is made available in both redundant IEDs.

As seen above, integration of functions has to follow the development of protection concepts, without violation of core conventional practices, and keeping engineering complexities at minimum.

4 Additional Requirements from User's Philosophy

With due importance for reliability and dependability without endangering security, integration enhances compactness in design and overall reliability by reducing hardware levels, when optimised within following framework:

4.1 Protection and Protection related Functions

- Every protection zone is related to an object confined by circuit breakers and associated CTs and VTs at its boundaries. Each object shall have dedicated protection IED, redundant in Transmission for feeders.
- Each of such zone related IED shall house a Main protection function. Back-up protection functions may be integrated in the Main protection IED
- The functions supervising current or voltage transformers shall be integrated within the IEDs
- Switchgear Control and Interlocking shall be implemented in an independent IED
- Protection related functions may be integrated within Feeder protection IEDs

4.2 Protection Schemes and Interfaces

- Trip arrangements may be integrated within Protection IEDs
- Circuit breaker Close Block latch may be integrated in an IED, sometimes with a stringent condition that redundant power supplies be available
- Trip circuit and DC supply supervision may be integrated with special care
- After providing the necessary binary inputs and outputs for all integrated functions and the alarm and trigger outputs for external devices like stand-alone Disturbance and Sequence of Event Recorders, a minimum quantity of I/Os has to be provided as spare

5 Impact of IEC 61850 in Integration

5.1 Basics

In Substation Automation Systems, the basic requirement for the communication standard IEC 61850 [1] was to have *interoperability* between IEDs from different suppliers. The different solutions for integration with all the requirements, starting from the switchgear arrangement (single line diagram) to

the operational philosophy of the utility, called for a communication standard which supports the *free allocation of functions*. This is valid also for the use of unconventional current and voltage sensors and breaker IEDs as mentioned before. Both requirements are fulfilled by IEC 61850. Examples for the application of IEC 61850 have been given e.g. in [2]

5.2 Support of integration by IEC 61850

The functions and switchgear objects are represented by the related data objects (Logical Nodes LN containing all function related data and attributes) as basis for the communication independent from their allocation to IEDs. The applications functions are issuing and consuming this data according to their functionality. In Figure 4 it can be seen that the integration of the Back-up protection represented by the LN PTOC (Time overcurrent protection) in the Bay Control IED functionally represented by the LN CSWI (Switch control) has no impact on the data model and on the logical communication links. Since there is only one IED, there is only one physical connection to the station bus. Also the internal representation of the circuit breaker by the LN XCBR exists only once after the integration. Therefore, any integration step is strongly supported by IEC 61850 without any impact on the operation of the system. If the application SW in the IEDs is already structured according to the IEC 61850 data model, the implementation of higher integration is even more facilitated.

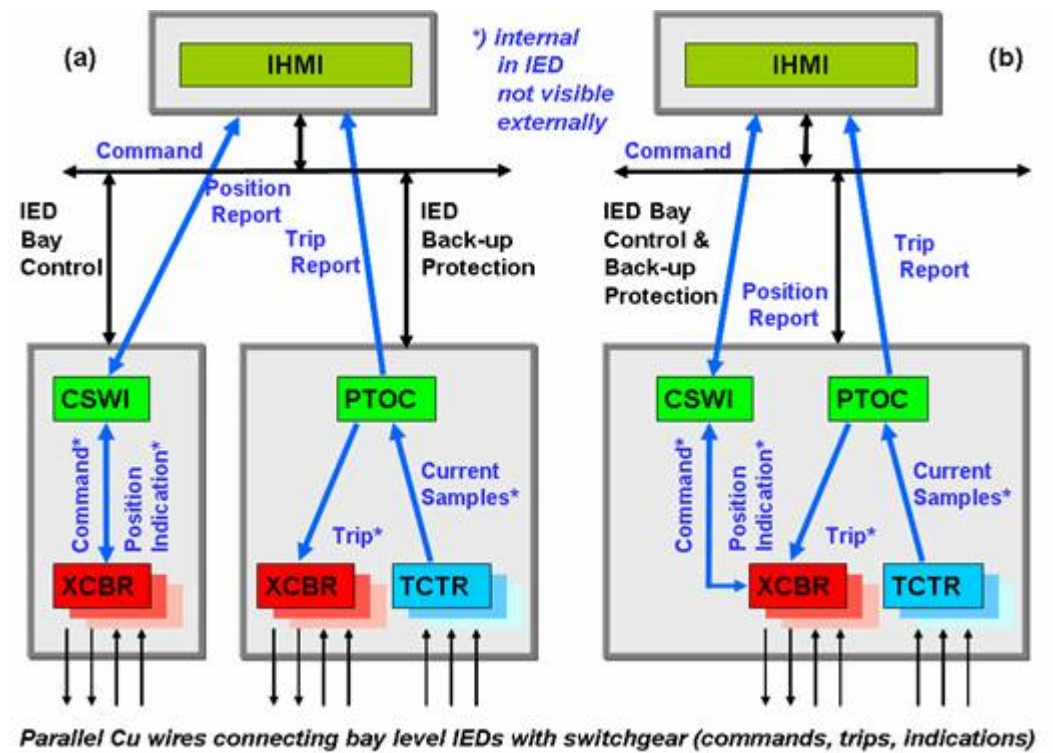


Figure 4 – Application example of free allocation of functions according to IEC 61850 -

(a) Two IEDs dedicated for Control and Back-up Protection are merged in (b) one IED with the identical functionality

6 Outlook

6.1 Redundant IEDs for control and protection

As a consequence of the n-1 criterion, there has to be at least two independent IEDs per bay and two related communication paths also in the future. The consequences for the different types of communication architectures based on the features of IEC 61850 are discussed in [3].

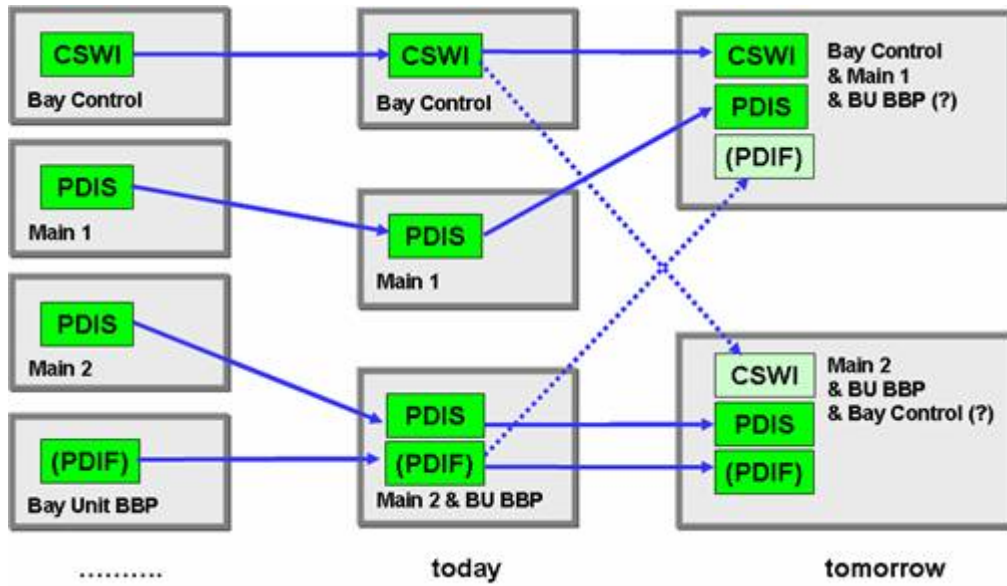


Figure 5 – The trend towards maximum acceptable integration at bay level

6.2 Maximum functional integration

As seen in Figure 5, the trend towards maximum integration per bay would stop in many cases with two IEDs per bay. The functions in the IEDs are roughly indicated by prominent LNs. As a final theoretical consequence by applying the n-1 criterion, the whole substation may be protected and controlled completely by redundant centralized computers. The needed interfaces at process level would have to be connected by a redundant communication network according to IEC 61850. This level of integration is limited at least today by the very high requirements for such central computers [4]. Other reasons like cost, vulnerability of extended communication links, and maintainability may result in more restrictions for this type of solutions but this is outside the scope of this paper.

7 Conclusions

The cost pressure will continue and push in the direction of higher integration. As long as common well-proven requirements for protection and control are fulfilled, a higher level of functional integration may be achieved and successfully implemented in the future. IEC 61850 facilitates higher integration. The level of acceptance of functional integration in many countries is limited by existing specifications written for legacy protection and control technologies. Therefore, the application of higher functional integration is mainly depending on the acceptance by the users.

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