Study Committee B5 Colloquium
2007 October 15-20
Madrid, SPAIN

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Functional Integration – Possibilities and Challenges

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Summary

The design of a protection and control (P&C) system must always be based on basic requirements of the power system. Increased functional integration has been a trend since long. The P&C products of today have the capability to integrate all functions for an object in one IED and to some extent even functionality for several objects. This development will continue and the necessary technology to integrate P&C functions for a complete substation exists. The free allocation of functions and the standardized process bus according to IEC 61850 support the development of totally integrated P&C systems.

Vattenfall and ABB have carried out joint research projects regarding completely integrated P&C systems. Several studies have been performed and a pilot installation of a totally integrated P&C system for a 130/40 kV substation has been realized.

Different principle designs of integrated P&C systems have been analyzed. The results have shown that it is possible to design totally integrated P&C systems that fulfill all basic power systems and operational requirements.

The main reason for further functional integration is to be able to continue the cost reduction per function. Possibilities to create large user benefits have also been identified in completely integrated P&C systems with all information available in central main computers. The possibility of improved supervision and plausibility checks of the complete protection system will improve the reliability and availability and reduce costs. Addition of new functionality can be done without any new hardware and extensions of new bays can be done with limited addition of hardware to the P&C system.

The pilot installation has been in full operation for more than one and a half years and demonstrates the feasibility of totally integrated P&C systems. The required functionality and performance have been fulfilled, and several advantages have been demonstrated.

Methods and tools for managing operation and maintenance activities have been identified as important fields for improvements. New methods for maintenance and testing need to be developed. For example it should be possible to replace the traditional type of preventive maintenance by integrated and more effective methods.

Keywords

Functional integration, functional allocation, IEC 61850, protection system, control system

1 Introduction

The design of a protection and control (P&C) system must always be based on basic requirements of the power system. Generally accepted design principles that fulfill these requirements have been established and used for a long time. Conventional P&C systems typically consist of two levels, the object level and the station level, and are characterized by distributed functionality where the functions are allocated and performed at lowest possible level.

A specific P&C system has mainly been designed for one object e.g. one line, one transformer or one busbar and has traditionally consisted of several protection relays and control devices. However, increased performance and capacity of the equipment have resulted in solutions where all protection and control functionalities for one object are integrated in one object IED (Intelligent Electronic Device). Today this degree of functional integration is generally accepted by most utilities.

The improvements of performance and capacity of modern CPU modules make it today possible to perform all protection and control functions for several objects in one IED. In combination with a process bus it is possible to integrate and perform all functions for a complete substation in one centralized main computer - a totally integrated protection and control (P&C) system. The IEC 61850 standard allows free allocation of functionalities and defines a process bus. Thus, the basis for totally integrated P&C systems exists. The structure and design of the P&C system will be considerable changed but the power system basic requirements must still be fulfilled. Special attention must be paid to the design as high degree of integration can result in unacceptable losses of functionality in case of one single failure in the system.

The main reason for further functional integration is to be able to continue the cost reduction per function. However, in a totally integrated P&C system with all information available in central main computers there will also be possibilities to create large user benefits.

Vattenfall and ABB have carried out joint research projects regarding totally integrated P&C systems. Several studies have been performed. A pilot installation of a totally integrated P&C system for a 130/40 kV substation has been realized. The paper deals mainly with results and experiences from these projects and studies.

2 Requirements on protection and control systems

There are many different requirements on P&C systems but here we will limit our discussion to requirements related to power system operation. For the protection system it is mainly a matter of dependability or in other words the probability for a protection to operate correctly in case of a power system fault. A control system must meet high availability and reliability requirements. These requirements have influence on the principle design of P&C systems. It is suitable to discuss the requirements on protection systems and the requirements on control systems separately.

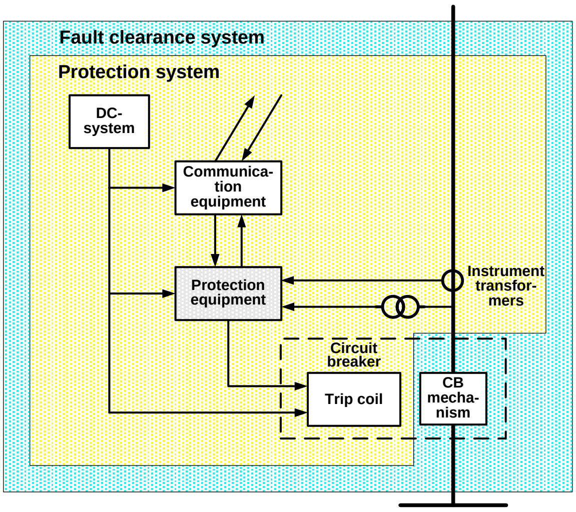

Figure 1. The fault clearance system for one object

2.1 Requirements on protection systems

By definition the protection system consists of instrument transformers, protection equipment, auxiliary supply, telecommunication system, tripping circuit including the circuit breaker trip coil and all necessary wiring. To perform successful clearing of power system faults the protection system and the circuit breaker must operate correctly. Therefore we often define the fault clearance system as the protection system together with circuit breakers (see Figure 1). It includes all functions for automatic clearing of power system faults. All components in the fault clearance system have to operate properly to guarantee a reliable clearing of a fault. Independent of the high performance and quality the protection equipment may have, it is of no use if any of the other components in the fault clearance system fails.

The protection equipment may comprise electromechanical, static and digital relays. Numerical protection IEDs with higher degree of functional integration are now replacing the old types of relays but the principles to achieve a reliable fault clearing will remain the same.

When integrating functions for different objects in the same IED the fault clearance system will change from representing one single object to be representing two or several objects. In case of a totally integrated P&C system there will be one fault clearance system (Figure 2) for the complete substation. The same principles for a reliable fault clearance will still be valid. Special attention must be paid to I/O units, the process bus and the DC supply to these components.

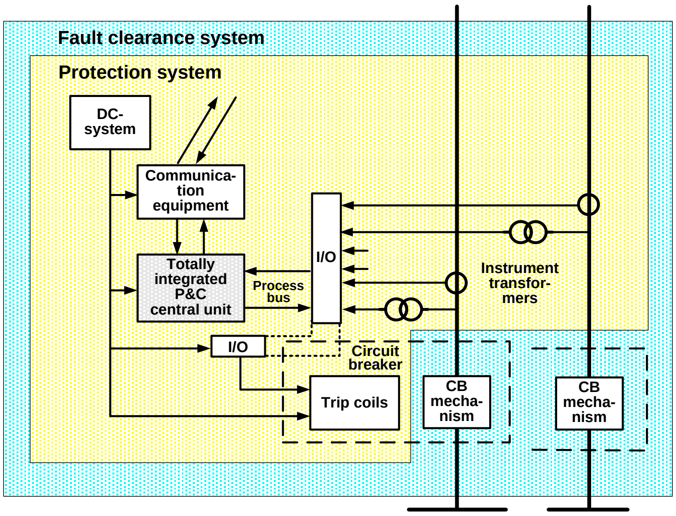

Figure 2. Fault clearance system for a substation with a totally integrated P&C system

We cannot assume that all components in the fault clearance system always will operate correctly. It is well known that protection equipment and circuit breakers sometimes can fail or that loss of input from voltage and current transformers can occur. Interruption of the DC supply or of a tripping circuit may also happen. These kinds of failure in the fault clearance system must not result in a failure to trip in case of a power system fault.

As each of the components in the fault clearance system has a low risk of failure it has become a common practice among utilities to apply the single-failure criterion in the planning and designing of the fault clearance system.

The single-failure criterion requires that the failure of any one component in a fault clearance system should not result in a complete failure to clear a power system fault. It is a commonly accepted design principle that the basic power system requirements, regarding dependability, are fulfilled if the single-failure criterion has been applied.

The practical application of the single-failure criterion means that the performance of the fault clearance system has to be studied during different conditions and power system faults must be possible to clear, in an acceptable way, even if there is one failure in the fault clearance system. For example the following failures shall be considered:

- Loss of input from a voltage transformer
- Loss of input from a current transformer
- Failure to operate of a protection equipment or a protection function
- Interruption of the DC supply
- Interruption of a tripping circuit
- Failure to operate of a circuit breaker
- Failure in the communication equipment in case where communication is critical for operation.

In case of higher functional integration the analysis must be applied to the corresponding fault clearance system. For example in a totally integrated P&C system also the following faults must be considered:

- Failure in the P&C central unit
- Failure in any of the I/O units

- Failure in the communication between the central unit and I/O units
- Interruption of the DC supply to any of the I/O units or the process bus equipment

To be able to fulfill the single-failure criterion back-up protection is a necessity. The main protection and the back-up protection may reside in different substations, remote back-up, or in the same substation, local back-up. In case of local back-up, we distinguish between substation local back-up and circuit local back-up. A circuit local back-up protection senses the same current and voltage as the main protection. A substation local back-up protection uses another current transformer than the main protection. An ideal back-up protection would be completely independent of the main fault clearance system. The design of the back-up protection depends on the conditions of the connected power system and the required performance of backup operations. For example interconnected transmission lines often rely on circuit local back-up protection system but sometimes it can also be sufficient with a combination of remote back-up and substation local back-up protection. In most substations the back-up protection is achieved with combinations of different back-up principles.

In a totally integrated P&C system some of the failures will have more serious consequences, compared to a conventional P&C system, as more functionality is lost. Evidently it is important to pay much attention to the design of the system to fulfill requirements on dependability and availability.

2.2 Requirements on control systems

Control functions include all functions for operation during non-system faults. Both manual and automatic functions for the optimization of operation, voltage and frequency control are included. Functions for restoration of the operation after a disturbance are also control functions. A typical structure of a conventional control system is shown in Figure 3. As much as possible of the control functionality is allocated in the bay level units but the station overall functions are of course allocated to the station level.

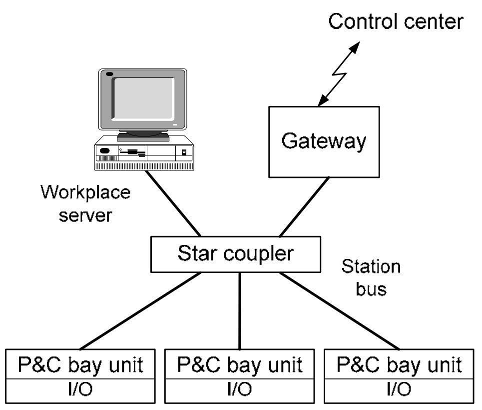

Figure 3. Typical structure of a conventional control system

There is no strict requirement on backup or redundancy of the control functionalities in a substation. However, the basic distributed architecture and functional redundancy for the control function in a conventional system, allows a high availability and dependability even if no explicit redundancy is used. If the connection to control center uses separate hardware instead of the same hardware as the workplace server at station level operation, a backup is established for one part of the station level. The station bus communication physically consists of star couplers that are common for the complete system. There is of course a risk that one single failure can cause a total loss of the ability to operate the substation. By specific design measures, e.g. duplicated power supply to the star coupler etc, it is possible to reduce the risk to an acceptable level and the control system will achieve almost complete backup on the station level. However, on the bay level there is still no backup and the control of one single bay may fail. This structure of conventional control systems and the degree of backup is commonly accepted among utilities but we must have in mind that the design philosophies among utilities also can differ much. If higher availability and dependability is needed, then redundant devices or modules must be used.

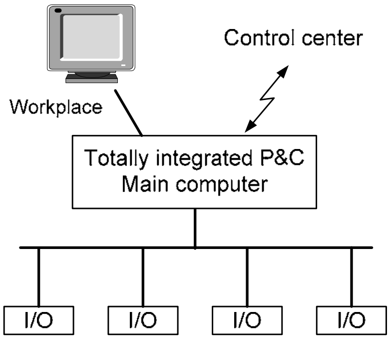

Figure 4. Totally integrated P&C system

Figure 4 shows the principle structure of a totally integrated P&C system. The main computer corresponds to the server, gateway and star couplers in the conventional system and the I/O hardware corresponds to the I/O part of the P&C bay units. In addition all control functions are allocated to the main computer. This will result in complete loss of control functionalities in case of e.g. extensions and modifications of the main software during normal operation of the substation. The risk of failures that give complete losses of the control functionalities will also increase. In most substations the decrease of the availability and dependability compared to a conventional P&C system is not acceptable and duplication of main computers will be necessary. The importance of the substation will decide the necessary degree of redundancy.

3 Possible principle design of totally integrated protection and control systems

Different principle designs of totally integrated P&C systems were analyzed regarding the possibilities to fulfill the single-failure criterion. Combinations of different network types were considered. Figure 5 shows an example of a substation with a transmission side that needed a circuit local back-up system and a subtransmission side where remote back-up was sufficient. By duplication of the main computers, the process busses and some of the I/O units all requirements are possible to achieve for this station. A complete circuit local back-up system should have duplicated I/O units. However, it is also possible to design the system with single I/O units but still maintaining practically the same dependability. This is possible due to the fact that all measured currents and voltages are available in each of the main computers and in case of a failure in one I/O it is possible to calculate the missing quantities. To prevent that one DC failure shuts down several I/O units the DC supply to the I/O units must be duplicated in this case.

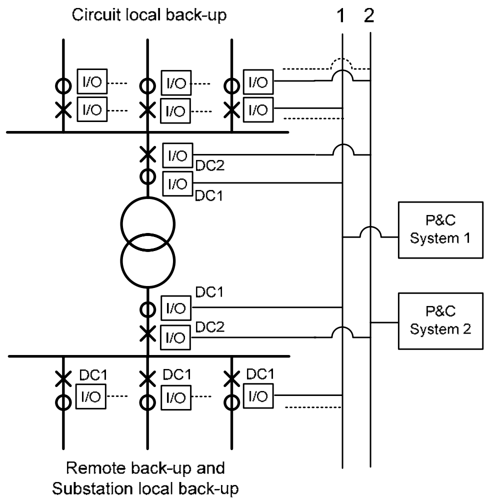

Figure 5. Example of a principle design of a totally integrated P&C system

In fact, for small stations with sufficient remote back-up protection it should be possible to design a P&C system with a single main computer that fulfills the requirements on the protection. Some special measures must however be taken. In some of the I/O units it must be possible to allocate supplementary protection functions to achieve necessary substation local back-up. These I/Os must also have duplicated DC supplies. Even if it is possible to design a single computer system it is quite likely that most systems will have duplicated computers due to control requirements. It must also be possible to operate the station during modifications and other actions in one of the systems while operations are performed from the other system.

The analyses have shown that it is possible to design totally integrated P&C systems that fulfill all basic requirements of the power systems.

4 Benefits and possibilities

A totally integrated P&C system is composed of general hardware and base software that are independent of the substation. Depending on the specific station the necessary functions or application software are selected and downloaded into the main computers. All measured power system quantities in the station and other information are available in the main computers. This can create benefits and possibilities compared to conventional P&C systems. Some examples are given below:

- By using all information in the main computer it is possible to achieve comprehensive supervision and plausibility checks of the complete protection system. This will improve the reliability and availability and reduce costs.
- Extensions of new bays can be done easier and more cost efficient

- New or improved functions can easily be added without any new hardware
- By easier and more frequent upgrading of the functions it is possible to keep uniformity among substations. This will facilitate for the personnel and reduce the risk of mistakes.

Totally integrated P&C systems are of course most suitable for new substations or for retrofit of complete P&C systems in old stations. If the I/O units are located close to or even integrated in the high voltage equipment in the switchyard the secondary cupper wires are replaced by optical fibers.

In case DC batteries are distributed into the switchyard it will be possible to eliminate the DC distribution between the switchyard and the control building where the main computers are located. The optical fibers will be the only necessary connections between the control building and the switchyard. The EMC environment will be improved and the risk of disturbances will be reduced.

5 Pilot installation and experiences

A pilot installation of a totally integrated P&C system for a 130/40 kV substation has been realized. The old P&C system was completely replaced by the new integrated system. The substation consists of three 130 kV lines, one capacitor bank, two transformers and six 40 kV lines and has been in service with the integrated P&C system since October 2005. The P&C system is based on a control system used for HVDC stations but is not a commercially available P&C system for AC substations.

There were no plans to have any conventional P&C system as backup. Therefore it was decided to design a complete duplicated system including duplication of all I/O units. As the substation was relatively large with comprehensive functionality and in combination with a certain degree of carefulness regarding the large number of functions and the capacity of each computer it was decided to split the system in two parts, one for the 130 kV side including the transformers and the other one for the 40 kV side. The experience shows that the capacity in one single main computer is good enough to integrate functionality for the complete substation. However, redundant systems will still be used, for dependability and availability reasons. Thus, the number of computers for the P&C functionality could be decreased from the present four to two computers. The main protection functionality is distance protection for all lines, complete transformer protection including transformer differential protection and busbar protection for both the 130 kV and the 40 kV busbars

The totally integrated P&C system has now been in full operation for more than one and a half years without any major problems.

An evaluation program has been performed after the commissioning of the system. The objective was to evaluate the functionality and performance of the technical functions and the consequences for operation and maintenance of the system, including work processes.

The evaluation of the pilot installation showed that the requirements on functionality and performance were fulfilled, and there was several advantages with this kind of totally integrated software based P&C system. However, it will be difficult to maintain the station specific knowledge among the personnel as this station is unique. A large-scale introduction would make it possible to get full benefit from the operation and maintenance of the system.

New work processes and routines must be introduced within certain areas to get full benefit of the system. One important example is verification and testing. For example in a conventional protection system each object will rely on the back-up protection during the necessary time for testing of the main protection for that object. However, in a totally integrated system all objects will rely on back-up protection during all the time for testing of the main protection for all objects. This is normally not acceptable. Both methods and tools for testing need to be developed or improved. These tools and methods must be part of a totally integrated concept where all information is available in one place. The goal should be to eliminate the need of traditional preventive maintenance.

The pilot installation has also demonstrated the possibilities to easily add or modify functions without changing the cabling or the connections to the primary equipment in the substation. For example if the substation was not equipped with any busbar protection it had been possible to add such a complex function by adding a software module in a later stage.

6 Conclusions

Increased functional integration has been a trend since long. The products of today have the capability to integrate all functions for an object in one IED and to some extent even functionality for several objects. This development will continue and the necessary technology to integrate protection and control functions for a complete substation exists.

Vattenfall and ABB have carried out joint research projects regarding totally integrated P&C systems. Several studies have been performed and it has been shown that totally integrated P&C systems can be designed in a way that all power system requirements are fulfilled.

The main reason for further functional integration is to be able to continue the cost reduction per function. However, in a completely integrated P&C system with all information available in central main computers there will also be possibilities to create large user benefits. The possibility of improved supervision and plausibility checks of the complete protection system will improve the reliability and availability and reduce costs. Addition of new functionality can be done without any new hardware and extensions of new bays can be done with limited addition of hardware to the P&C system.

A pilot installation of a totally integrated P&C system for a 130/40 kV substation has been realized. The system has been in full operation for more than one and a half years and demonstrates the feasibility of totally integrated P&C systems. The functionality and performance have been fulfilled, and several advantages with totally integrated software based P&C system have been demonstrated.

Methods and tools for managing operation and maintenance activities have been identified as important fields for improvements. New methods for maintenance and testing need to be developed. It should be possible to eliminate the traditional type of preventive maintenance and replace it by integrated and more effective methods. To be able to manage operation and maintenance of individual high voltage equipment it is necessary to switch off some of the functions in the totally integrated P&C system. This must be possible to handle in a secure and efficient way.

The technology for totally integrated P&C systems exists and it has been shown that it is possible to design, construct and operate this kind of station. Valuable feedback regarding issues that have to be considered in commercial P&C products has been obtained. We are convinced that these kinds of integrated systems will be the future protection and control systems. The question is just when there will be a wide acceptance of these kinds of solutions among the users.

Bibliography

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