CIRED 2009, Paper 0764

Increasing cost-efficiency of substation automation systems by centralised protection functions

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New legislative and customer oriented requirements pose challenges to substation automation. Power quality needs to be monitored and reported accurately, controlling and monitoring of the substation needs to be possible from a distant Network Control Centre (NCC), etc. Also old substations need to be refurbished in a future-proof manner that new future requirements (e.g. via distributed generation) can be met without additional costs or interruptions in electricity distribution.

Technology developed by ABB in cooperation with Tampere University of Technology (TUT) and Fortum Finland addresses these challenges with centralised protection functions. The new concept facilitates easy upgradeability of substations, while still keeping the installation costs low and the reliability of the system high. New value added functionality will also increase the cost-efficiency of the substation, making the refurbishment of substation profitable even before the end of the lifetime of the relaying..

INTRODUCTION

Substation automation has traditionally been a business with long time frames and a conservative approach regarding technological advances. Primary equipment in the substations has a typical life span of 30 to 50 years, and upgrades on the secondary equipment have often been forced to follow almost the same cycle.

The business area is now going through major changes. Part of the changes comes from the legislation, as in the Nordic countries the medium voltage (MV) electricity distribution business was opened to a free market. Regulation rules coming from this create new reporting and monitoring requirements for electricity distribution companies. Even short interruptions in the supply of electricity need to be compensated to customers. Variations in the power quality need to be monitored. Emphasis in the regulation model is on the quality of the distributed energy, so that higher quality will generate higher profits to network operators.

Also the control of the network moves further away from the actual physical network. Many company fusions have created bigger players in the distribution business. In addition communication network technology has developed fast over the past years, enabling a more centralised control. This all has led to an increasing need to gather data from larger networks and to also pre-process data before it is viewed by the NCC personnel.

The rapid increase of distributed energy generation (DG) also poses new challenges as the MV network is being used in a different fashion than it was initially designed for. This is a good example of future changes in the business, which will require fast reactions from electricity distribution companies.

The traditional way of handling these new requirements and challenges posed on the electricity distribution system has been to increase the functionality of bay level protection and control Intelligent Electronic Devices (IEDs). This has been an adequate approach when the protection and control IED capacity has been steadily increasing while the CPU prices still have remained at a reasonable level. This approach, however, has some weaknesses. The maintenance and functional updating measures required by the protection equipment of substations have been time consuming and expensive. These measures have normally meant switching off the whole protection system and causing interruptions in electricity distribution and redundant secondary testing of the switchgear.

In Finland most of the MV distribution network has been installed after World War II. These installations start to be outdated and a significant amount of stations must be refurbished. This is also the case with Fortum Finland. ABB, in close cooperation with TUT and Fortum Finland has developed and prototyped a new concept, which increases the reliability and cost-efficiency of substations. The concept also keeps future upgrade costs small without having a large impact on the initial installation costs. This all is achieved by using centralised protection functions.

SETUP FOR CENTRALISED FUNCTIONS

Recent advancements in substation communication have brought new possibilities for handling these requirements. The introduction and the increasing acceptance of the IEC 61850 standard have made available fast and standardised Ethernet based communication. First, the station bus (part 8- 1 of the standard) allows replacing copper wirings on a horizontal level between IED devices. Secondly, the process bus (part 9-2) makes the digitized measurement information from instrument transformers available for other devices in a standardized way. Combining the station and process bus enables an approach where part of the protection and condition monitoring functionality is moved from the bay level IEDs to a centralised Station Computer. The setup is described in Figure 1.

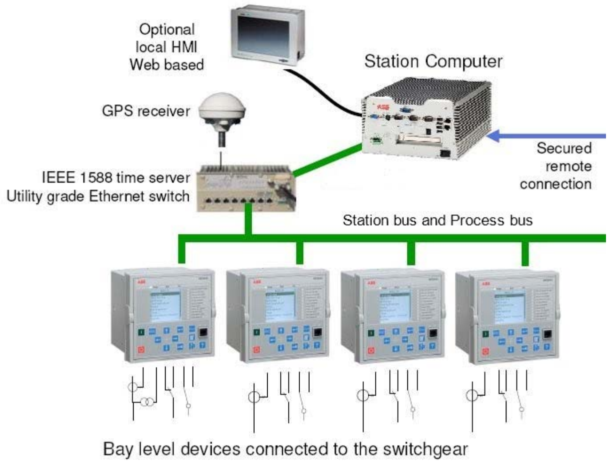

Figure 1. New setup with a central Station Computer

A similar approach has also been investigated by Nuon Tecno [1] [2]. The main difference to that approach is that in the solution presented here not all functionality is removed from the bay level IEDs. The most important and time critical protection functions still run in the IEDs but all additional functionality is moved to the Station Computer. With such a setup updating and maintenance activities can be handled without affecting the primary protection.

The approach also makes it easier for electricity distribution companies to plan their substation upgrades. For small and remote substations the refurbishment can be done without the Station Computer unit. Using only bay level IEDs will still be the most economical solution for those cases. The possibility to extend the functionality later by only adding the Station Computer decreases upgrade costs dramatically.

At first sight it might appear that having protection functionality in both the Station Computer and in bay level IEDs adds unnecessary redundancy and costs to the station. But that is not the situation. Communication via the station and process bus also requires additional performance by the IED. Adding basic protection functionality on top of that does not critically affect the CPU requirements of the bay level IED. The concept has been successfully prototyped with REF615, including protection and communication with the station and process bus in the same IED.

The approach is also future-proof. When requirements change in the future so that more functionality is needed even on small remote substations, the software of the Station Computer can be updated without affecting the existing installation or the primary protection.

CENTRALISED PROTECTION AND MONITORING FUNCTIONS

The most critical protection functionality does not benefit largely from a centralised solution. Basic bay level overcurrent and earth-fault protection algorithms can run in both bay level IEDs and in a Station Computer, and in these cases the existing product portfolio is already sufficient.

There is much functionality which benefits from a centralised solution, although presently already available in bay level IEDs. For example, the accuracy of directional protection algorithms can be improved when data from all bays is available. This data can be used e.g. for blocking of 'symphatetic trips'. This will both decrease the area affected by the fault, and also reduce the time needed for locating the fault.

New protection algorithms are developed, which require a centralized solution. E.g. high-impedance earth faults are very difficult to notice because of the small fault current, especially in compensated networks. Although this type of fault does not pose an immediate danger to the power system equipment, it is a considerable threat to humans and property [3]. Novel methods exist for detecting these highimpedance earth faults which need data from several bays simultaneously. Also many novel fault location algorithms require measurement data from the whole substation.

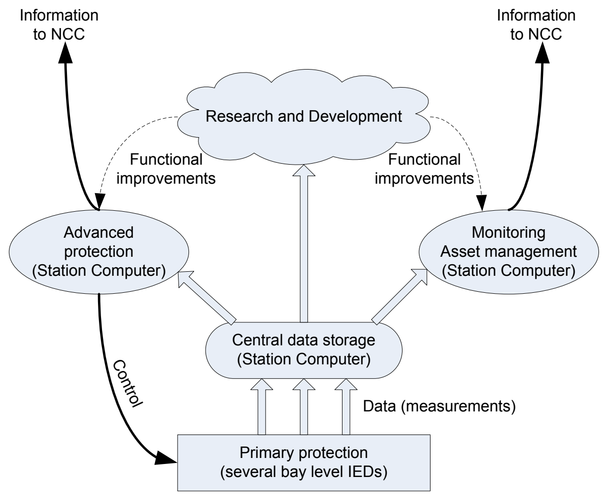

Figure 2. Data flow with centralised functions

The ability to process measurement data from the whole substation on a Station Computer facilitates new functionality on several areas and not only in protection, see Figure 2. The actual physical location of the functionality is described in Figure 2 within brackets.

Advanced support for condition monitoring and asset management is a valuable feature for electricity distribution companies. Today, existing bay-level IEDs already perform extensive data collection from the network and from the primary equipment (breaker operation counter, transformer temperature, etc.), but the problem has been to process this data. It often stays in bay level IEDs, due to the lack of proper analysis tools or lack of time of the operator personnel to collect the data – or due lack of both.

Pre-processing this data on a Station Computer enables more extensive reporting on the status of the primary equipment. In the long run this is essential for properly monitoring the substation and planning future maintenance and upgrade activities.

In addition to benefits for electricity distribution companies, an important aspect to distribution automation companies is described as a cloud in Figure 2. In addition to simulation data and specifically arranged test measurements, the possibility to easily acquire and utilize real fault disturbance data from the whole substation gives an important advantage to algorithm development within Research and Development Departments of device manufacturers. New functions can be piloted and tested more extensively in this setup, because testing can be made in substations without affecting the active protection.

COST-EFFICIENCY RELATED TO STATION INSTALLATION AND UPGRADES

From the electricity distribution companies' point of view cost-efficiency has several aspects. The most self-evident, but the least contributing part in the long run, is the installation cost. Taking into account only this aspect would lead to a highly simplified view of the concept, where centralised protection on a Station Computer would not be cost efficient unless the cost saving gained through the reduced functionality of the bay level IEDs exceeds the expenditure of it.

The typical asset value share of distribution networks in Finland gathered from several statistics is presented in Figure 3. The figure shows that only a 10% share of the asset value is due to primary substations. From that share only 10% is due to relaying and automation, accounting for only 1% of the total asset value. Clearly the installation cost of the substation is not the main item affecting the costefficiency. On the other hand substation automation has a large impact on the reliability of the network. From this fact one can conclude that focusing on substation automation is a good chance to increase profit with small investments.

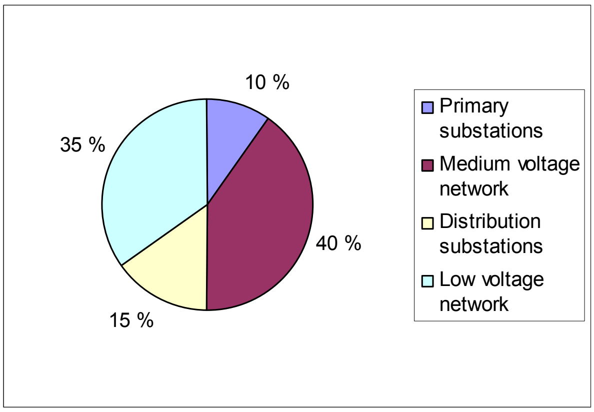

Figure 3. Typical asset value share of the distribution network in Finland

The maintenance and upgrade costs of a traditional bay level protection system of a substation can be of the same order of magnitude as the original installation costs. Not only because of the investment cost but also because of the interruptions of the electricity distribution normally required. Then the possibility to update the functionality on a Station Computer during shorter or even non-existent power distribution interruptions with reduced need for secondary testing generates considerable cost savings and can even be the decisive factor when planning future maintenance activities. Advanced condition monitoring functionality in a centralised Station Computer would also help in planning these activities in advance.

COST-EFFICIENCY RELATED TO INCREASED RELIABILITY AND SAFETY

More difficult to estimate, but the item which will have the largest impact on the total lifecycle costs of the substation, is the profit obtained from increased reliability and safety of the distribution network. Advanced functionality enabled in the Station Computer can shorten interruption times in fault situations, for example, through, accurate fault location. Increasing the accuracy of protection algorithms used, for instance, in directional earth-fault protection schemes, can prevent false tripping and minimize the area affected by the fault. Often these advanced protection algorithms require information from several switchgear bays and they could not even be realized without a centralised solution or a fast and reliable communication network.

For acquiring more accurate estimates on the cost-efficiency an example network was studied at TUT [4]. Outage cost values applied currently in the regulation model in Finland were used as basis. They are at the moment 1.1 €/kW and 11 €/kWh for the unexpected outages, 0.55 €/kW for high-speed auto-reclosing outages and 1.1 €/kW for delayed auto-reclosing outages.

The example network consists of eight feeders with an average power of 6 MW. This network has around 20 permanent faults per year in average. In the referenced study [4] outage costs are presented for a 20-year period. Annual outage costs calculated from those results are around 80 k€ for permanent faults and 75 k€ for short interruptions.

Calculating outage cost savings is difficult and requires certain rough assumptions. Unnecessary trip cost can be evaluated on basis of the length of the outage. A 6 min outage in the example network [4] was calculated to cause app. 16 k€ additional cost and 1 hour outage already app. 86 k€ additional cost. If we assume that unnecessary trips count for 1% of the trips in the example network, this would mean one such occasion every 5 years. If we assume that the false trip would last for one hour, the cost because of this trip would be already in the same range as the annual cost of all permanent feeder faults.

As described earlier, high impedance earth faults do not normally pose an immediate threat to the power system equipment, nor to the electricity distribution, because of the small fault current. But a situation like this is a remarkable safety risk, which can lead to injuries or even deaths. There is no proper statistical information about the frequency or financial costs for these faults [3]. But a rough idea can be obtained from the cost figures of road traffic accidents, see Figure 4.

Injury	Average costs
Death	~2 000 000 €
Permanent injury	~1 000 000 €
Temporary injury	50 000 - 200 000 €

Figure 4. Cost figures of road traffic accidents in Finland, year 2000

The probability of such an accident is small, in Finland approx. 1 death and 2 injuries per annum. But in addition to personal injuries also the financial cost for even a single accident can be very large. Also a high impedance earth fault often develops to a "normal" low impedance earth fault, if not detected in time. If the fault can be cleared before this happens, additional outage costs are avoided.

The calculations presented above strongly depend on the estimations about existing protection malfunctioning. Existing statistics for that are insufficient, and the probability of such cases should be investigated more in order to accurately define the cost-efficiency of new functionality. Also more detailed statistics on high impedance earth faults are missing. Changes in the regulation model can also affect the outcome.

In any case it can be shown that the costs during the operation of the substation automation contribute much more to the overall lifecycle costs than the actual installation costs. With existing functionality, like overvoltage protection, this is also accurately calculated [4]. With the new functionality proposed here similar calculations are not yet available. During the development of functions utilizing the possibilities of a centralised Station Computer also the cost-efficiency needs to be thoroughly studied.

CONCLUSION

Technology developed and prototyped by ABB facilitates new centralised protection and control functionality for substations. Combining the station bus and the process bus creates an environment where the protection and control bay level IEDs can handle the primary protection, and simultaneously communicate towards a central Station Computer. The substation can be upgraded with new functionality without affecting the installations or the primary protection.

Increasing the reliability of the distribution network can be very profitable for electricity distribution companies. Instead of installation or upgrade costs the most important elements in the long run are the costs related to direct outage times. New functionality enabled in the central Station Computer can increase the cost-efficiency of the network so much, that upgrading it could be profitable even before the end of lifetime of the existing relaying. Also, providing enhanced station level information, e.g. power quality, condition monitoring and fault situation analysis, can give valuable indications for the future maintenance tasks.

REFERENCES

[1] F. Volberda, M. van Riet, A. Pikkert, 2007, "The Power of Simplicity", CIRED 2007

[2] M.J.M. van Riet, F.L. Baldinger, W.M. van Buijtenen, F.J.T. van Erp, F. Volberda, F. Provoost, 2005, "Alternative approach for a total integrated secondary installation in MV substations covering all possible and required functions", CIRED 2005

[3] IEEE Power System Relaying Committee Working Group D15 Report, 1996, "High Impedance Fault Detection Technology", http://www.pes-psrc.org/

[4] P. Verho, M. Marttila, K. Kannus, J. Pylvänäinen, M. Pouttu, 2007, "Optimization of Overvoltage protection of Distribution Networks", CIRED 2007

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