

## CONFIGURATION AND INTEGRATION OF SUBSTATION SECONDARY EQUIPMENT

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### SUMMARY

Modern substation secondary system design is becoming increasingly based on a smaller number of integrated multi-functional digital equipments. Within these, it is accepted that functions that were once historically separate, such as protection, control, communications and instrumentation, will be integrated in some form in the future.

The degree of functional integration within a single hardware device will be an important issue for power companies and utilities, with the level of acceptance being determined by their views on costs, reliability, maintenance and operational needs.

This paper examines those factors that will influence the future configuration of the complete secondary system of EHV and HV substations, including:-

- management of assets
- reliability and maintenance
- advances in digital technology, serial data communications and information technology
- changes in the electricity market

The paper is limited to those systems that are installed and operate within the substation. Remote control systems, that operate in conjunction with devices inside the substation, are excluded. The paper concludes that reducing the total life-cycle costs of substations will become the dominant force in both the design and the rate of deployment of integrated secondary systems for HV and EHV substations.

### KEYWORDS

Substation - Protection - Control - Instrumentation - Digital Technology - Intelligent System - Refurbishment - Maintenance - Testing.

### 1. SECONDARY SYSTEM FUNCTIONS

EHV and HV substations play a vital role in electrical power systems. They connect the generating plants to the electrical consumers at grid level and serve to distribute power within the network. The secondary system is fundamental and is needed to ensure that:-

- faulted parts of the network can be disconnected during an electrical disturbance. The protection system has to detect the faulted part and trip circuit breakers to disconnect the fault as soon as possible.
- primary equipment can be maintained so that it remains operational. Secondary equipment collects data on the status of the primary equipment.
- regional / national dispatching centres receive status information from each substation. Switching operations must be possible. The substation secondary equipment handles transfer of this data.
- local back-up control for the substation is possible in the case of a major remote control failure.

The major substation secondary functions are:-

- Power system fault protection
- Power system abnormal condition management
- Automatic control
- Operator supervisory control
- Local back-up and emergency control
- Metering and instrumentation
- Recording and local monitoring
- Automatic data analysis

To meet the technical requirements, most functions need to operate with both consistent and deterministic response times. As such, they are 'real time' functions, and need to be designed specifically with this in mind. To make maximum use of the computing resource,

software functions should be split into different response time categories, so that each major hardware unit can perform a mixture of foreground and background software tasks. Reference [2] identifies three time priorities. The fastest, P1, has reaction times up to 250ms. P2 covers response times up to a few seconds, while P3 addresses all slow functions.

Functions also operate at bay or substation level. A bay function has inputs and outputs within a single bay while a substation function has inputs and outputs within more than one bay. A few functions can be both.

## 2. MANAGEMENT OF ASSETS

The management of the existing power system assets is a major task for power companies and utilities. Several factors emanate from the power system to influence the configuration and the acceptable level of integration within substation secondary equipment.

### 2.1 Types of substations

All utilities and companies operating power systems have a variety of existing substation designs. Some of these variations are due to substation size or voltage level; others are due to different switchgear technologies being deployed, such as air blast, SF<sub>6</sub>, etc. Before installing any new secondary technology, end users need to assess how well the solutions on offer fit the variety of substations under their control.

To understand the many variants, the Working Group set out to partition all known constructions into a minimum number of types. The need was to understand the influence of the primary equipment / civil works upon the optimum design of secondary system. The study looked at a broad range of EHV, HV and MV substations. The major influences were found to be:-

- Substation size, small, medium or large
- Type of switchgear, open terminal, GIS etc.
- Location of secondary equipment
- Existence of a common control / relay room

Substations divide into two main types depending upon whether the secondary equipment is centralised in one location, or decentralised about the site. In the decentralised case, three further subdivisions exist, each with a recognised construction that exists today:

- on MV circuit breakers, the secondary equipment can be mounted directly onto the circuit breakers
- with gas insulated switchgear, the secondary panels can be placed adjacent to the GIS to form a complete primary and secondary module
- with large open terminal substations, it is common to employ small buildings close to the primary plant to house the bay level secondary equipment

Modern methods of substation construction favour those types that demand less floor space. There is also a preference to maximise the work done at the

manufacturer's factory: the GIS module being one example of this approach. However, as the secondary system has to be applicable to both existing and new substations, the need to consider all types of construction remains.

### 2.2 Construction options for refurbishment

Within those countries with little or no overall growth in electricity demand, utilities and power companies find that they are not building many new substations. This trend will be accelerated by government and environmental pressures on electricity suppliers to enter into demand side load management. The need will shift to upgrading existing assets in the most effective way. This includes substations that are in need of modernisation. There are four potential approaches:-

- Complete substation refurbishment
- Complete secondary system refurbishment
- Complete function refurbishment, e.g. protection
- Individual equipment refurbishment, 'As needed'

The engineering attraction of total substation refurbishment is somewhat obvious, in that it represents the best long term opportunity to bring the complete substation up to modern standards. It also offers the least number of engineering constraints. However, the costs of total refurbishment will drive the decision makers to examine the potential of other solutions.

The limited evidence available indicates that utilities and power companies are prone to refurbish only those elements that genuinely need replacing. As it is rare for both the primary and secondary equipment to reach their end of life at the same time, then complete substation refurbishment is not proving to be common. Note, secondary equipment has a typical life of 20 to 25 years, while primary equipment can last for 50 years. End users can also find that they have recently upgraded part of the secondary system, e.g. the disturbance recorders. It seems illogical to throw away such equipment, and to replace it with more modern versions.

The evidence available supports the view that each utility will come to its own best refurbishment method. This may even vary from substation to substation, as the economics of different constraints are met.

Despite the diverse arguments for and against each approach, one firm conclusion that can be drawn is that those designs of new secondary systems that cope well with partial refurbishment are likely to meet the broad range of requirements better than those that are optimised solely for new substations. The need is for flexibility to cover both new substations and the refurbishment of old substations.

This gives support for a modular approach to substation secondary system design, where functional modules can

be installed and made operational on a 'stand alone' basis. Where these same units can later be interconnected by serial data links to make an integrated system, then the benefits of both approaches will be met. This is the optimum solution, as it meets the greatest number of the known practical constraints.

### 2.3 Commercial supply

Discounting any associated technical problems, new integrated secondary systems could be designed to be supplied in 1 of 4 ways. The commercial options are:-

- Fully open multi-vendor systems, where several vendors supply mixed parts to form a system.
- Mixed vendor sub-systems, where one vendor supplies the complete secondary system for one bay.
- Mixed vendor sub-systems, where one vendor supplies a complete function, e.g. protection.
- Single vendor systems, where the complete secondary system is supplied by one vendor.

It is expected that most purchasers will prefer the open multi-vendor, or mixed vendor systems. This will demand the publication of, and more importantly, the world-wide deployment of, comprehensive international specifications. The work currently performed by IEC and IEEE in this field is therefore important.

The more open the design, the greater the need for standardised communication protocols and co-ordinated data bases. This will demand very detailed technical collaboration and agreement between the major users and manufacturers. This is unknown today.

## 3. RELIABILITY AND MAINTENANCE

Given that the secondary system protects and controls the primary system, then the financial implications of a lack of reliability at secondary level represent monetary values far in excess of the cost of the secondary equipment. It is, therefore, critical that the design of any secondary system can match the operational needs, in terms of reliability and the ability to maintain both primary and secondary equipment. Continuation of supply to consumers, and avoidance of unnecessary primary equipment outages, are fundamental.

### 3.1 Reliability

Under normal operating conditions, every implemented function will be performed by the integrated secondary system. However, in the event of a failure, then the secondary system will become degraded in some way. To control the consequences of failures, it is preferable if some less important functions are designed to temporarily fail so that the more important tasks remain continuously available. This means that the required reliability for each function will be different. The Working Group has found that general values for reliability cannot be given because they depend on

various parameters such as the voltage level and the layout of the primary network.

### 3.2 Dependability and security

Protection specialists divide reliability into two further sub-classes, referred to as dependability and security. This is because protection rarely operates, and when it does, it has important consequences. Basically, by tripping circuit breakers, protection disconnects major parts of the grid, and any incorrect operation can lead to an unnecessary loss of consumer supplies.

When a fault occurs, the protection looking after the faulted 'zone' of the power system *must* operate, but all other protection looking after other zones *must* restrain from operating. Consequently, if protection operates when it should, then it is 'dependable'. If protection remains stable, and does not operate when it is not meant to, then it is 'secure'. The two factors are inter-related, and design actions to improve one quality normally reduce the other.

### 3.3 Redundancy

It has been standard practice within secondary systems to use redundancy to improve the reliability of critical functions. It has taken three forms:-

- redundancy to cover stochastic events such as a defect in a device
- redundancy within protection systems by using different operating principles
- redundancy to cover planned outages such as maintenance or software exchange

Being safety and / or power system stability related, the reliability demanded for protection functions is usually much higher than for other functions. For example, an EHV line protection function will generally be performed by duplicated equipment, each with a different operating principle. In another context, the need to have reliable primary fault clearance can demand alternative systems. A prime example being that of breaker fail protection. This covers the rare, but difficult, condition when the circuit breaker fails to successfully open and interrupt the fault current.

Given the primary system consequences of a lack of secondary system reliability, it is expected that end users will continue to demand equal or better reliability in all critical functions. Hence, if the required level of reliability of a particular function demands redundancy, then full integration within the secondary system is very unlikely to be accepted by end users. Such functions will need some form of segregated hardware.

### 3.4 Self checking

With traditional segregated secondary systems, few functions are lost when a hardware unit fails. Such failures are likely to remain undetected until the next required operation or until the unit is maintained. This is not acceptable when many functions are integrated

into the same device. Consequently, a high level of integration can only be considered where the overall availability of the hardware is improved by the use of automatic self-test and continuous supervision techniques. Fortunately, more sophisticated supervision facilities are becoming part of modern numerical secondary systems.

### 3.5 Maintenance of secondary equipment

The maintenance and testing of integrated secondary equipment will be potentially more difficult, especially once the substation is live. To improve matters, the functional units of the modular software design need to be capable of being isolated in some way from the rest of the system. Each function or module must be capable of being fully tested, with the inputs and outputs being clearly identified. This feature will have to be built into the design.

Being new to end users, maintenance of substation related software is expected to demand special care. Software should comply with the following requirements:-

- reliable, safe operation & consistent response times
- flexible in relation to software upgrading
- software documentation generated automatically
- efficient and comprehensive diagnostic system
- easy system access for modification
- modular application programs
- run under a real time operating system
- provide on-line diagnostic tools

### 3.6 Upgrading of software

Upgrading of application software will become more important. Such modifications will normally occur during the initial commissioning of the system, but could prove necessary at any time in the system's life. Three categories of software changes can be identified:-

- modifications to the site specific configuration
- modifications to correct existing functions
- modifications to introduce new functions

The normal preference would be to carry out modifications with the equipment off-line. However, with integrated systems, the need to keep important functions running means that on-line modification techniques will have to be developed. An example is the double data base, where one is operational, while the other can be freely modified and checked prior to activation. With this technique, it is possible to quickly revert to the previous 'working version'. This improves the security of making any change to a live substation.

## 4. DIGITAL TECHNOLOGY

As in other industries, the foundation level technology for new designs of secondary equipment is being dominated by modern digital technology, both within the individual products, and for the serial data

communication links that are commonly used to network elements together. Inside equipments, software algorithms are rapidly moving to fully numeric solutions, where every variable, such as an instantaneous value of current or voltage, is represented by a number. One key benefit of digital technology is that new developments, experience and techniques can be shared from other industries. Where possible, readily available digital technology is preferred for inclusion in secondary equipment designs. A review of the essential elements follows:-

### 4.1 Microprocessor technology

In conventional secondary equipment, most secondary functions were performed by smaller, lower powered, separate units of hardware. With limited computing power, functional integration was restricted and not fully an option.

In general terms, the technical capabilities of modern digital technology is no longer seen as the limit to the integration of functions within substation secondary systems. For each application, there is more powerful chip-sets already available in the general market place. These are being built into suitable equipment, and are being deployed within new substation designs.

### 4.2 Communications

Digital communication technology is essential for all the integrated secondary systems approaches reported in technical papers. Low and high speed serial data communication lines, such as point-to-point and local area networks, will be needed to connect individual devices and systems together. Parallel lines such as the General Purpose Instrumentation Bus (GPB) could also be utilised in the design.

Section 2.3 has identified that commercial preference from the end users is expected to drive the substation industry towards the solutions of fully open multi-vendor systems, or at least, mixed vendor sub-systems. However, the Working Group has found that the introduction of standardised protocols for data exchange between devices of different manufacturers is not yet common practice. Without adequate progress, the lack of suitable standards will limit the co-ordination and functional integration within substation secondary equipment.

It is worth noting that recent progress has been made in IEC between TC57 and TC95 on a protocol standard for the informative interface for substation secondary equipment. This will be voted upon in 1996, and should begin resolving some of the problems. However, several other standards are needed to complete the work, and new Working Groups have been established to look into these areas.

#### 4.3 Information technology

With increased information becoming readily available from modern secondary digital equipment, together with the desire to cut substation operational costs, by cutting staff, then there is a clear opening for deploying more information technology in the substation. A prime example is the use of a man-machine interface on the substation control desk, where all data and switching operations are centred. Portable software tools for setting and commissioning functions, such as protection, are also becoming standard options.

#### 4.4 Further technology options

Apart from the immediately available new digital technology mentioned above, several ideas for further advances are being discussed. Three that could impact upon substation secondary systems are:-

**Integrated database.** Integrated functions are designed to share information. Some researchers have identified that it is possible to create a single real time database for the substation, where all data would be collected. Every application function would access this database over a serial data link to obtain the necessary voltage and current samples and status information. With this technique it would be no longer necessary to hardwire every function to the primary information source. In this way, it is claimed that the investment costs of the secondary equipment could be reduced.

**Fibre optic communications** are expected to challenge many of the traditional arguments that have influenced the physical location of the substation secondary equipment. The prime advantages include interference free transmission, wide bandwidths, plus no effective limit on the distance that information can be transferred across the substation. This would encourage the main computer resources to be in a common room, protected from electromagnetic interference. Local analogue to data conversions would need to take place at plant level, to ensure that electrical interference from the primary plant was controlled at source.

**Intelligent Systems.** With the drive to run most substations remotely, and, therefore, un-manned, then the value of a standard substation MMI is limited to occasional visits, such as maintenance periods. What is needed is the intelligent and automatic analysis of data and events. Expert systems offer an opportunity to do this. They are of interest to a wide variety of industries, and new developments are expected to benefit substation design and working practices. Intelligent systems would operate to extract highly concentrated information for the user without transmitting a lot of data back to the control centre.

### 5. CHANGES IN THE ELECTRICITY MARKET

The changes in the market place for electricity are expected to positively influence the rate of deployment

of new integrated secondary systems. Many countries are actively deregulating their laws governing the supply of electricity. As in other fields, governments are moving away from direct control of the electrical power industry, and encouraging more open competition. This will lead to new pressures to reduce both the initial cost of substations, and the time to build, run, and maintain them. The key factor driving the integration of functions within substation secondary equipment is, therefore, the reduction of overall life-cycle costs.

#### 5.1 Life-cycle cost control

Substation related costs for electricity suppliers break down into three main areas; initial investment, operational, and maintenance. Cost control by using more automation is addressed separately.

**Initial investment costs:** The engineering and erection costs of new substations are lower when the amount of installed hardware is less, while the construction time reduces. Pre-testing of the secondary equipment can be carried out at the manufacturer's works, instead of on-site. This can tighten time-scales, reduce costs, and accelerate the initial flow of revenue.

**Operational costs** could be reduced by the increased availability of information about the status and capabilities of the primary equipment. This would allow higher loading of the primary system and potentially delay primary equipment replacement or extension. New secondary investment could include enhanced remote control functions and / or condition monitoring of the primary plant.

**Maintenance costs.** The total maintenance cost of the primary and the secondary equipment needs to be evaluated. The maintenance of the secondary equipment will probably demand higher skills because of the increased complexity of the system. However, the maintenance needs of the primary equipment should decrease. For example, it is forecast that the introduction of an effective condition monitoring scheme for the primary plant will allow electricity suppliers to move away from relying totally upon regular primary equipment maintenance periods. The alternative approach being discussed is that of an event driven strategy, where the need for maintenance would depend upon detecting changes in one or more identified measurands. Within the secondary equipment, the maintenance philosophy will be supported by further developments in the error detection and the automatic supervision of modern digital hardware.

**Automation.** It is predicted that the pressure to reduce operational manpower will create a need to automate more of the day to day operations within substations. This could become a major factor in decisions to upgrade secondary systems. Automation can both

reduce operational costs and improve quality of supply to consumers by cutting the average period of disconnection. Quality of supply is a measure that is being introduced to assess electricity suppliers.

## 5.2 Organisational changes

New technology, and the need to reduce costs, is leading to a re-assessment by electricity suppliers of the best organisation to specify, build and maintain substations. Decisions on what work is done internally, and what is contracted out, are being reviewed. Relevant issues are:-

**Departmental organisation.** The introduction of integrated secondary systems offers the opportunity to change the conventional type of organisation. Historically, this has been led by separate departments of protection, control, instrumentation and communications. Merging these into one secondary equipment department is a possibility. This would accelerate the introduction of the new secondary technology by avoiding the difficulties inherent in separate specifications, budgets, investment plans, etc.

**Software Management.** As the complexity of the software increases with functional integration, smaller utilities and power companies may not wish to employ the skilled manpower needed to manage substation related software. The alternative will be to rely on maintenance contracts, handled either by the manufacturer, or by a consultant. It is assumed that larger concerns will prefer to employ such specialists.

**Training.** Many electricity suppliers aim to minimise the number of employees to cut operational costs. For the remaining staff, it will be necessary to set up a training programme to develop new skills, appropriate to the operation and maintenance of the new secondary technology.

**Configuration management.** It is recognised that a stronger focus is needed to organise and improve the structure of information held in drawing and filing systems within end users' offices. The modern term being used to describe the new methods refer to 'configuration management' of all the information relating to the secondary equipment. The two cornerstones of the technique are the ability to trace all changes, and the ability to reconstruct any previous version of hardware, software and documentation. The new approach aims to counter the problems of the rapid increase in information availability, and the shortening technology life-cycle.

## 6. CONCLUSIONS

The paper has presented the background to how the introduction of digital secondary systems in substations will lead naturally to the integration of functions into a lower number of hardware devices.

It has highlighted the major influences that will affect the design of the complete secondary system of the electrical substation. To maximise the perceived benefits, the system has to integrate the functions of protection, control, instrumentation and communications into a single system. The technology will be based upon a complete digital solution, both at equipment level and for the serial data communications that are needed to link elements together.

Faced with little growth in electricity consumption in many countries, electricity suppliers, in both the private and public sectors, will need to have a more active strategy to manage, and upgrade their existing physical assets. Consequently, to meet the full requirements of the end user, the solution must be equally suitable for new substations, and be capable of being built into refurbishment programmes on a progressive item by item basis.

It is foreseen that the impact of the new secondary system technology will contribute to management decisions to merge the once separate departments inside power utilities and companies.

In overall conclusion, the Working Group recognise that the most important driving force will be the reduction of the total costs of EHV and HV substations. These 'life-cycle' costs will shape and direct what is perceived by end users as the 'best' solution for an integrated secondary system. They will also effectively govern the rate of deployment of the new technology. However, to release the full values of integration requires that the senior managers of power utilities and companies are willing to take a medium to longer term view of the benefits, rather than a short term perspective.

## REFERENCES

1. B. Svensson, J.M. Theunissen, A. Newbould, J.C. Nunes Bianco; 'Configuration of substation secondary equipment'. [CIGRE Symposium on integrated control and communication systems, August 1995, Helsinki. WG 34.07 Paper.]
2. C. Guilmain, C.G.A. Koreman, S. Lemmer, C.M. Parker; 'Functional integration within substation secondary equipment'. [CIGRE Symposium on integrated control and communication systems, August 1995, Helsinki. WG 34.07 Paper.]
3. P. Fauquembergue, M. Kezunovic, M.V. Gonzalez Sabato, A. Sanz. 'Intelligent system applications to protection, control and monitoring within substations'. [CIGRE Symposium on integrated control and communication systems, August 1995, Helsinki. WG 34.07 Paper.]