OPERATION EXPERIENCES WITH INTEGRATED CONTROL SYSTEMS FOR SUBSTATIONS

Dipl.-Ing. H.-J. Hylla, Dipl.-Ing. R. Trebst
Mitteldeutsche Energieversorgung AG
Abteilung Leittechnik, Magdeburger Straße 51, D-06112 Halle / Saale (Germany)
Tel.: + 49 345 216 2571 – Fax: + 49 345 216 2115 – E-mail: Hans.Hylla@MEAG.de

INTRODUCTION

The political and economic changes of the newly-formed German states caused new requirements of the electrical power supply. The basic demand on a more effective utilization of the power network leads to the substitution of the existing and historically evolved substation and protection systems. This paper discusses the different aspects of the substitution process as well as the general changes in power system management philosophy. Finally practical remarks and hints are given for further projects and standardization procedures.

MOTIVATION

The Mitteldeutsche Energieversorgung AG (MEAG) is the main regional power supply company in the southern part of Sachsen-Anhalt. The MEAG receives 70 % of the total power demand from the VEAG. Besides an in-plant generation of 7 % the remaining energy is imported from industrial power stations.

The total power consumption in 1997 was about 5304 mill. kWh, the maximum load in this time period was 996 MW. The 110-kV overhead system consists of a network with approximately 2500 km system length and a total number of 96 primary substations. 53 of these primary substations are owned by the MEAG.

The 110-kV power system management and load management are carried out in the MEAG main administration in Halle, Germany. Three load dispatching centres are installed in Halle, Dessau and Klostermansfeld for power system management of the medium-voltage (MV) distribution networks. The MV distribution system consists of 3245 km of underground cables, 4298 km of overhead lines and about 7000 secondary substations. Preferred MV levels are 20-kV and 15-kV historically evolved.

This paper discusses the use of substation control and protection systems in the primary substations of the MEAG. The technical demands, the arised problems and the present introduction experience are mainly focussed in this paper.

The inauguration of the first primary substation equipped with digital substation control and protection was carried out in March 1996. Due to the fact that at this time the used technology was already introduced and proven the initial situation of the MEAG is presented first of all.

INITIAL SITUATION

MEAG is a regional utility company in the newly-formed German states. The breaching of the Wall lead to a fast privatization of trade and industry. Frequently the technical renewal process of the electrical power systems in East Germany was assumed to be a greenfield project. The historic situation in 1991 has to be regarded subtly differentiated:

- The electrical power network and substations were strongly obsolete and as a result susceptible to faults.
- The total annual energy consumption was reduced to a value of about 30 % compared with the values before 1989.
- The 110-kV power system was suddenly oversized.

The existing remote control systems based on different technical standards including relay control systems of the sixties and microprocessor-based substation control systems of the late eighties. The equipment was produced by two different manufacturers but the used devices were totally incompatible concerning hardware and protocolling.

The system management of the 110-kV power system was carried out by the help of an illuminated mimic diagram and a so called BLV-type solution computer support uniformly used in all GDR load dispatching centres. Due to a missing control direction switching operations were directed by phone and executed manually. The switching staff had to drive to unattended substations.

The MV system management was carried out by four load dispatching centres with a partial support of remote control systems. The different demands of HV and MV system management lead to the use of two different telecontrol systems in the same primary substation.

At the present point of view the total information range was remarkably modest. The power circuit-breakers of the outgoing feeders were only controlled. Monitored informations were integrated into a few group informations. In case of disturbance this process often complicated the detection of fault causes.

The MV electrical power network was presented in the load dispatching centres by a paper-based wall plan with a typical length of about 27 m. The network control state was marked with coloured pins which were not always clearly distinguishable.

CONCEPTION

The MEAG division „Power System Planning“ instructed a company group to build a network development study for year 2000 and later. Subsequently the division „Substation Control and Protection“ added the demands for an optimum computer-based system management. The result of the actual state analysis can be summarized as follows:

- The total number of load dispatching centres has to be reduced from four to three.
- All remaining centres have to be equipped with devices from **one** single manufacturer.
- A modern digital communication network has to be built up.
- The process data range of new-formed primary substations is based on a manufacturer-independent demand list arranged according to panel types.
- New-formed primary substations are consistently equipped with digital protection.
- Digital control systems are **not** used at the moment.
- The used telecontrol systems are characterized as follows: existing substations have to be operated limited; the telecontrol interfaces of the load dispatching centres have to be built redundantly.

Some remarks illustrate the decision in 1991 against digital control systems. The known realizations of this modern technology were mainly installed in high (HV) or ultra-high voltage substations. These installations often had experimental character and unsolved problems concerning complexity and parameter assignment combined with extensive costs. As a result the use in distribution substations was unjustifiable in terms of a time limited construction flow.

Based on a confirmed system management strategy and calls for tenders in 1992 a total number of 70 telecontrol substations were installed and put into operation in the years 1992-1996. Fig. 1 shows the central connection diagram of the reconstructed primary substations. The resulting wiring and cabling complexity lead to a revision of the digital control system decision in 1991. In 1996 a Europe-wide call for tenders according to digital control and protection systems was carried out.

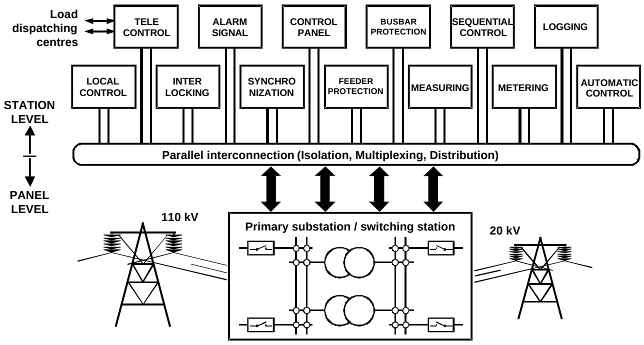

Fig. 1: Central connection diagram

DEMANDS ON SUBSTATION CONTROL AND PROTECTION

The demands on substation control and protection depend mainly on the operation philosophy of the individual supply companies and the resulting technical realization. Interconnection utility companies gained experience with the first generation of substation control and protection systems in the eighties [1]. MV distribution networks were mainly equipped with telecontrol systems often noticeably extended by computer-based functions.

The call for tenders based on the VDEW reference list and was completed with additional demands and characteristics of the MEAG:

- The MV switching station has to be controlled completely by compact and economic panel control units.
- Protection and control systems have to be supplied by MEAG.
- Serial connection of all protection units in accordance with IEC 60870-5-103.
- Placing of a number of primary substations to one single manufacturer of control and protection systems.
- Supply of the local control computer by MEAG.

Swiching stations in electrical distribution networks can be divided into three groups:

- 110-kV busbar substations with MV switching station
- 110-kV H-based substation with MV switching station
- MV switching station without 110-kV part (rare)

Fig. 2 presents the relation between the number of functional units in the HV and MV level [5]. A cost-limited use of MV panel control units depends on restricted functional demands of the users and on the manufacturer´s possibility to meet all utility company requirements. Most functional units are outgoing feeder panels requiring only one measured value, the conductor current. The discussion about telecontrol feeder panel earthing lead to the demand of an additional monitored measured value, the reverse voltage. To avoid more expensive equipment the binary converted value of a capacitive voltage divider was connected to a user configurable signal input.

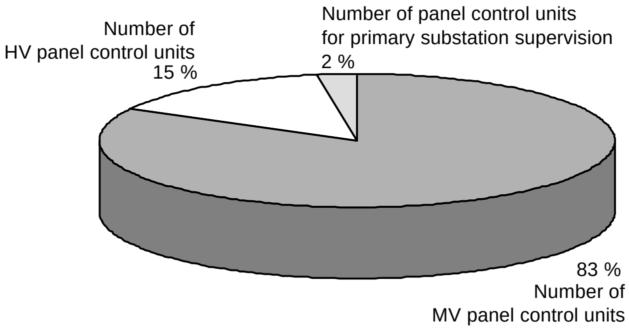

Fig. 2: Number of panel control units in MV primary substations

BASIC STRUCTURE OF SUBSTATION CONTROL AND PROTECTION SYSTEMS

Substation control and protection systems are typically divided into the station control level and the panel control level. The local control is connected to the station control level. A compact version of the higher network system management is used by the MEAG. Fig. 3 shows the structure and the functional division of the used digital substation control and protections systems.

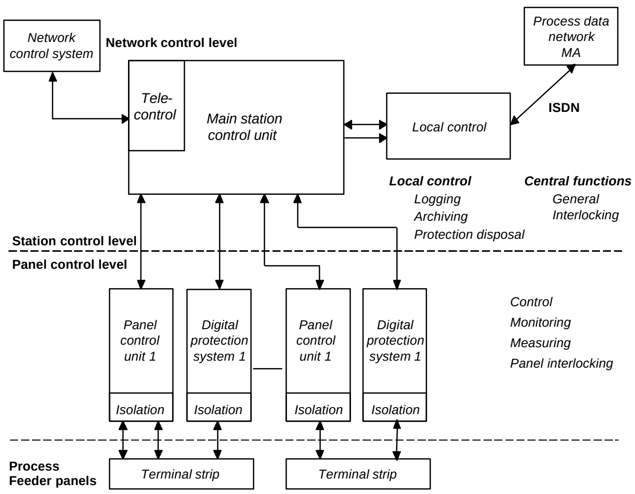

Fig. 3: Digital substation control and protection systems -structure and functions –

In 110-kV busbar substations the panel control units are installed in decentrally placed relay buildings near the related outgoing feeder. In simple constructed primary substations a central installation in the control room is preferred.

The substations are unattended and telecontrolled from the control centres in normal operation. In case of disturbance the switching staff should use the local control by preference. The mosaic mimic diagram of the panel control level allows locked switching functions in case of a local control failure. Independent mechanical resp. electrical control is supplied by the switchgear cell operating functions.The switching authority is determined by the state of a station-remote keylock switch installed in a control-room cubicle and a local-remote switch directly installed in the outgoing feeder panel (see table 1).

Position l-r switch	Position s-r keylock switch	Local control	Station control	Remote control
Remote	Remote	-	-	Effective
Remote	Station	-	Effective	-
Local	Remote	Effective	-	-
Local	Station	Effective	-	-

Table 1: Switching authority depending on the control station

Panel and station control level are coupled by an optical waveguide system. Panel and station control units are installed non-redundantly. The 110-kV panel control units are assigned to a single station control unit which is realized as a mimic diagram and represents the safety level for the local control level. On condition of working panel control units the station control level permits locked switching. In case of a faulty panel control unit switching is still possible unlocked.

To obtain selected informations independent of the station control system an additional emergency information system is installed using separate terminal strips of the process controll level. The emergency system provides a minimum information range which is independent of the normal connection systems. In case of faulty control and protection equipment this additional information is used to determine primary equipment faults requiring local control.

Designing the station control system structure independent of the panel control units causes a consistent compliance with the control hierarchy structure:

- Station control unlocked
- Station control locked
- Local control
- Remote control.

The control authority is conferred in compliance with the practical principle: „A short process distance leads to a better possibility for gaining the switching authority.“

The decision between station and local control is made by the station control keylock switch. The remote control authority is given by the control-room keylock switch.

The basic station control function of remote controlling a single device from different control centres has to be avoided or has to be normed by organizational measures. The integration of switchgear interlocking equipment in the substation control system leads to a decrease of wiring and cabling complexity. All system management demands are covered by the possibilities of software-based switchgear interlocking. The integrated switchgear interlocking permits even a gradual substation start-up which is essential for reconstruction measures.

Electromagnetic compability

Suspected problems concerning the interference of the in-process panel and station control units did not take place. The in-process equipment is designed according to current EMC standards and hence electromagnetic interference problems are solved by constructional measures.

The communication between and even inside the in-process control and protection equipment is carried out by optical waveguide systems. The modular extendable process periphals of the panel control units and the central unit communicate via optical waveguide star couplers. Very small and isolated potential areas avoid coupling of disturbing and even destroying amounts of energy in electronic circuits.

Serial protection coupling

Protection equipment can be coupled in parallel as well as in serial. The substation control and protection system introduction of the MEAG lead to the exclusive use of protection equipment with a serial standard interface (IEC 60870-5-103). After a long introduction period this standard communication equipment is designed by several manufacturers and shows an adequate quality level.

On principle the serial interface can be used for transmission of monitored informations, measured values, malfunction signals, fault reactances and characteristic curve switch commands. A conscientious selection of standardized and essential informations was carried out with regard to the existing parallel coupling systems.

An essential innovation was introduced by fault filing of the protection equipment. The malfunction listings are buffered by the main control system computer allowing a transmission to the local control computer via a number of serial ports. In case of a receiving malfunction listing the local control computer causes a transmission via ISDN.

The commissioning procedure of the substation control and protection equipment is carried out by means of a simulated power network failure which is generated by Omicron test equipment. This failure causes simultaneous malfunction listings of four protection units (transmission line, bus-tie, transformer on high- and low-voltage side).

Based on this test the dynamic behaviour of the fault filing system can be monitored. By means of self-developed software the malfunction listings can easily be taken from the main data server in the main administration for evaluation. At the moment these tests were realized for the coupling of protection equipment from two different manufacturers with two different substation control and protection systems.

The former VDEW-ZVEI-interface 6 is converted into a European standard which represents an important landmark towards „open“ interface standards. In future the users should support noticeably the interface standardization to prevent manufacturer-specific and hence individual solutions in bus technology as well as in sensor and actor technology.

In future the following characteristics of control and protection equipment are founded on optical waveguide based serial interfaces:

- Network operation
- Process integration
- Reliability
- Extension and open-type conditioning
- Transparency
- Simple and easy services

Main station control unit

The main station control unit represents the central communication node. This device includes the local control unit and the interface to the load dispatching centre. The main station control unit contains general control functions such as station interlocking as well as automatic systems, e. g. automatic transformer transfer. These automatic systems are designed as control system independent and individual devices yielding the following advantages:

- In case of a station control level disturbance the station operation is still guaranteed.
- The parameter assignment, testing routines, maintenance and compatibility are simplified.
- All substations are based on the same function and control structure.

Considering systems engineering aspects a function integration in substation control and protection systems should be preferred. However the existence of several different equipment manufacturers and the resulting number of different parameter assignment tools lead to the decision of standardized and independent devices.

A central radio clock synchronizes all component clocks used for real-time processes. The serial connected protection units are also supplied with the necessary time base and the synchronizing pulses. Unfortunately a manufacturer-independent synchronization system is not available. Hence the local control unit is equipped with a separate radio clock.

Local control

A fundamental demand for the local control unit is the uniform display and control procedure for the complete supply company [2]. Considering different manufacturers as well as different substation control and protection equipment the realization is often complicated [3].

The MEAG solution of a company-wide display and control concept even goes one step further. The station control is carried out by a compact version of the power management system used in the load dispatching centres and in the system control centre. This system consists of a PC-based solution equipped with two high-density 17-inch displays. The first display shows permantly the system management logging file, the second display represents the station survey diagrams. According to the high resolution of 1280 x 1024 pixels nearly all substations can be presented on a single screen. Hence this complete overview allways guarantees a safe and simple switching operation. The display of the panel control level is not necessary due to the station control level details. The local control data model is equal to the system management data model allowing an automated generation using the existing I/O interfaces.

This almost exclusive mouse-based communication interface is accepted very well by the operational staff. Even employees not yet familiar with PC systems only need an unexpected short training period.

INTEGRATION IN THE POWER SYSTEM MANAGEMENT

Demands on digital substation control and protection systems are based on the substation operation as well as on the power system management requiring unattended substations. Several aspects of the power system management strategy are discussed elsewhere in this paper explaining the demands on the used equipment. Here some more remarks are given concerning the complete concept of control centres, remote control as well as substation control and protections systems of the MEAG.

The 110-kV power system is managed by the MEAG main control centre in Halle. The system management of the MV power systems is carried out by the three load dispatching centres „East“, „West“ and „South“. The first MV substation equipped with telecontrol devices from the SAT company was put into operation in March 1993 in the form of a pilot study. Simultaneously the power system management of the load dispatching centre „East“ commenced test operation.

The start-up of the 110-kV main control centre in Halle was in July 1993. The process data supply was carried out by data allocation in the terminal blocks of the load dispatching centres. Hence the main control centre is supplied with those informations which are important for the 110-kV system power management.

The other two load dispatching centres and the redundant telecontrol terminal blocks were put into operation until April 1994. In the same period the existing (old) telecontrol systems were coupled with the new telecontrol nodes of the respective load dispatching centre. The remaining old systems were substituted by new telecontrol technology.

Until the beginning of 1997 70 substations were completely equipped with telecontrol systems. Hence all old substations which were susceptible to faults could be completely renewed. The system power management of the HV and MV power networks was set on a new and remarkable high level of quality:

- The 110-kV substations can be operated unattended. Switching operations are carried out by the control centres via remote control.
- All HV and MV power networks are completely integrated in the system power management. Therefore complex display devices (mosaic-type mimic diagrams, wall survey diagrams) are obsolete.
- Detailed individual informations are available including real-time stamp informations of the digital protection equipment.
- Topological interlocking, on-line load flow calculation, automated switching sequences and network reliabilty calculations increase the operation security of the control staff in the control centres.

In 1997 the first substation was put into operation which was equipped with an integrated control and protection system based on AM 1703 and serial protection coupling (see fig. 4). The decision for digital components was founded on a total cost comparison between a substation concept with central wiring and telecontrol and a digitally equipped substation.

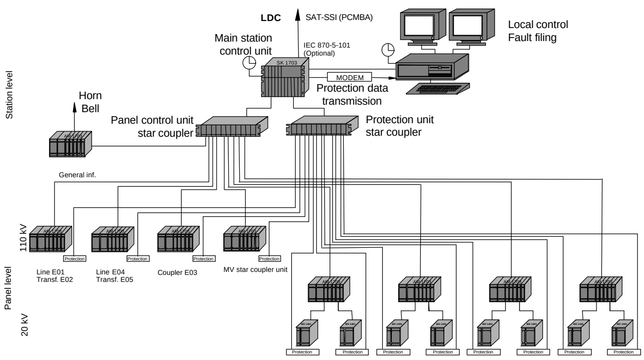

Fig. 4: Survey diagram of the primary substation „Radis“

TELESERVICE AND TELEDIAGNOSTICS

In the last years electronic equipment is characterized by an increasing reliability level. However failures and resulting operational limitations cannot be avoided completely. Redundance and emergency concepts are effective measures as well as a powerful teleservice and telediagnostics concept.

Most operational functions of modern control and protection systems are software-based solutions. The typical software complexity leads to a step-by-step debugging of the inevitable software bugs. By means of teleservice failures in practical operation can be analyzed by experts from any possible place. Therefore access assignment and protection against improper use are important demands on the telecontrol access concept.

SYSTEM PARAMETER ASSIGNMENT

The different demands of the utility companies lead to the parameter assignment concept of modern substation control and protection systems. The complexity of parameter assignment is often the main reason for introduction failures and problems. Hence the operational staff should be trained in detail by the manufacturer.

The different parameter assignment tools (control system, protection system, test operation, different manufacturers, several software releases) normally cause redundant data input and data management. A practical solution might be the often quoted integrated source data pool. This data pool consists of a SQL-based data base and should be designed and maintained by the respective utility company.

Practical solutions are not yet realized and therefore standardization activities concerning the data model are necessary in the near future. Public system interfaces and an object-oriented data model concept are important requirements for a universal system parameter database. Furthermore object-oriented planning and design lead to a remarkable decrease of parameter assignment failures which are typical for flexible system technology.

EVOLUTIONARY PRODUCT DESIGN

The innovation cycles of computer and automation technology differ from each other considerably. The typical PC life cycle is about 2-5 years. Substation control and protection systems are designed for a typical life time of about 15-20 years. In this period the operational functions have to be guaranteed by supplying compatible equipment as well as useful or necessary extensions. This contradiction between short component life cycles and the long life time of the complete product is an obvious manufacturer problem.

The users need modern but also reliable equipment. Refusing all innovation cycles leads to obsolete systems in consequence. In contrast the test and use of all new ideas yields a decreasing system stability and additional work to clear the typical „teething troubles“. Hence the downwards compatibility of all components represents an important system criterion.

CONCLUSIONS

The improved quality of substation control and protection systems presently allows an extensive use. Therefore MEAG has equipped approximately 450 MV switchgear cells with compact panel control units over a period of 1 and ½ years. The solution of arising logistical problems shows a remarkable quality level of standard substation control and protection equipment.

In comparison with conventional systems a cost saving potential can be noted depending on a high level of substation equipment standardization. Individual solutions have to be avoided. As well all technically possible system functions have to be checked carefully for their importance. Each additional function leads to an increase of complexity, higher quality tests and a resulting cost increase. Due to the standardization of a sensor-actor bus system the system structure will become more decentralized in the near future. We, the users of these complex and cost intensive systems, should demand strictly the standardization of these new emerging serial communication network systems.

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