AN INNOVATIVE APPROACH FOR DISTRIBUTION SUBSTATIONS IN A COMPETITIVE ENVIRONMENT

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The new generation of gas-insulated switchgear considers the needs of modern life-time asset management.
A welded stainless-steel gas module seals the unit entirely and makes it maintenance-free for life. There is no need for gas checks or topping up.
The welded gas module and screened insulation system provides immunity to harsh environments.
A flexible concept for busbar assembly simplifies the installation of current transformers. Erection times are significantly reduced.
It offers a convenient cable installation using bottom-entry and front-entry cable plugs, and access for cable testing from the front. The new design of gas modules and the busbars provides a compact design with front-side access only.
The migration of local control and metering functions into protection relays is an attractive option for efficient and economic distribution system management. Sharing of data by all involved functions, and data communication from the feeder level up to system level, fully utilises all viable synergies.

THE NEW BUSINESS ENVIRONMENT

The value of distribution switchgear is determined by how well it meets the needs of the user. In these changing times it is difficult to provide this value because of the rapidly changing needs and rules by which utility companies are operated.
Many of these new business factors are methods to stimulate competition in the electric utility industry. This new competitive environment is visibly affecting the traditional vertically integrated utilities of the past and modern distribution switchgear.
Thus, forthcoming investments for new- or retrofit projects in distribution switchgear challenge utility managers with strategic considerations:
- set long-term objectives
- include provisions for possible future substation automation schemes and other applications
- assess the competitive advantage
- quantify the return on investment
- discern an appropriate strategic direction from the various options proposed by vendors, consultants, and other utilities.

This must not be restricted to the switchgear itself. Best practice in asset management must cover all distribution system management aspects.
Therefore the market and the globalisation of the power distribution business demands adapted products. Customer requirements stay at the centre of interest. The globalisation, the opening of markets within Europe and the growth of the markets in Asia and South-America have doubled the number of switchgear manufacturers and thereby confronted the user with a variety of switchgear types.
Although the market forces the manufacturers to meet a multitude of different customer requirements, a market survey has revealed recurrent common features.

A TOTAL DESIGN APPROACH

Traditional switchgear had been designed with air-insulation and with three major components, e.g. high voltage switchgear, instrument transformers, protection and control. A quantum leap in compactness, performance, availability, reliability, personnel safety, freedom from maintenance, insensitivity to the environment and minimisation of life-time costs has been achieved by a total design approach.
Using this approach, individual components from high voltage switchgear, optional unconventional instrument transducers, numerical relays and control, modern sensors and actuators are matched together as an economic system.

The new generation of gas-insulated switchgear considers the needs of modern life-time asset management (Fig.1), [1].
A welded stainless-steel gas module seals the unit entirely and makes it maintenance-free for life. There is no need for gas checks or topping up [3].
The welded gas module and screened insulation system provides immunity to harsh environments.

A flexible concept for busbar assembly simplifies the installation of current transformers. Erection times are significantly reduced.

Fig. 1, Modern GIS panel

It offers a convenient cable installation using bottom-entry and front-entry cable plugs, and access for cable testing from the front. The new design of gas modules and the busbars provides a compact design with front-side access only.

Innovation stages of gas-insulated switchgear

17 years ago, in 1982, the first gas insulated medium voltage switchgear with vacuum circuit breakers was launched onto the market. Compared with air insulated equipment, it has significant advantages:

- encapsulation of all live parts in SF_6 gas-filled enclosures
- total exclusion of pollution, moisture and condensation or small living creatures which may influence the high voltage parts
- no oxidation of contacts or connections
- no hardening of lubricants
- secondary windings of current transformers totally separated from high voltage parts
- drive mechanisms accessible at all times

The high voltage parts of this concept were fully maintenance-free but the joints between individual chambers and the mechanical and electrical entries into the chambers were sealed with O-rings and the possibility of a certain leakage rate had to be accepted. The gas pressure was therefore monitored and was it recommended to check the gas pressure and quality every 10 years. This was the same interval used for regreasing the drive mechanism of the circuit breaker.
In 1983 ring main units were launched onto the market with switches sealed - without any gaskets - into a seam-welded chrome-nickel-steel container. This unit is in service in many thousands of distribution system substations and is totally maintenance-free. Neither the gas chambers nor the drives can or need to be serviced. This concept has also proven itself and is widely used.
In 1992 the fully maintenance-free vacuum circuit breaker was launched [2]. Due to the correct combination of material and special lubricants even the drive mechanism became maintenance-free for the lifetime of the equipment. This new circuit breaker completed the list of components necessary for a maintenance-free switchgear.
In 1996 this concept was extended to include a switchgear with circuit breakers up to 24kV, 1250 A. The first circuit breaker switchboard which was sealed for life, without any need of gasworks on site [3].
However, with traditional GIS equipment – particularly in the range up to 36kV, 2500A, 31.5kA - there are a number of areas for further upgrades:

- the need to check SF6 levels
- c.t. accommodation
- cable access
- provisions for substation- and distribution system automation

Designs have been developed over time to eliminate many of these deficiencies. However, a new total design approach for gas-insulated switchgear excels improvements of individual parts.

FEATURES OF A MODERN GAS-INSULATED SWITCHGEAR

The switchgear design concept meets the requirements of the industry as well as utilities, with ratings up to 36kV, 31.5 kA, 2500 A.

Panel design

For environmental immunity, compact and maintenance-free design, particular requirements must be met and special features have to be provided.
It has to be an SF6-insulated and metal-enclosed medium-voltage circuit-breaker switchgear in modular construction designed according to IEC 60298.
The modular panels of a single-busbar switchgear consist of hermetically welded modules filled with SF6-gas. The busbar module contains the combined disconnector and earthing switch. The circuit-breaker module contains the vacuum circuit-breaker rated up to 2500 A and the cable. The rear panel connection is implemented with a pressure-relief duct per panel running from the bottom to the top (Fig. 2).
Sealing for life against loss of gas and - almost more important - against ingress of moisture is essential. The only known method which is beyond question is a completely hermetically seam-welded metallic enclosure without gaskets. The motion of the drive mechanisms has to be transmitted through stainless steel bellows which are seam-welded into the enclosure, just as in the vacuum

interrupter itself. Even the bursting disc which is provided for ultimate pressure relief in the event of internal fault, has to be seam-welded in position.
To absorb initially enclosed moisture from the components, dessicant bags are fitted in each container. Once in operation however, no significant quantity of moisture can enter the container and dessicant renewal is unnecessary.

Instrument transformers

The busbar voltage transformer and the feeder voltage transformer can be plugged into separate sockets of the modules.
The current transformers have to be ring-core transformers mounted on the module couplings .
All transformers are located outside the gas compartments and are thus freely accessible.
There is a strong economic incentive to also accommodate unconventional instrument transducers. They save space and supply better suited measurement quantities for further processing in IEDs.
The small-signal current transducers are mounted in smaller ring-core housings, and the resistive voltage dividers are directly mounted on a socket with a particularly small housing.

Modular coupling technique

Only a modular coupling technique enables installation on site without gas work. It serves to interconnect two hermetically welded modules.

Mechanical and electrical control board

The three-position switch and the circuit-breaker are generally motor-operated.
Manual control of the three-position switches, the circuit-breaker, the mechanical switch-position indication, and the mechanical interlock are integrated in the mechanical control board.
For safety and ease of operation, the actual electrical control board is located in front of the mechanical control board. The electrical control board comprises the human-machine interface of a bay controller such as SIPROTEC [7] and a so-called IVDS-system like CAPDIS, with active zero indication (active indication of safe isolation from supply).
However, the switchgear is also designed as to integrate modern numerical substation automation systems such as SICAM [9]. Remote access is feasible via copper wires (RS485 ports) or fibre optics (FSMA ports).
Nevertheless, the design allows the use of both, traditional multi-core cabling or modern numerical substation control.

Statistical life expectancy and service experience

The gas filling of a hermetically welded enclosure and the integrity of its insulation - with today's materials, manufacture and test procedures - is statistically good for some 1600 years.
Regarding the life of the silicon rubber insulation – beside the ageing tests - some 25 years operation experience is recorded even on high voltage outdoor equipment.
Cast resin components such as bushings - have been manufactured since 1958 practically without alterations and have impressively proven their durability in this time period.

Design for zero maintenance and environmental immunity

A crucial part of this switchgear are the hermetically welded modules. They contain the corresponding primary switching device, the maintenance-free vacuum circuit-breaker or the three-position switch. Only a solution without gaskets enables a maintenance-free and environment-independent application, as welded modules satisfy even the hardest sealing problems such as the ingress of humidity. Among others, the user is relieved from gas quality checks. Most modern production technologies, such as laser cutting and welding procedures and integrated leak testing systems used in the manufacturing factories guarantee the customer that the modules are gas-tight for life.
A bolted coupling interconnects all modules. Only the concept of this coupling enables the modular construction (Fig. 2) of the panels and the interconnection of the hermetically welded modules.

Fig. 2 , Panel modules

With this concept, the user can replace modules or panels, extend the switchgear or remove it after its service life without any gas work.
The compact construction of this gas-insulated switchgear is not only due to the gas insulation and the combined disconnector and earthing switch, but also to the co-ordinated, protection, control and metering system as well

as the unconventional small-signal current transducers and resistive voltage dividers.

SF_6 insulation of the high voltage section protects against environmental influences. This modular concept has proven its impunity to the environment in flooded switchgear rooms in South America.

Maintenance is less intrusive and takes place only after failures are alarmed by a monitor. The failure can be immediately corrected upon occurrence, resulting in significantly lower (undiscovered) down time of individual components. It is also predicted that this type of event-orientated rather than preventive maintenance saves costs and reduces human mistakes to a minimum.

Most modern 3D-CAD procedures allow the manufacturers to make specific documentation, such as panel sections, exploded and detailed views, front views and constructional data available to the customers at a very early stage. As for the after-sales-service, the new media such as e.g. Internet and Intranet provide new possibilities for documentation, spare part orders, switchgear extensions, service and hotline. Making consequent use of these possibilities, the concept contributes significantly to optimising the integration of the switchgear in the customer's processes.

INNOVATIONS TOWARDS THE PROCESS SIDE

Significant advances have been achieved in protection and substation automation in the recent decade. All these innovations went into one single direction, from the protection relay respectively the feeder control unit via substation control system or remote terminal unit RTU further up to a remote control centre. Now there is the technology available for innovations on the process side, e.g. on instrument transformers, status and supervision sensors.

Modern numerical relays and intelligent electronic devices, IEDs, virtually do not burden the instrument transformers for data acquisition. These lower requirements allow new measurement transducing approaches, particularly, if the traditional measuring inputs of relays and IEDs are modified to accept more appropriate signals. Some of today's technical options exceed the economic viability in distribution switchgear. Bearing cost and complexity in mind, passive transducers meet the technical and economic requirements best.

Small-signal current transducers with adapted shunt burden R_b cover a linear range of some $1:10^5$. They supply relays and IEDs with saturation-free current proportional voltages within their ratings, even with fully displaced fault currents.

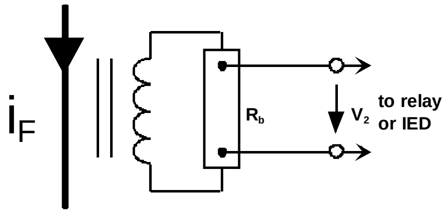

Fig. 3, Small-signal current transducer

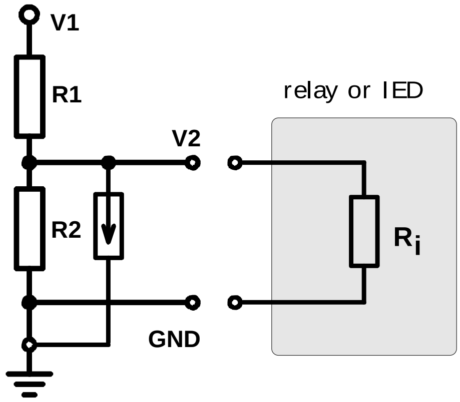

Fig. 4 , Resistive voltage divider

Small and compact resistive voltage dividers are now affordable on each separate feeder. They are free from ferro-resonance and need not be removed while performing high voltage test on the switchgear's associated power cables. As an additional safety measure , resistor R_2 has a parallel surge arrestor for the unlikely event, that R_1 fails (Fig. 4). The GND lead separates the measuring input from the reference potential.

The nominal current-proportional and voltage measurement quantities are still proprietary. Thus Relays and IEDs need to be adjusted to their outputs. However, a working group within CIGRE's Technical Committee TC38 has put forward a proposal for standardisation.

ONE FEEDER, ONE UNIT CONCEPT

In the past, each function of a distribution switchgear was separately performed by function-dedicated equipment. The installation, testing and operation of each kind of equipment has sometimes even been the responsibility of separate departments.

Comprehensive relay and control schemes were engineered and assembled from individual relays and associated equipment. Interwiring between individual components and scheme testing were carried out manually in the manufacturer's or user's workshops.

The migration of local control and metering functions into protection relays is an attractive option for efficient and economic distribution system management. Sharing of data by all involved functions, and data communication from the feeder level up to system level, fully utilises all viable synergies.

The combined Relay & Control Unit provides most standard functions for system protection, control and metering. It replaces three, separate, function-dedicated equipment components, and requires only one set of instrument transformers, control cabling, and supervisory circuits.
One unit can protect, meter, and control a feeder or motor. The unit is suitable for metal-clad switchgear, where the unit is located in the low voltage compartment, as well as for relay and control panels in a separate location from the switchgear. In the latter case especially, the cost

Fig. 5, Numerical feeder unit assembled at the panel front

of engineering, assembly, panel wiring, testing, and commissioning is drastically reduced.
Traditional cabling is only done towards the 'process side', i.e. switchyard and d.c.-supply. For metering, alarm annunciation and supervisory control, serial communication links may be used.
A further upgrade is the optional use of fibre optic cables. Their inherent galvanic separation significantly reduce the total noise generated into the station battery circuits.

Scope of functions

Which technical functions are selected out of the total scope depends on the requirements for a particular feeder, as well as on the service policies of the power distributor. For example, in applications with separate control facilities, an advanced protection relay which displays meter readings will suffice [7]. For a totally integrated approach, a configurable graphical display shows the feeder mimic diagram, meter readings (current, voltage, and power), and diagnostic data (Fig. 6).
A keypad enables local access to data, manual control, and alteration of relay set points. The unit features on-screen menus and password-security.
As an alternative to using the front-panel display and keypad, the man-relay dialogue is possible remotely via the utility's communications network, or off-line by a temporarily connected laptop computer via a data port on the front panel.

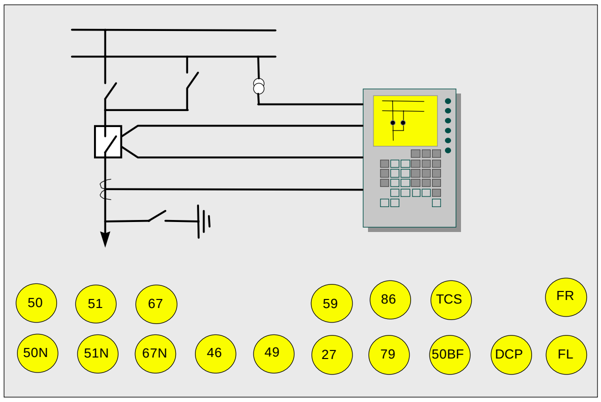

Fig. 6, Relay as host for metering and control

All settings and parameters may be selected in an engineer's office, then downloaded at site to the relay via serial data links. For repetitive use, the engineer can create a set of "master settings", so that in future applications only a few settings need be altered.
Since all the data is stored on modern media, it can be made available to anyone that needs it for configuration, operation, analysis or diagnostic. Paper-based filing becomes obsolete.

Dependability and security considerations

A multi-function unit has to satisfy the minimum requirements of each of the embedded functions. In particular, the unit may not compromise on vital issues affecting system security. While a loss of control and metering does not instantly endanger the power supply, a loss of protection would immediately threaten the distribution system. Therefore, a lowering of the existing high performance standards for protection is not tolerable.
The complete hardware system must meet the stringent relay standards concerning dependability, security, working environment, and maintenance.
A loss of metering or supervisory control leaves the remote operator "blind" and allows only slow actions, but it has no immediate impact on the distribution system. Sufficient time remains for troubleshooting and, if necessary, for local control using back-up facilities (Fig.7).
Relays and meters have contradictory current-transformer and voltage-transformer requirements. Whereas relays operate at a multiple of the nominal current and a fraction of the nominal voltage, meters operate exclusively under normal service conditions. Relays require accurate measurement quantities during system faults, while meters only do so during service conditions.
There are two broad classes of metering applied in distribution systems. One for system and equipment monitoring, and one for revenue purposes. For accurate revenue metering, dedicated metering current-transformers are mandatory. For monitoring purposes, however, where less stringent accuracy is acceptable, the protection current-transformers may be shared for both applications.

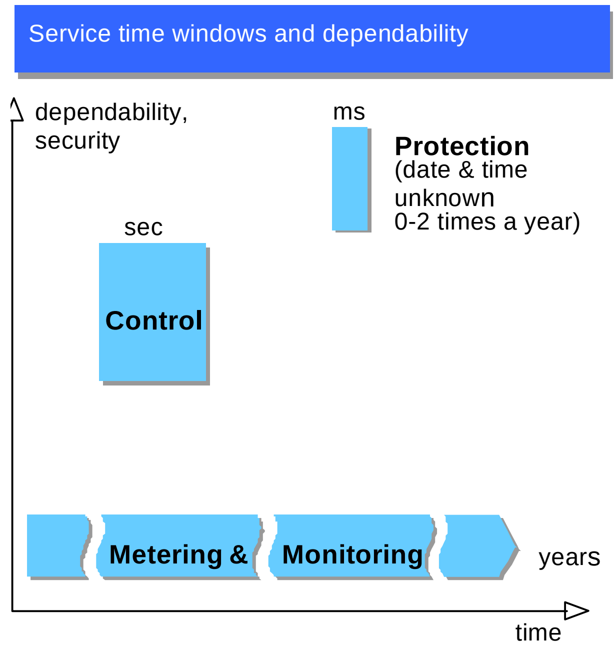

Fig. 7, Different requirements in relaying and control

This makes obsolete having separate metering current-transformers and interposing saturation current-transformers for thermal protection of meters. The relay is designed to relay standards with a thermal-withstand capability of 100 times full load current.
With unconventional instrument transducers these considerations do not apply. The small output signals do not overload the connected devices and the huge linear range is sufficient for both, relaying and metering.

PROVISIONS FOR SUBSTATION AND DISTRIBUTION AUTOMATION

The comprehensive fault report data of numerical relays itself is not the answer to rapid and accurate decision-making processes. The data must be accessed easily, retrieved and analysed, converted into information for the engineer. The engineer must be able to respond for all feeders of the power system as quickly as possible.
Distribution automation schemes are an attractive solution, but have been prohibitively expensive to implement. The primary reason has been that most traditional substation equipment was optimised for dedicated tasks, but had little or no data communication capability.
The use of combined protection and control units, connected to low-cost Enhanced Remote Terminal Units (ERTU), can make advanced distribution automation schemes economical in situations where in the past they were not.

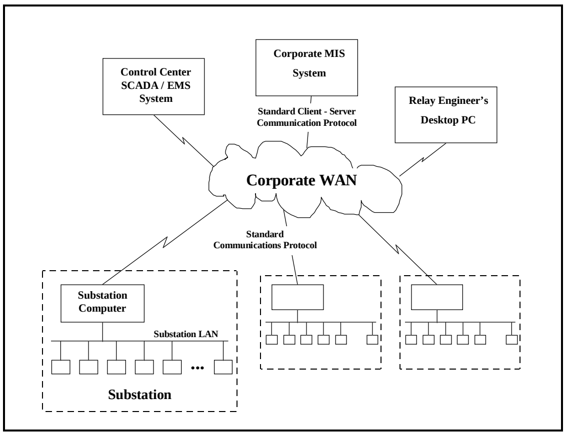

Fig. 8, Remote access to substations by various subscribers

The adoption of standard data communication protocols, such as IEC 60870-5-103, is enabling data communication with devices made by other manufacturers [6].
The proprietary communications protocol formerly used between the Control Centre and the substation has been replaced with a higher - level protocol the IEC 60870-5-101 [9] . The communication to an EMS system located in a Control Centre with an WAN-protocol is via IEC 870-6 TASE.2 (ICCP). This protocol will have more in common with today's enterprise communications protocols than with RTU-style protocols.
An intelligent substation computer or ERTU can also provide substation supervisory control (Fig. 8). In unmanned substations, the operator desk may become obsolete, replaced by temporarily connected notebook computers for service or diagnostic purposes.
A considerable cost of distribution automation has been the physical connection for data communication from the remote stations to the system control centre. Today, low-cost data communications (such as trunked radio and power cable screen communication) make system automation schemes more affordable.
Where such investments cannot be justified, or where data is exclusively transmitted to standard PC-Management Terminals, remote access is feasible via dial-up modems. Star-couplers in the remote stations can "poll" the individual feeder units.

CONCLUSIONS

Gas-insulated switchgear offer the user zero maintenance, environmental immunity, compactness, and thus, efficient use of space as well as economic life-time assett management [5].
The migration of local control and metering functions into protection relays is an attractive option for efficient and economic distribution system management. Sharing of data for all involved functions, and data communication from the feeder level up to system level, fully utilises all viable synergies.
The extent of implementation into modern distribution systems depends strongly on the engineer. It is up to him to incorporate newly available technological options into the power distributor's design and operation policies.

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