Expanding the Scope of Protective Relays across Traditional Boundaries

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Summary

The new competitive environment is having visible affects on the traditional vertically integrated utilities of the past and on modern relay and control system design. Changing needs and rules by which utility companies are operated require new approaches in design and management of protection and substation control.

In the past, each function of distribution switchgear was separately performed by function-dedicated devices. The installation, testing and operation of each set of devices was even sometimes the responsibility of separate departments.

The migration of local control and metering into protective relaying is an attractive option for economic and efficient asset management, although it breaks with traditional practises. Data sharing of all involved functions, and interoperable data communication from the bay level up to system level, fully utilises all viable synergy.

Modern intelligent electronic devices (IEDs) now enable the manufacturers to meet a multitude of different customer requirements and previously dedicated stand-alone functions, e.g. system protection, metering and supervisory control. This combined IED is a comprehensive database of all feeder-dedicated status and event data. It allows economic co-ordination with substation- or distribution automation schemes and one common human machine interface (HMI) concept for all involved disciplines.

However, a one bay, one IED approach requires a reconsideration of traditional engineering and management Pratises. Thus, the German Association of Electric Utilities, VDEW, have established since 1987 working groups, which define their requirements on modern numerical IEDs and serial communications among IEDs. Target of the efforts is the defined scope of core functions and communications interoperability among IEDs of different make.
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2. VDEW Recommendation for Combined Protection & Control IEDs

The initial VDEW recommendations on co-ordinated protection & substation control were more dedicated to subtransmission and transmission type substations. Thus, the VDEW released in 1998 recommendations for distribution type substations, that include the economic use of combined protection, control, metering and supervision IEDs. Products in compliance with the recommendation are in the meantime commercially available from all major relay suppliers.

The IED comprises all feeder-relevant functions such as protection, metering, supervisory control, feeder mimic display and if necessary inter-feeder interlocking.
VDEW divides the combined IED into 5 function blocks, protection, Metering, supervisory control, data base & serial communications and Feeder mimic & alphanumeric display and parameterisation, Fig.2.

**Protection scope**

Fig.3 shows the scope of protective core functions. The IED contains all major functions for the protection of distribution type overhead lines and cables. Specific functions may be covered by extra devices. For economic reasons, the scope shown in Fig. 3 may also come in separate versions, e.g. current-only or current and voltage supplied IEDs.

![Diagram](image)

Legend:
- 52 breaker
- 50N/51N IDMT& DT earth fault relay
- 67N optional directional ground fault protection
- 21 distance protection
- 27/59 over-and undervoltage
- 79 optional auto-reclosure
- 85 tele-protection interface
- FL distance-to-fault locator
- FR fault recording memory
- LM line load monitor

Fig. 3 Scope of core functions

**Metering and Instrument Transformers**

All measuring quantities (current and voltage) are derived from the protection relay’s instrument transformer circuits. 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 power 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, standard protection current-transformers 5 P20 or 10 P10 suffice, Table 1. This obviates the need for separate metering current-transformers and interposing saturation current transformers for thermal protection of connected meters. The IED is designed to IEC 255 relay standards with a thermal-withstand capability of 100 times full load current.

With unconventional instrument transducers such considerations do not apply (chapter 3). The small current-proportional output voltages do not overload the connected IEDs and the huge linear range suffice for both, relaying and metering.

<table>
<thead>
<tr>
<th>Accuracy class</th>
<th>Accuracy at I_N</th>
<th>Phase displacement at I_N</th>
<th>Accuracy at ALF</th>
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<tr>
<td></td>
<td>%</td>
<td>minutes, centiradians</td>
<td>%</td>
</tr>
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<td>5P</td>
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<td>± 60</td>
<td>± 1.8</td>
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<tr>
<td>10P</td>
<td>± 3</td>
<td>-</td>
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<td>± 0.5</td>
<td>± 30</td>
<td>± 0.9</td>
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<tr>
<td>1 FS</td>
<td>± 1</td>
<td>± 60</td>
<td>± 1.8</td>
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<tr>
<td>N/A</td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
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</table>

AFL accuracy limiting factor

Table 1 Accuracies of instrument transformers to IEC 680

**Control, Interlocking and Status Indication:**

The IED shall have provisions for supervisory control of max. 5 switches per feeder,
- 1 breaker
- 2 busbar isolators
- 1 line isolator
- 1 earthing switch

**Communication ports and protocols:**
- IEC 60870-5-103 and in future the extended IEC 61850 standard for communications among IED and station controller
- Feeder supervisory control requires an extension of the present IEC 60870-5-103 protocol
- off-line man-machine dialogue at site: RS 232 port and proprietary HMI protocol

**Operator panel :**
- manual control facilities for all feeder switches
- protection parameter input
- read-out of status- and fault reporting data

**Feeder mimic and alphanumeric display:**
- Dynamic position indication of all feeder switches
- all IED and external event and fault reporting data
- load data in primary values
- relay set points
3. State-the-Art of Combined IEDs and associated Items

**Novel Instrument Transducers**

Significant advances have been achieved in protection and substation automation in the recent decade. All these innovations went in one single direction, from the protection relay respectively the feeder controller via substation controller or remote terminal unit (RTU), right 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, such as proximity switches.

Modern numerical relays and other intelligent electronic devices 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 Rb cover a linear range of some 1:105. They supply relays and IEDs with saturation-free current proportional voltages within ratings of 50A-2500A, even with fully displaced fault currents.

After the pilot phase, these transducers and the associated IEDs are now commercially available.

**Feeder Control and Scheme Logic**

The ‘one feeder, one IED’ approach transfers the external wiring complexity and numerous individual devices into the built-in programmable logic controller PLC. The PLC is an ideal replacement for traditional hardwiring. The controller performs logic, timing, counting, and real-time clock operations. The PLC replaces applications that currently use relays for control, applications such as supervisory control and scheme logic, and applications in which cost is a primary design issue.

Heavy duty relay contacts eliminate the need for interposing relays and result in less panel space and system cost.

Traditional cabling is only done towards the ‘process side’, i.e. switchyard and d.c.-supply. For remote metering, alarm annunciation and supervisory control, serial communication links may be used.

This approach simplifies planning, engineering, stock keeping, assembly and documentation for both user and manufacturer. There are only a few connections to be made to the outside world. This results in shorter lead times and in standardised production of switchgear panels, as the PLC-parameters only need to be downloaded at the final production stage.

Once the few standard control configurations of a utility are standardised and type tested, repetitive quality for all further projects can be achieved, merely by downloading the configurations and parameters from a library.

The PLC is divided into 4 execution levels: Interlocking, (non-time critical), slow PLC (non-time critical), fast PLC (time critical) and measurement processing (cyclic every 600ms).

Engineering of the PLC logic circuits is supported by a continuous function chart tool CFC as per IEC 1131-3, giving flexibility to work with a wide variety of controls. CFC provides transparency to the engineer. The engineering process is limited to application tasks. It also produces its own documentation. Thus the downloaded scheme documentation is always ‘as built’.

The controller and its associated tool is derived from well proven standard industrial PLC products sold in huge quantities.

**Feeder Mimic and Alphanumeric Display**

A configurable and dynamic graphical display shows the feeder mimic diagram, meter readings (current, voltage, power and kWh), and diagnostic data.

A keypad enables local access to data, supervisory feeder control, and alteration of relay set points. The IED features...
on-screen menus and password-security. The mimic diagram editor (Fig. 6) creates the graphic display on the front panel of the IED. Of particular advantage is the programmable function key, where specific switching sequences can be allocated.

Fig. 6  Mimic diagram editor

**Metering**

Modern devices display virtually all electrical quantities which can be derived from the c.t. currents and v.t. voltages with the exception of revenue metering. All measured quantities may be downloaded to a remote management terminal via serial communication ports.

**Fault Reporting**

The IED contains a 5 second fault recording capacity which can be split in up to eight different fault events. Operational and fault annunciation are also recorded to facilitate unambiguous post-fault analysis.  
There are convenient graphical tools (DIGRA, Fig. 8) for the visualisation and analysis of wave form capture. If one excludes transient recording, they offer similar features those of professional fault recorders.
In addition to ordinary wave forms, DIGRA also supports the display of relay characteristics, vectors, angles, impedances, r.m.s. values, sequence components, harmonics and synchronisation of several fault records on a mutual time basis.

4. **Dependability and Security Considerations**

The use of one single IED improves the overall scheme MTBF. While the MTBF of each individual discipline is equal to a scheme using hardware-segregated units, improves the MTBF of the total scheme by a factor of 3, simply because not fitted components cannot fail.
Fewer multi-core cabling and wiring as well as the optional use of fibre optic cables expose the IED lesser to EMI and significantly reduces the total noise generated into the station battery circuits.

Fig. 7  Functional segregation

Thus dependability and security is more an issue of a clear segregation of the implemented disciplines and their parameterisation. The individual functions of the combined IED must operate without repercussions to other functions figure 7. Entrance to any of the other implemented functions can only take place via inputs and output, thus the program sequence cannot be influenced.
The same principle applies to parameterisation. The user can only dialogue with one of the segregated and password-protected functions at the time, Fig. 8.

Fig. 8  Segrated structure of HMI program tool

A multi-function unit has to satisfy the minimum requirements of each of the integrated 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.

5. 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 easily accessible, retrieved, analysed and 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 IED now provides one common data base for all involved disciplines. The use of combined protection and control devices, 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.

Between 1994 to 1998 an international communication standard for the interfaces 5, 6 and 12 could be agreed upon, Fig.10.

- IEC 60870-5-101, Telemetry (interface 12) between system control centre and substation
- IEC 60870-5-102, Revenue Metering (interface 5)
- IEC 60870-5-103, Protective Relaying (interface 6)
- IEC 60870-5-104, Telemetry over wide area networks

Standardisation of the interfaces 10 and 13 had to be postponed, since a common specification for differing and complex practises in Bus Zone Protection, interfeeder interlocking, switching sequences etc. could not be formulated at that time.

This will be covered by the forthcoming extended "object orientated " standard IEC 61850. IEC 61850 also covers process bus communications, i.e. between IED and novel sensors replacing traditional instrument transformers contacts and coils on the MV switches, Fig.12. Efforts are underway for the harmonisation of this standard with the North American UCA-2 standard.

For investment security, modern IED provides for exchangeable communication processors with allocated or forthcoming standard communication protocols, Fig.11.

The adoption of standard data communication protocols, such as IEC 60870-5-103, is permitting data communication with devices made by other manufacturers. 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. The communication to an EMS system located in a Control Centre with a WAN-protocol is via IEC 60870-6 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. 10. 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 communications, make distribution 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.

6. Conclusions

Combined Protection and Control IEDs enjoy increasing acceptance for use in new switchgears and refurbishment projects. The migration of local control and metering functions into protection relays is an attractive option for efficient and economic distribution system management.

A one feeder, one IED approach transfers the external wiring complexity and numerous individual devices into the built-in PLC. One common data base on each feeder, sharing of data for all involved disciplines, and data communication from the feeder level up to system level, fully utilises all viable synergies.

For extensions of existing plants, plain numerical protection relays are still needed for consistency with existing devices.

7. References