Smart cable accessories for the measurement of state variables in medium-voltage networks

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ABSTRACT

The present paper reports on field tests at medium-voltage cable accessories with integrated sensors for current and voltage measurement in combination with a special telecontrol equipment as an alternative to conventional transducer technology in medium voltage grids. Topics of the project were the investigation of compatibility with existing stations and the availability and quality of the ascertained data.

INTRODUCTION

The important role distribution systems play in Germany´s energy transition is often not adequately taken into account in the public debate. Some 90 per cent of the wind, solar and biomass-fired power plants – corresponding to about 1.2 million plants in Germany today – are connected to the distribution network.
The use of cutting-edge network technologies can make a crucial contribution towards scaling down or stretching necessary grid expansion measures as shown, among other things, by a study of the German Energy Agency (dena) conducted at the end of 2012 [1].
The energy transition takes place most notably in rural regions where wide open spaces are available for the erection of large-scale wind power plants and solar PV installations. At the same time, however, power demand is highest in urban areas. This causes the electricity in the grids to no longer flow unidirectionally but bidirectionally – a one-way street is turned into a two-way street.

MOTIVATION AND BACKGROUND

New constraints in distribution grids

It is not so long ago that the required electrical energy was fed in by a few big power plants in the transmission grids. The energy was transported from the point of highest voltage to the connected customers via the transmission and distribution grids.
The energy grids were designed in a way that monitoring (bottleneck management) and control (observance of the voltage band) were only required at extra-high voltage and high-voltage level. The distribution system as such (medium and low voltage) did not have any instrumentation and control technology. Following the change of the political framework conditions in the energy sector aimed at reducing carbon emissions, the promotion of renewable energy production plants (wind, solar and biomass) and the nuclear phase-out, Germany's energy landscape has changed. In the past, energy was predominantly fed into the grid at the highest voltage level. Today, the largest share of electricity fed into the system is fed into the medium and low-voltage grids leading to a reversal of the energy flow on many days of the year. This means that an increasing amount of energy is transported from the bottom (distribution grid) to the top (transmission grid). Unfortunately, the energy grids were not designed and built for this situation. To meet the changing requirements it is becoming increasingly important to expand the network and to install measurement systems at the medium and low-voltage level in order to detect voltage range deviations or network bottlenecks early on. The measurement data produced can be provided to grid management to identify deviations from limit values (voltage, current) as early as possible. Moreover, they can also be used for control purposes (e.g. long-range control) in order to increase transmission capacities without expanding the network.

New solutions for changed constraints

From this follows the need to obtain information about the flow of power in the distribution grids. While new plants/installations can be equipped with the necessary technology at the factory already, the refurbishment of existing networks poses huge challenges. A promising solution for the acquisition of measurement data in medium-voltage networks could be cable accessories with suitable sensors for current and voltage measurement. These cable accessories are a good technical and economic alternative to conventional transformer technology (which in many cases cannot be implemented for financial reasons or due to the lack of space). They can be retrofitted into existing substations without interfering with the switchgear.
As operational requirements are not necessarily identical with the specifications in the manufacturers' data sheets, proof had to be furnished that the cable accessories with sensors are not merely a viable product idea but that they can be integrated into and used in different plant configurations in practice. A project was launched for this purpose. Apart from 3M Deutschland, the developer and manufacturer of the cable accessories, RWE Deutschland, Westnetz and Bilfinger Mauell were involved in the project.

SCOPE OF THE PROJECT FOR TESTING THE COMPONENTS

Within the scope of this project, the use of smart measurement technology at medium-voltage level in existing RWE equipment was tested by using cable accessories manufactured by 3M in Neuss and a tailor-made measurement and automation system by Bilfinger Mauell based in Velbert. From RWE's perspective the following requirements had to be fulfilled:

- Installation of the new measurement systems into existing equipment without losing the operating permit for the medium-voltage equipment
- Recording the measurement values at medium-voltage with an accuracy of 3% for current and 0.5% for voltage.
- Continuous and secure IT-based transmission of measurement values to RWE's grid management
- Simple set-up without expanding the respective substation following instructions by RWE's grid operation unit

In a first step, RWE Deutschland and Westnetz formulated the network-operator requirements and defined corresponding specifications. After that, the components were trialled in the field. Bilfinger Mauell, in collaboration with 3M, was tasked with developing a small telecontrol system for the conversion and transmission of the measured values.

COMPONENTS

As already mentioned, the tested system consists of the components cable accessories and telecontrol system.

Cable accessories

The field trial was conducted in the 20 kV grid of Westnetz in two different installation locations: on the one hand in a compact station and on the other in a building station. In the latter, "classic" medium voltage terminations were used (Figure 1, left), whereas in the compact station cable plug connectors were tested (Figure 1, right).

termination cable plug connector

Figure 1: Cable accessories (3M Deutschland)

Both sets are equipped with calibrated, high precision, passive current and voltage sensors that are mounted directly to the XLPE insulated power cables using field-proven connection joint technology. The sensors comply with the IEC 60044-7 and IEC 60044-8 standards, allowing highly accurate measurement without calibration and adjustment to the primary values. The transmission accuracy (magnitude; angle) of the sensors is constant over the lifetime and does not need to be readjusted. An important part of the cable accessories is the integrated connector consisting of plug and socket with high-current contact blades. Thus, the operation with the maximum current of the corresponding switchgear or local network station is guaranteed. By using the plug and socket system, the sensor cable sets are suitable for a wide voltage and cable cross-sectional area.

The termination or the cable connector is delivered with a four-meter sensor cordset. This can be shortened if necessary or be extended up to ten meters with an extension cable (patch cable). The sensor cable can be supplied with different connections.

Telecontrol system

The development of the new system platform of the telecontrol system was based on a number of requirements:

- Small dimensions and environmental characteristics adapted to the operation in substations
- openness regarding the coupling of different data transmission devices based on radio, wire, powerline or fiber optic cabling with standard IEC protocols (60870 or 61850)
- openness with respect to a local data collection on its own I/O devices
  - Binary I / O cards 24-220 VDC
  - Analog input / output cards 0 [4] - 20 mA
  - Direct measurement for medium and low voltage via standard interface or small signal technology
- Local fail-safe data storage and remote retrieval of events and data for later analysis
- IT security in accordance with BDEW White Paper for secure telecommunications facilities
- Installation and service of the systems by grid operator commissioned by companies without specialist knowledge
- Simple, intuitive configuration of the system and local automation via built-in WEB server or offline tools

The system is available as assembly and mounting device in various sizes from 76 mm to 290 mm width and a height of 97 mm and a depth of 132 mm (with connector). The system with the manufacturer's designation ME 4012 PA-N (Figure 2) has the standard three different communication interfaces (Ethernet, serial and fieldbus). Depending on the application, the protocols of the IEC 60870 or IEC 61850 respectively MODBUS RTU can be operated over it. The ME 4012 PA-N system is configured by default via the integrated processing unit on the web server. For specific applications, individual configuring can be made.

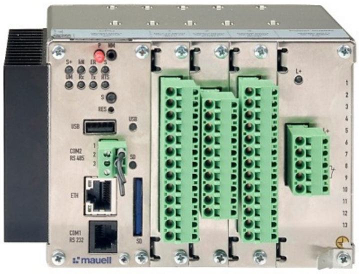

Figure 2: small telecontrol system (Bilfinger Mauell)

INSTALLATION

Before installing the cable accessories into the grid, they had been tested by Westnetz for compliance with the requirements of the standard DIN VDE 0276-620.
The installation of the cable accessories occurs without intervention in the switchgear. The existing terminations respectively cable plug parts are replaced with the sensor sets. Figure 3 shows the main assembly steps.

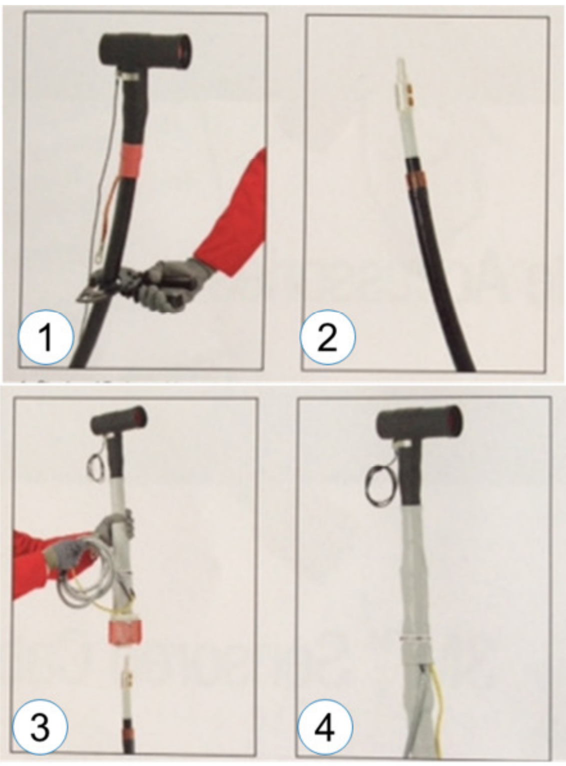

Figure 3: Assembly steps of the cable plug connector

Assembly steps:
1 cutting off existing cable plug
2 setting off cable and mounting termination stud
3 installing sensor accessory
4 assembling cable plug and connecting sensor cable

In conclusion, it was found that the assembly of the components could be done easily and with a reasonable amount of time.
After connecting the signal cable to the remote control unit mounted in the station, the sensor cable accessory is ready for use.
Figure 4 shows the terminations built-in a compact station; in Figure 5, the cable plug connectors are shown in the assembled state in a building station.

Figure 4: Sensor terminations, assembled in a compact station

Figure 5: Sensor terminations, assembled in a building station

OPERATIONAL EXPERIENCE AND CONCLUSIONS

After installing the devices, the measured values from the sensor cable accessories and the reference measurements were recorded and evaluated during the one-year project period. The detailed analysis of the data obtained confirmed their availability and quality:

- The measurement error is in the class accuracy (0.5) of the conventional voltage transformer measurement
- The accuracy of current measurement is by adjusting the correction factors within the stated requirements.

Figure 6 shows an example of the result of a voltage measurement over a measurement interval of about three hours. Shown is the voltage U_V0_3M measured with the sensor accessories, the reference voltage U_V0_MS and the maximum permissible tolerance band U_V0_MS +/- 0.5%.

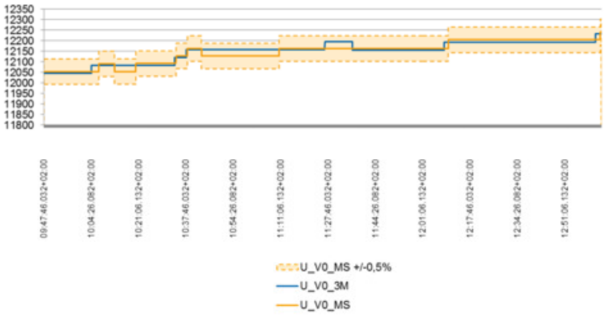

Figure 6: Example for a voltage measurement

The 3M cable accessories have the biggest potential uses, if in the future more measurement results should be involved from the MV grid in the control system. Thus, measurements of load-center stations or long line-taps in the increasing integration of renewables can contribute to greater transparency in the medium voltage distribution grid and facilitate operation management. Because of their small size, the cable accessories with integrated sensors can be retrofitted in all systems connected via cable. However, this is only useful in stations where no settlement or protection functions are required, otherwise conventional transducers are required. The connection to the control system can be done by means of the telecontrol system ME 4012 PA (Bilfinger Mauell) or with the aforementioned devices for earth fault / short-circuit direction detection, which also have a process control integration options.

As stated already in the introduction, cable accessories with appropriate sensors can represent an alternative to conventional converter technology. A crucial role in a comparison play of course economical aspects. In addition to the hardware costs for accessories and telecontrol technology also costs for installation, maintenance and process control connection must be considered. Additional costs when installing the sensor cable accessories are not to be expected in comparison with the conventional instrumentation. Initial results show that the simple installation should take little more time than that of a conventional cable fitting (3 hrs.).

After installation, no maintenance or recalibration is required so that the operating expenses are not different from that of conventional transducers.

Both the sensor cable accessories as well as the conventional transducers must be connected to a telecontrol system and this to the control system. The effort that must be provided for this purpose, is comparable for both technologies.

In summary it can be stated that the cable accessories investigated here have a slightly better economy for retrofitting in building stations with air-insulated switchgear panels in comparison with conventional current and voltage transformers. When used in a compact station where a retrofit with conventional transformers is not possible, they are much more economical. Similarly, the construction of a new standard station in conjunction with the sensor cable accessories is significantly more economical than the construction of a larger station with integrated conventional instrumentation.

SUMMARY AND OUTLOOK

The medium-voltage sealing ends and male cable connectors developed by the manufacturers 3M Deutschland and Bilfinger Mauell are able to provide the required measurement data thanks to the integrated smart sensor technology. The specific accessories consist of Rogowski coils for current measurement and capacitive voltage dividers. The obtained data is recorded with the help of suitable measurement equipment and transmitted to the network control centre using IEC standard protocols.

Following laboratory tests and the performance of necessary checks as required by the applicable standards, the factory-calibrated accessories were installed at various locations in Westnetz's 20-kV network and were tested in the field. The tests proved that the accessories are suitable for the integration into existing stations. Also, the availability and quality of the measured data were analysed in detail and confirmed. The present paper shows that the proposed combination of accessories and sensor technology presents an attractive alternative to conventional transformer technology in the monitoring and control of medium-voltage networks.

Although the sensor cable accessories meet the accuracy requirements for the implementation of protection concepts, but due to lack of compatibility to protective equipment for small outputs in the range of a few mV to V available on the market, it would be desirable if the producers were willing to provide additional input cards. Another potential application is the use for billing purposes. However, this requires an official calibration, so that for accounting measurements at present conventional transformers must be used.

REFERENCES

[1] Deutsche Energie-Agentur GmbH (dena), 2012, *dena-Verteilnetzstudie. Ausbau- und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030,* dena, Berlin, Germany