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Digital Substation in Distribution Networks.

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ABSTRACT

This article discusses the aspects of application of digital substations in power distribution networks. Since direct transfer of engineering solutions for the new technology from high voltage substations to distribution networks is economically inefficient, then new engineering approaches are proposed with respect to components of control and protection systems, which should be used both at new construction and at retrofitting of substations. The main purpose of implementation of new equipment is improvement of operation properties, increased reliability and acceptable costs in comparison with existing transformer substations (TS) of distribution network.

Keywords: digital substation, distribution networks, IEC 61850, digital networks, direct action relay, merging units (MU).

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INTRODUCTION

Application of digital substations in distribution networks was insufficiently disclosed in technical publications, since it was assumed (quite reasonably) that such technology cannot be accepted due to its high cost, more complicated maintenance and absence of evident advantages.

It is obvious that this technology will be highly demanded if it is able to provide the following results:

- decrease in variety and amount of control and protection devices;
- cost reduction;
- decrease in operation costs;
- increased reliability;
- improvement of technical specifications.

It can be achieved only when new devices will be developed corresponding to the digital substation concept and taking into account specific character of distribution networks (the keenest price, moderate skills of service personnel).

This article discusses technical specifications of the devices, demonstrates methods of their merging with power equipment of transformer substations, sectionalizing stations and distribution stations.

Herewith, digitalization is applied to the existing transformer substations [1, 2, 3] in the frames of regular structure of digital substation: MU for communication with control objects, communication medium: process bus based on switches, data processing units – IED (Intelligent electronic device). General principles of digital signal processing are permanent [4, 5].

The background of data exchange is IEC 61850 communication standard, which requires that MU and IED would support VLAN (Virtual Local Area Network) - IEEE 802.1Q, IEC 61850-9.2: Sampled Value (SV), IEC 61850-8.1 (GOOSE, MMS), time synchronization service IEEE 1588, v.2 (PTP) [6, 7, 8].

HIGH VOLTAGE EQUIPMENT (6-10-20 kV)

Retrofitting of existing cells with direct action relay:

Power equipment (instrument current transformers, zero-sequence current transformer, circuit breaker) is permanent. Direct action relay in the breaker drive [9] is replaced by microprocessor unit of control and protection, as well as actuator solenoid.

Protection and control device.

The device is made as an independent unit, it is mounted on the top cover of breaker drive and connected to the windings 10P and 0.5 of instrument transformers of three phase current.

The peculiar features of the device are as follows:

- microprocessor unit which performs the following functions:

a) relay protection (with breaking action via solenoid);
b) emergency recording combined with monitoring of short circuit current;
c) control of accumulator charge and discharge circuit;
d) measuring of instantaneous current value (current from winding 0.5 of current transformer);
e) power measuring and technical metering via 6 kV feeder bays without high-voltage measuring transformer (VT) is also possible due to receiving of digital stream of SV from MU VT-0.4 kV.

- existence of embedded molecular energy accumulator connected via rectifier to current circuits 10P; in short circuit mode the accumulator is charged by short circuit current and then discharged onto actuator solenoid,

thus increasing total efficiency of the system and providing reliable circuit breaker opening even at low short circuit currents;

The actuator solenoid is installed on direct action relay and acts directly on trip bar in breaker drive. The solenoid in normal mode is not bypassed by current (contrary to conventional direct action relay), which provides maximum operation lifetime of electromagnet insulation.

Promising switchgears:

The promising design is intended mainly for new construction and in major retrofitting of TS with replacement of cells.

The promising cell is equipped as follows:

Cell fixed portion:

a. Current transformer of conventional design, accuracy class 0.2S (if commercial metering of 6 kV connections is required). The counter is made as test block, which eliminates necessity of terminal box, increases maintenance safety and reduce significantly the time of counter dismounting and mounting for verification.
b. Zero-sequence current transformer (ZSCT) is of conventional type.
An MU is located on the ZSCT terminals, which provides digitalization of signal from ZSCT. Location of MU in the vicinity of ZSCT improves the accuracy of current measurement 3Io.
c. Digital voltage sensor is intended for voltage digitalization at the section buses according to IEC 61850. It is a capacitive divider loaded onto microprocessor unit. Digitalized signal in the form of SV stream from MU via fiber optics is supplied inter-sectional switch and then to all the sectional cells. Power supply for MU is provided by capacitive divider.
Voltage sensor is made as insulator unit, thus eliminating separate cells for bus VT or power feeder VT, leaving space in TS for new connections, as well as providing VT backup.
d. Drive (manual or electric) of withdrawable module is combined with lock, contactless inductive position sensor and MU microprocessor unit with digital interface.
e. Drive (manual or electric) of grounding blade is combined with lock, contactless inductive position sensor and MU microprocessor unit with digital interface.

A peculiar feature of MU is digital exchange between them and MU of other commutating devices by means of Generic Object Oriented Substation Event (GOOSE) messages, which facilitate implementation of rapid blocking. In order to execute operations with faulty MU it is possible to unblock MU of withdrawable module and MU of grounding blade.

Instead of relay compartment a section for cell switch is provided, cross bus is excluded, its functions are performed by digital links.

Withdrawable module:

a. Vacuum circuit breaker with driver equipped with contactless inductive sensors of extreme and current positions of the breaker.

b. Digital MU, providing typical functions of protection terminal [10, 11]:

- relay protection and automatics (overcurrent relaying, current cutoff);
- automated breaker control;
- position control and breaker diagnostics;
- measurement of parameters of regular mode (including the level of non-symmetry, control of excess of declared maximum);
- recording of emergency mode;
- human-machine interface (LED, instantaneous current value);

c. Current sensor made as magnetosensitive microcircuit, installed in the gap of ring-type magnet - such sensor of small weight and sizes makes it possible to measure current both in regular mode for telemechanics (with accuracy up to 1-1.5%) and in short circuit mode for relay protection (with accuracy up to 4-5%), herewith, it facilitates provision of rapid bus differential protection eliminating the necessity of separate device of arc protection. The terminal box of current sensor is equipped with MU which supplies power to microcircuit and digitalized signal from it.

The advantages of combination of current sensor, MU and breaker on withdrawable module are as follows:

- increased reliability (due to decrease in link length between devices and elimination of detachable joints);
- decreased height and length of cell;
- improved access to all units for inspection and maintenance.

Solution of inter-sectional issues is delegated to separate (inter-sectional), installed at the distance determined by requirements of safe operation.

IED is connected to cell switches by digital cables (twisted pair) and executes the following functions:

- bus differential protection (replaces arc protection);
- intersectional relay automatics: automatic load transfer, automatic frequency load shedding, under-
- voltage protection;
- detection of single phase short circuits to earth on the basis of comparison of 3Io current
- amplitudes from all MU ZSCT of this section;
- back up of relay protection of connections (for the down time or checking of MU cell);
- verification of operability of measuring channels (phase incremental addition of instantaneous
- current values of all connections and power supplies);
- detection of source of degradation of electric power quality metrics (comparison of connection
- currents);
- generation of TM stream, communication with mobile devices of emergency rescue team;
- synchronized time for all MU;
- backup place of control (display with keyboard).

Fuses

It is proposed to equip compact kiosk-type transformer substation without breakers, where high voltage equipment is protected by fuses, by specialized intelligent safety devices instead of regular units.

Such device is supplied by 6 kV and includes:

a) vacuum chamber with spring drive and manual charge of the springs;
b) current transformer;
c) microprocessor unit for:

- current measurements in regular and emergency mode;
- current protections;
- synchronous cut-off (when current passes zero);

d) mesh-modem * for transfer of signals and measurements from device;

The device is made with the same dimensions and connection type as high-voltage fuses.

Advantages of such solution (in comparison with conventional fuses):

- decreased scattering and increased time stability of properties;
- increased accuracy of activation,

- decreased selective time interval and, hence, decreased time of activation of protective relaying and automation in supplying centers;
- decreased time of activation;
- reliable activation at minimum short circuit current.

LOW VOLTAGE EQUIPMENT (0.4 kV)

Retrofitting of control systems at 0.4 kV TS side is aimed at increased observability with minimum amount of devices and operational costs. The following retrofitting variants are proposed:

Input (sectional) automatic circuit breaker:

In order to decrease total costs and to implement policy of import substitution it is proposed to apply Russian automatic circuit breakers with independent tripping mechanism and separate microprocessor unit of control and protection. While using A3700 automatic breaker it is possible to substitute standard embedded control unit with microprocessor one. Herewith, microprocessor control unit is equipped with digital interface for data transfer to intersite IED, it performs the following functions: relay protection (current protection, and, when required, remote backup protection), under-voltage protection, automatic frequency load shedding, emergency recorder.

Intelligent fuses with microprocessor control

Intelligent fuses are alternative to conventional fuses, they are made as a module with dimensions of conventional 0.4 kV fuse, including: two-position power relay, current transformer, microprocessor controller, which provide synchronous relay commutation when current passes zero, thus decreasing requirements to relay contact system and significantly increasing its operation lifetime. The module is energized by current transformer.

This device is quite portable, it has no disadvantages of fuses (high scattering and time degradation of properties) and automatic breakers (in particular, dependency of trip setting of overcurrent protection on ambient temperature).

Measuring complex

Measuring complex is intended for control of regime parameters and electricity metering for all connections. The major components of the complex are: current metering plates and intersection metering device.

a) Current metering plate is a current transformer on rigid frame with microcircuit which transforms input signal (0....200 A) into standard signal of 4-20 mA with the option of plate thermal control. An advantage of such design is minimum sizes of current meter, which especially important upon dense packing of 0.4 kV equipment.

Current metering plates are installed onto pins of power 6/0.4 kV transformers, onto bolt terminals of output cables. If connection is based on several cables, then the current metering plates are installed at fitting of each cable, since in this case it is possible to detect heterogeneity of current distribution between parallel connected cables.

b) Intersection metering device (IED) is a unified metering center for all connections of one 0.4 kV section. In addition, it is connected to 0.4 kV buses for voltage control. On the basis of supplied data it performs the following functions:

- metering of current, power and electricity amount for each connection, including input and section
- circuit breaker;
- remote/automatic breaking of consumer automatic breakers (via independent tripping mechanism) in
- the case of excess of declared maximum and/or non-payment for consumed energy;
- balance calculations for 0.4 kV section in general (including control of illegal connections);

- calculation of loses in 0.4 kV voltage feeders of consumers;
- calculation of voltage at 6 kV side by current and voltage at 0.4 kV input for power calculation and
- accounting of electric energy for 6 kV connections (after recalculation with account for transformer
- connection group, coefficient of transformation and its instantaneous load).

ENGINEERING EQUIPMENT

Necessity to have new technical solutions for engineering systems of TS is stipulated by the following circumstances:

- integration of engineering systems into unified data environment of TS (for dispatching purposes);
- reduction of occupied space by engineering systems as well as their cost;
- Taking into account the aforementioned, it is proposed to equip both rooms in TS (6 kV and 0.4 kV) by
- ceiling modules combining the following devices and equipment:
- lamp;
- infrared heater;
- powder-type extinguisher;
- sensors: fire alarm, motion sensor, video camera, thermal sensor;
- control equipment (MU), providing automatic deactivating of lighting and temperature decrease
- inside rooms without personnel, checking of correct state of lighting and heating, as well as data
- transfer to intersite IED by mesh-modem.

INTERSITE EQUIPMENT

Intersite level of TS control system includes the following items:

Panel PC (intersite IED):

The PC combines information from the following devices:

- inter-sectional IED of 6 kV side (number of sections);
- inter-sectional IED of 0.4 kV side (number of sections);
- engineering ceiling modules.

Functionality of intersite IED is determined by its central position in data exchange and includes the following:

- total balance calculations for TS;
- participation in automatic transfer of current dead section for localization of breakage and recovery of
- power supply for undamaged TS;
- generation of cumulative telemechanics stream along total TS;
- generation of cumulative data stream from electric power recording system;
- time server for all MU and IED installed in TS;
- local archive required at communication interruptions (including TS deactivation)

The PC is not equipped with its own display, detailed information is displayed by means of notebook of emergency rescue team.

Radio modem:

The modem is used for status data transfer, electric power metering data, as well as receiving of standard time signals. In addition, it provides communication with adjacent TS in order to execute automatic transfer of current dead section and localization of breakage.

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CONCLUSIONS

Implementation of digital substations for distribution networks can be reasonable only in combination with dedicated devices specially designed for the concept of digital substations.

Expected advantages are as follows:

- decrease in fabrication (retrofitting) cost due to unification of devices and reduction of their amount;
- increased reliability due to backup of individual component and functions;
- simplification of on-site operation of emergency rescue team due to reduced amount of devices and communications between them, extended diagnostics and remote access to the components;
- increased number of connected 0.4 kV clients, stipulated by reduced scope of equipment of control systems in TS.

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