NEW FUNCTIONALITY STANDARD IN INDUSTRIAL AUTOMATION: BINOM3 SMART INSTRUMENTS

Abstract: New instruments for industrial automation such as BINOM3 multi-functional power quality analyzers and revenue meters (St. Petersburg, Russia) are described. The BINOM3's main specifications and operational data are provided and its functional advantages are shown for practical applications.

Keywords: harmonic distortions, meter, power quality analyzer, disturbance recorder, oscilloscope for electrical process monitoring, **feeder bay controller.**

With the development of information technology, the observability and validation requirements of the electric power grids and systems have become more stringent. Complete electrical equipment operation data allow the operator to clearly identify deviations from normal operation and, in the event of disturbances, thoroughly investigate their development. Based on the results obtained, it also allows the operator to take sound measures to reduce power losses, increase equipment capacity and extend service life, improve power supply reliability, and prevent emergencies.

The observability improvement issue has gained special relevance due to the development of power electronics having a significant impact on the electric power quality. Voltage sinusoidality and symmetry distortions are becoming quite common. Harmonics and voltage unbalance negatively impact the operating modes of core electric power system equipment and may lead to its failures, false actuations of protection and automation devices, and additional power and energy losses. This problem also may have serious consequences for the customer, such as damage to power equipment and interruptions of production processes. Analysis of power grids in the Federal Grid Company of the Unified Energy System (Russia) has confirmed the high level of grid power quality distortions and formed the basis for the tightening of requirements for measured parameters [1].

As the requirements relating to automation systems at power stations and substations have tightened, more advanced hardware has been installed there. The amount of information being measured, processed, and stored is increasing and its scope is becoming more complicated. A power facility equipped with modern instrumentation, becomes a high-volume source of informational messages reporting the status of electric processes in electrical equipment.

One feeder bay status at a switching substation is characterized by more than 2,000 parameters. These include voltage, current, active power, reactive power, total power, power factor for each phase and the entire feeder bay, frequency, harmonics and interharmonics (up to 50th order) of the current and voltage for each phase, phase shift factors and angles; active, reactive, and total power of the harmonics for each phase and feeder bay, **symmetrical**

components of current, voltage, power, etc. Parameter values are calculated at intervals of 10 periods each and, in order to assess the dips, interruptions, and swells, at the half cycle of the fundamental frequency. The data volume generated in one minute at a single feeder bay may comprise more than 600,000 events. At a 110 kV substation, 100 feeder bay devices generate a huge amount of data—over 60,000,000 events in just one minute.

As a measure of the binary data volume generated per unit of time, **the entropy of such an informational messages source** may significantly exceed the communication channel capacity. For a centralized system, where the entire data flow is routed to the server, the communication network may not support reliable data transmission (free of lags or losses). Moreover, a significant portion of the measured values is transmitted in order to perform averaging over large intervals, to set extremum points, and to obtain relevant event samplings. For this reason, more advanced automation architecture is required.

Distributed architecture is introduced based on decentralization, i.e., on shifting the data processing, analysis, storage, and operation functions directly to the data source or down to the electrical feeder bay level. Each feeder bay is equipped with a multifunctional device containing the following integrated tools:

1. Flexible mechanism of **messages flow** sorting and filtering according to pre-set criteria, averaging at various intervals, extrema capturing, analytics gathering and comparison with rated regulatory values.
2. Customizable archiving system.
3. **Unified** interfaces enabling access to all data.

Shifting these functions to the field/end-user equipment greatly simplifies the automation architecture and gives it a number of important new features:

- Reduces the number of devices at the feeder bay to only one multifunctional one that replaces a set of specialized units, which reduces the investment in automation and yields cost savings;
- Increases the share of computing, response speed, and stability and maximizes the accuracy and validity of measurements;
- Avoids overloading the communication networks; in case of communication channel failure, the units continue to function autonomously, but after the channel is restored they resume transfer of data captured during their unavailability; data from the overflow queue may be restored from their backup storage;
- Often eliminates the need for dedicated data acquisition/archiving/imaging servers and, if such servers are still employed, does not require substantial effort to configure them for defining new devices, which greatly simplifies and standardizes their configuration, commissioning, and maintenance;
- Provides mobile access to data stored in the device; data is displayed in the form of ready-to-use logs, charts, graphs, tables, all created within the device;
- Since the centralized functions are distributed among remote devices and each of those is an independent and complete node of the system, such architecture makes it easy to add new devices whenever an electrical part of a station or substation is expanded or new facilities are commissioned; in such cases, the system is simply scaled up.

This technology has been implemented in the new generation of BINOM3 multifunctional power quality analyzers and revenue meters (Algorithm JSC, St. Petersburg, Russia).

BINOM3: A SMART FIELD DEVICE WITH APCS FUNCTIONALITY

BINOM3 is a combination of integrated subsystems functioning synchronously and implementing the **APCS (AUTOMATED PROCESS CONTROL SYSTEM)** functions at the feeder bay level. At this time, BINOM3 functionality and specifications are unique for both domestic and global market for similar and specialized devices implementing only certain functions. The basic BINOM3 series specifications and operational parameters are provided below.

MEASURING TRANSDUCER	FEEDER BAY CONTROLLER
Rated current: **1 A, 5 A.** Rated voltage: **220/380 V, 57.7/100 V.** Stable-accuracy measuring range: **2Un, 2In.** RMS measurement interval: **200 ms** (10 cycles at 50 Hz, 6,400 instantaneous values). Vector diagram of currents, voltages and power. Network parameter archiving. Drift control beyond threshold values.	GOST 26.205-88, GOST R IEC 870-3-93, GOST IEC 60870-4-2011, GOST R IEC 60870-5-104-2004, GOST R IEC 60870-5-101-2006. **16 Digital inputs (DI, teleindication), +24 V.** DI sampling rate: **100 µs.** Accuracy of referencing the DI RS readings to UTC: 1 µs. **Single- and double-point teleindication.** **2, 3, 4 Relay outputs (RO) channels.** Single-stage and two-stage **telecommand conditions**. Switching capacity: up to **5 A** in **220 VAC**, **220 VDC** circuits.
ENERGY & REVENUE METER	**POWER QUALITY ANALYZER**
GOST 31818.11 **(IEC 62052-11:2003)**, GOST 31819.22 **(IEC 62053-22:2003)**, GOST 31819.23 **(IEC 62053-23:2003)** Metering in **4 quadrants** over **16 channels.** Metering of fundamental frequency power, direct sequence, power losses. Accuracy class: • active energy: **0.2S;** • reactive energy: **0.5.** 2 metering profiles: • **Commercial (revenue)** rate, storage for **49 months (30 min);** • **Technical rate**, storage for **99 days (3 min).** **Daily/monthly** metering, storage for **9 years 10 months.** Metering over **4 tariff zones**, in total, out of tariffs. Event log for Measuring instrument status. **80020, 80030** (XML) template creation.	GOST R 8.655, GOST R 51317.4.15 **(IEC 61000-4-15:2010)** GOST 30804.4.30 Class A, **(IEC 61000-4-30:2008)** GOST 30804.4.7 Class I, **(IEC 61000-4-7:2009)** GOST 32144 **(EN 50160:2010)**, GOST 33073. **PQI (Power Quality Indicators)** statistical analysis. Adjustable averaging intervals and analysis periods. **Factory default rated values of PQI.** Optional modification of default values. Matched (reference) voltage (other than nominal). Generates electric **Power Quality Test Report.** Measurement of current and voltage harmonics, harmonic power (up to **50th order**), and interharmonics (up to **49th order**). Logging of **voltage dips, swells, interruptions.** Wiring options (three-wire, four-wire).
DISTURBANCE RECORDER	**DATA MULTIPLEXER**
Waveform recording: • Instantaneous voltage/current value recording period: 31.25 µs; • Accuracy of referencing of readings to UTC: 1 µs; • Pre-history duration: 60 s; • Waveform duration: 120 s; • Number of waveforms: up to 1,000; • Triggering by events; • Storage format: binary; • Storage format on user HD: COMTRADE; **Recorder:** • **voltage dips, swells, interruptions;** • ECA, RPA contacts, and ECA device actuation; • **current/frequency/voltage threshold violation.**	Over 2,300 parameters **Data communication:** • Optical port; • RS-232, IEC 101, 460.8 kbit/s; • RS-485/422, IEC 101, NMEA/PPS, 460.8 kbit/s; • RS-485/SYNC, IEC 101, NMEA/PPS, 460.8 kbit/s; • Ethernet, IEC 104, SNTP, 100 Mbit/s; GPRS/3G support Operation within a digital substation: • IEC 61850 SV (LE) support; • IEC 61850 GOOSE support (versions expected to be released in 2016). COSEM/DLMS (revenue metering data exchange). Universal Coordinated Time (UTC): • 1 µs timing accuracy; • GLONASS/GPS receiver connection option.
“BLACK BOX” FOR LOGGING ELECTRICAL PROCESSES	**FEEDER BAY WORKSTATION - DATA SERVER AND WEB-VISUALIZER**
Archiving **DI (teleindication)** changes, RMS and averaged values. Archiving speed: up to 5,000 events/s. Number of archives: up to 32, each archive represents a data set for a group of parameters. Simultaneous display of up to 50 graphs. Combining waveforms and RS/measurement graphs. Storage media: Built-in memory cards, external network storage.	4 GB MicroSD built-in memory card. Privileged access options. 1 GB storage for: • 41.5 minutes of waveforms; • 16 million digital and analog events; • 125 years/877 years for 1-day/7-day analysis periods. Built-in Web server (operation and configuration). Wiring diagram, SVG vector graphics. Bar charts/histograms, tables, graphs, waveforms. Built-in protocols and reports printed from your browser. Saving to user HD in *.xls and *.pdf formats.

Instrument documentation is available from **www.binom3.ru.** From **www.binom3.com online** access is also available to the instrument installed in the 0.4 kV distribution panel of the Algorithm JSC Development Department; instrument type is BI-NOM337U3.220I3.5S16T2. After registering on the website, you can go to the device’s built-in Web-server and familiarize yourself with its functions.

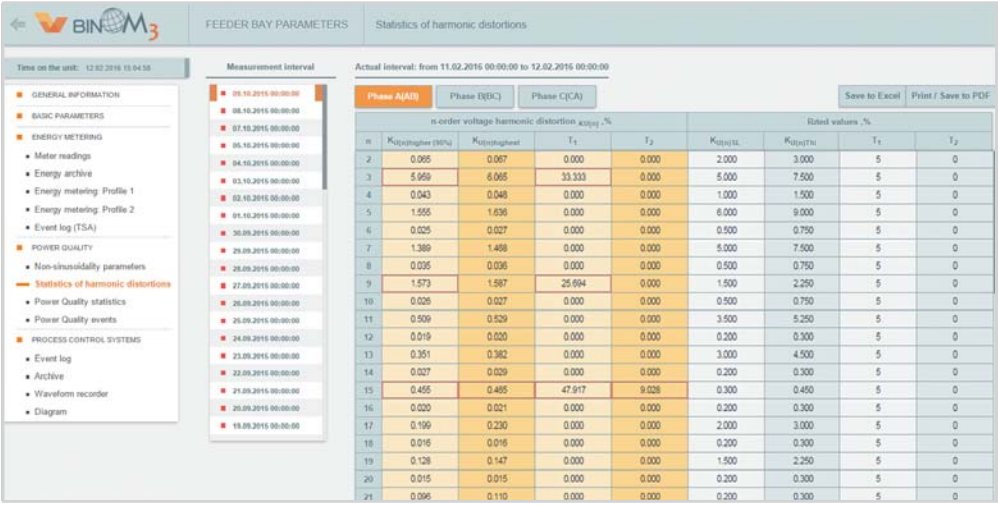


Figure 1.
BINOM337U3.220I3.5S16T2 Web server: Voltage harmonic statistics (values averaged over a time interval of 10 minutes; observation period one day)

APPLICATION EXPERIENCE

The results of practical BINOM3 application are described. Readings were taken by **online** access to the devices' built-in Web servers (without the use of dedicated external data acquisition and processing servers).

0.4 kV distribution panel of the Algorithm JSC Development Department

The customer load includes fluorescent lighting, computer equipment, uninterruptible power supplies, laboratory and test equipment. According to the BINOM3 built-in Web-server page, „Harmonic Distortions Statistics," drift of the coefficients of the 3rd-, 9th-, and 15th-order voltage harmonics above the permitted values established by GOST 32144 (**EN 50160:2010**) was observed.

The power quality mismatch with respect to 3rd and multiple voltage harmonics , as in this case, is known to cause a number of negative consequences.

First, it increases the likelihood of accidents in the utility networks. The 0.4 kV transformer winding that feeds the utility network is connected to the grounded neutral in a star configuration. Harmonics that are multiples of the 3rd are summed in the neutral wire and can overload it. Burnout of the neutral wire caused by asymmetric voltage is a cause of neutral wire displacement, surges, and damage to customer loads.

Second, the higher harmonics flowing through the network components cause further active power losses there. These losses increase the operating temperature and accelerate aging of the insulation, causing premature failures and shortening equipment service life, and reduce its current capacity at the fundamental frequency.

The source of distortions can be identified using the sign of harmonic power. As **it can be seen** on the histogram **shown** on the page, „Nonsinusoidality Parameters" of the BINOM3 device (Fig. 2), the power at the fundamental frequency for each phase has a positive sign (i.e., is consumed from the network), while the power at odd-order (3rd to 15th) frequencies in each phase has a negative sign (i.e.,

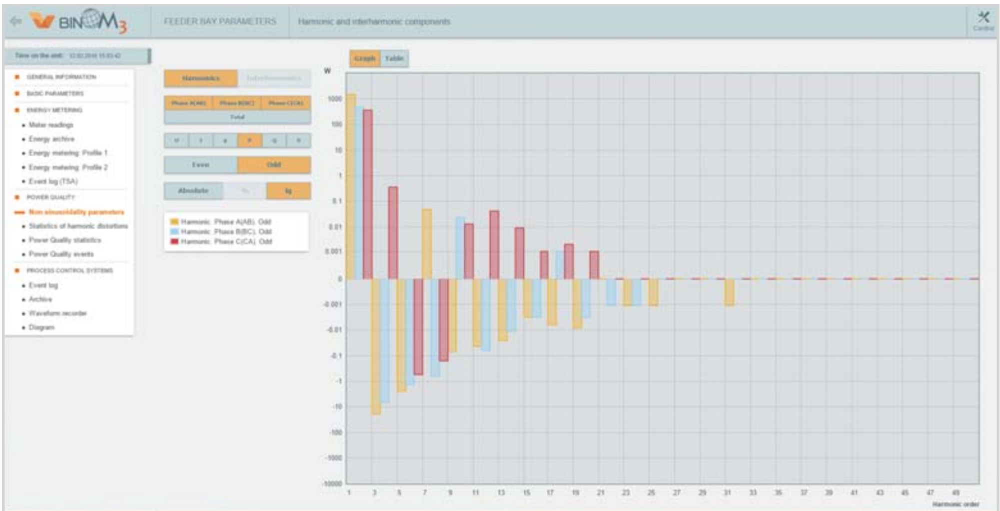


Figure 2.
BINOM337U3.220I3.5S16T2 Web server: Histogram of active harmonic power (RMS values, odd order, logarithmic scale)

Figure 3. BINOM337U3.220I3.5S16T2 Web server: Daily Energy Consumption Histogram (revenue metering channels: active power at fundamental frequency, active power with nonsinusoidality taken into account)

is returned to the network). According to [2], the customer load in question contains current harmonic sources, so it is a nonlinear load.

Nonlinear loads include data processing and computer equipment, appliances, fluorescent and LED lighting, variable speed drives, etc. When voltage is supplied at the fundamental frequency, a nonlinear load generates currents at harmonic frequencies, which in turn create voltage harmonics in the substation bus and power harmonics to the bus [1].

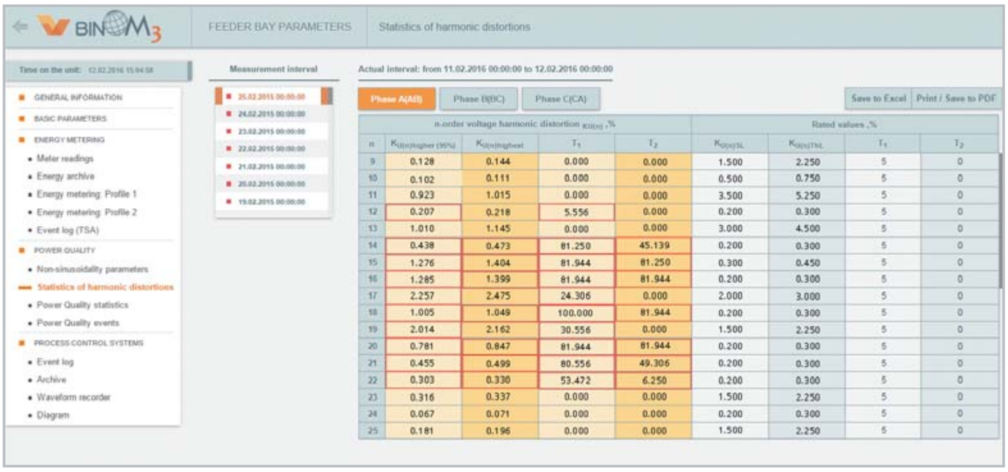
Third, the power of harmonics of higher than 1st order determines the energy of distortions. In this example, the harmonic power has a negative sign: it is returned to the network and thus reduces the energy consumed at the fundamental frequency. In the BINOM3 page titled, „Power Archive“ (Fig. 3), this fact is confirmed in the daily consumption histogram where the amount of energy at the fundamental frequency („+Wah1 Total“) is correlated with the amount of energy taking into account nonsinusoidality („+Wa Total“). The difference between them is the distortion energy that causes extra losses (undermetering) to the utility company (supplier).

As shown here, BINOM3 continuously monitors current and voltage harmonic levels, phase shift angles, and harmonic power at the installed location and creates a statistical database for analysis of the causes and patterns of changes in harmonics. Identifying the causes of harmonic distortions allows actions to reduce the level of voltage and current nonsinusoidality and magnitude of losses and improvement of the efficiency of electric power use.

Separate metering of total power, fundamental frequency power and positive phase-sequence power (segregation of active and reactive power in forward and reverse directions) allows measurement of distortion energy at the revenue metering point under asymmetric or nonsinusoidal conditions in the power grid and can be used as an economic incentive for the supplier or the customer to improve power quality [1].

The results of monitoring of voltage harmonic distortions and other standardized electric power quality parameters, dips, interruptions and swells are captured in the waveforms and in the Electric Power Compliance Verification Report form recommended by GOST 33073. Such reports are generated in the instrument internally, can be reviewed remotely without travelling to the facility, and can be printed out immediately. Statistics for previous periods are stored in the built-in memory card and are displayed for the user whenever a period of interest is selected (in Fig. 1, the measurement interval is shown as such).

It should be noted that to date, power quality monitoring for compliance with requirements of industry regulations and new standards adopted in 2014–2015 is not implemented in SCADA-type systems. Power Quality Monitoring and Control Systems (PQM&CS) are only being implemented as pilot projects. The theory of the problem is quite complicated, and requires special knowledge and mastery of the mathematical methods of statistical analysis. Creating a system involves time-consuming debugging. An important advantage of BINOM3 is its built-in workstation and archiving system for the monitoring point along with optimally customized form and report generators. All output forms and reports meet modern requirements.



	n-order voltage harmonic distortion $K_{U(n)}$, %				Rated values, %			
n	$K_{U(n)higher (95\%)}$	$K_{U(n)highest}$	T_1	T_2	$K_{U(n)SL}$	$K_{U(n)TNL}$	T_1	T_2
9	0.128	0.144	0.000	0.000	1.500	2.250	5	0
10	0.102	0.111	0.000	0.000	0.500	0.750	5	0
11	0.923	1.015	0.000	0.000	3.500	5.250	5	0
12	0.207	0.218	5.556	0.000	0.200	0.300	5	0
13	1.010	1.145	0.000	0.000	3.000	4.500	5	0
14	0.438	0.473	81.250	45.139	0.200	0.300	5	0
15	1.276	1.404	81.944	81.250	0.300	0.450	5	0
16	1.285	1.399	81.944	81.944	0.200	0.300	5	0
17	2.257	2.475	24.306	0.000	2.000	3.000	5	0
18	1.005	1.049	100.000	81.944	0.200	0.300	5	0
19	2.014	2.162	30.556	0.000	1.500	2.250	5	0
20	0.781	0.847	81.944	81.944	0.200	0.300	5	0
21	0.455	0.499	80.556	49.306	0.200	0.300	5	0
22	0.303	0.330	53.472	6.250	0.200	0.300	5	0
23	0.316	0.337	0.000	0.000	1.500	2.250	5	0
24	0.067	0.071	0.000	0.000	0.200	0.300	5	0
25	0.181	0.196	0.000	0.000	1.500	2.250	5	0

Figure 4. BINOM338U3.220I3.5 Web server: Table of Voltage Harmonic Distortion Statistics (values averaged over a 10-minute time interval, observation period one day)

0.4 kV Feeder for Urban Electrified Transportation Company

This example shows that the higher voltage and current harmonics can cause false actuation of safety devices and emergency control automation, thus reducing the reliability of electricity supply, creating pre-emergency situations and imposing stress on operational subdivisions.

Switching in the 0.4 kV network of the power supply system of an urban electrified transportation company (the St. Petersburg Metro) [3] is described. Alarm and circuit-breaking devices are powered from three-phase feeders of separate 0.4 kV bus sections through a rack-mounted automatic transfer switch (ATS). ATS voltage control relays monitor the voltage level on the bus sections. In the event of a voltage drop on a single feeder (bus section), ATS switches the power supply circuit of the alarm and circuit-breaking devices to another feeder of the bus sections. Voltage loss on either of the two AC bus sections is considered a pre-emergency situation and requires immediate identification and correction of the causes of the switching. Threshold values of pickup voltage other than the rated ones were preset for the voltage control relays. However, the relay has repeatedly tripped at the rated voltage on the bus sections (380 V). The causes of the relay tripping were analyzed using BINOM3.

During all one-day observation periods, whenever the voltage harmonic distortions drifted beyond their rated and maximum permitted values, e.g., 12th- and 14th- through 22nd-order harmonic distortions as shown in (Fig. 4), were logged. The relative duration of out-of-tolerance values may be up to 100%. Harmonic values depend on the power consumption parameters of the rolling stock and are constantly changing.

When the next voltage control and switching relay switches the power energizing the supply circuits of alarm and circuit-breaking devices to another bus section, the voltage dip is recorded in the BINOM3 Event Log (Fig. 5) stored in the internal memory card with the following parameters:

Dip start time 06:38:16.639, duration 29 ms, depth 95, 90%.

RMS values of voltage harmonics (Fig. 5) are written to the archive stored on the BINOM3 memory card.

A voltage dip event triggers logging of the phase voltage waveforms onto the BINOM3 memory card, including their prehistory preceding the dip event. The waveform is combined with the voltage total harmonic distortion (THD) – у нас THD? chart (Fig. 6). Both figures illustrate the different nonsinusoidality levels on different bus sections (on the supply feeder before and after switching).

An analysis of historical data showed that when the 9th-, 17th-, and 19th-order voltage harmonics increase by 1.4 times, a false trip of the voltage control relay occurs regardless of the operational presets, and the power supply circuits of the alarm and circuit-breaking devices are switched to another bus section. Upon review of relays from various manufacturers, the relay was replaced with a different model, based on the electromagnetic compatibility specifications corresponding to the EMI level identified.

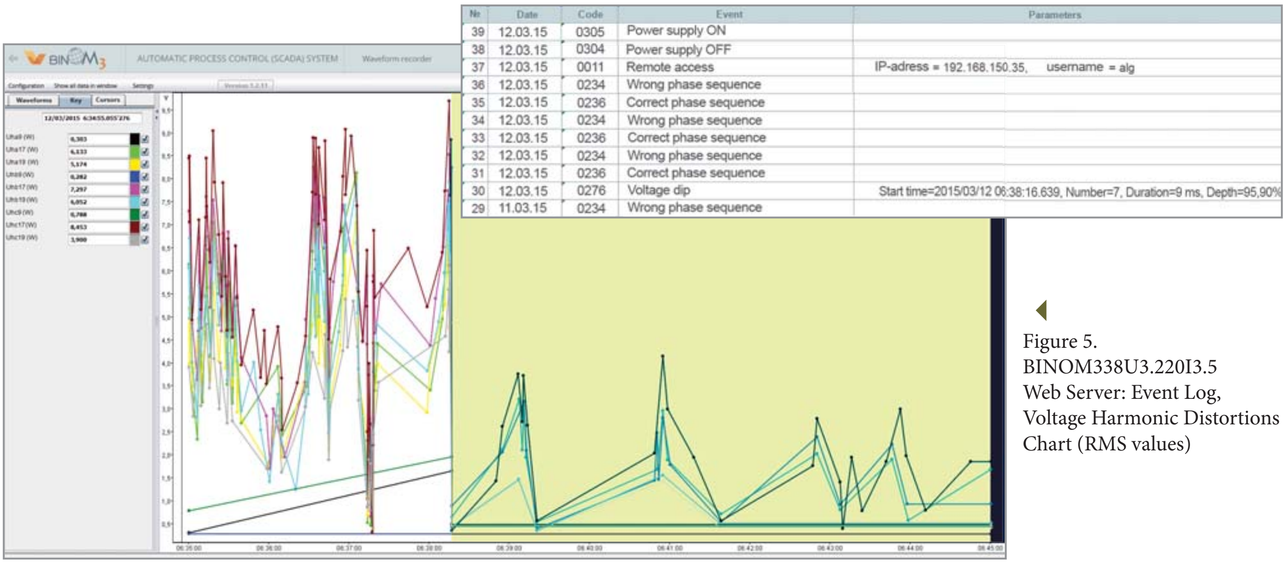
This example illustrates that the instrument's additional features, such as digital oscilloscope, archiving application, and built-in tools to work with waveforms and graphs, make it possible, by accessing the instrument, to „expand“ the chronology of abnormal conditions or accidents, identify their causes, and make reasonable decisions regarding their prevention in the future.

The BINOM3’s integrated oscilloscope function has unique parameters. When synchronized from a GLONASS/GPS receiver using a special sync pulse input, the BINOM3 provides simultaneous measurements with an accuracy of 1 µs on various facilities. Thus, this is the first time when it is possible to study geographically scattered power grids and remote facilities.

CONCLUSION

Advances in IT and microelectronic technology have enabled us to create a multifunctional on-site feeder bay instrument with the highest measurement accuracy and reliability as well as SCADA functionality. Such instruments make the advantages of distributed computing architectures readily available for industrial applications.

BINOM3 series instruments perform both commercial and technical revenue metering of electricity, including measurement of a wide range of electrical parameters, continuous monitoring and analysis of power quality, capture of the waveforms of normal and transient events, recording of incidents and switching of switching devices, as



№	Date	Code	Event	Parameters
39	12.03.15	0305	Power supply ON	
38	12.03.15	0304	Power supply OFF	
37	12.03.15	0011	Remote access	IP-adress = 192.168.150.35, username = alg
36	12.03.15	0234	Wrong phase sequence	
35	12.03.15	0236	Correct phase sequence	
34	12.03.15	0234	Wrong phase sequence	
33	12.03.15	0236	Correct phase sequence	
32	12.03.15	0234	Wrong phase sequence	
31	12.03.15	0236	Correct phase sequence	
30	12.03.15	0276	Voltage dip	Start time=2015/03/12 06:38:16.639, Number=7, Duration=9 ms, Depth=95,90%
29	11.03.15	0234	Wrong phase sequence	

Figure 5. BINOM338U3.220I3.5 Web Server: Event Log, Voltage Harmonic Distortions Chart (RMS values)

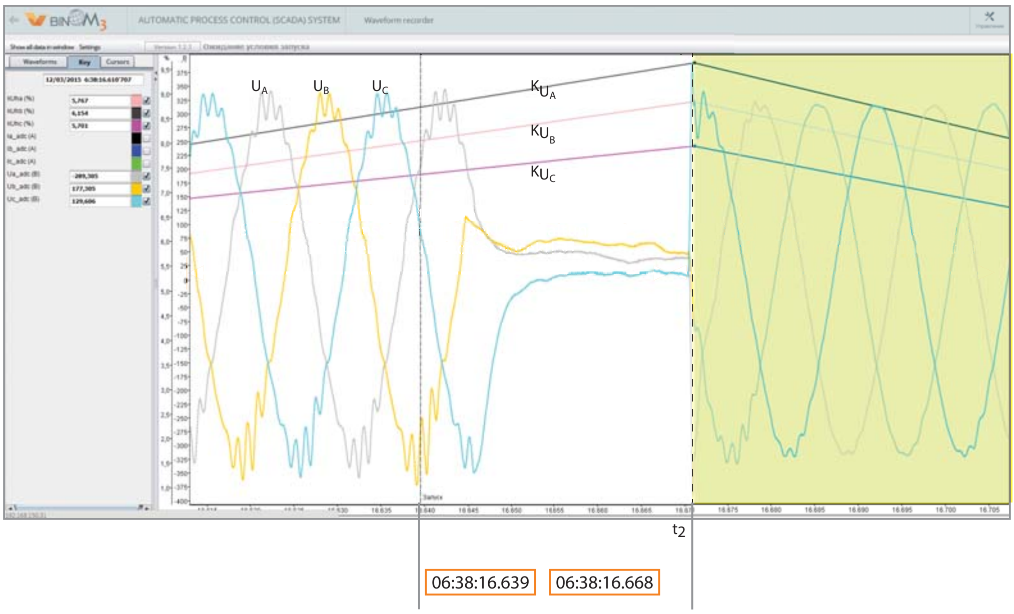


Figure 6. BINOM338U3.220I3.5 Web Server: Phase Voltage Waveform Combined with THD Chart (RMS values)

well as load control. The instruments are equipped with a built-in archiving system and workstation-based Web visualizer. All data are available in the instrument's direct access mode. Operational data are transmitted over communication links using standard data exchange protocols.

For an electricity supplier (utility or power distribution company) and for the customer, continuous monitoring and control of power quality parameters is crucial. The supplier can identify the source of distortions, monitor the customer's contribution to the permitted distortion level (which is defined in feeder bay specifications of the customer's connection to the power grid), improve the reliability of revenue metering, operate the power grid adequately to ensure reliability and efficiency of the power supply. The customer has the ability to monitor compliance with power quality standard requirements (or the power supply contract) at the point of delivery and to identify incidents of poor electricity quality, and has all supporting documentation necessary for claims against the supplier.

Whenever BINOM3 is used at the point of delivery from the supplier to the customer, power quality monitoring is performed around the clock in continuous mode as opposed to the common practice of periodic monitoring using portable measuring devices. Periodic monitoring is performed according a certain schedule or after an incident has occurred, and is unable to identify a random adverse event, which is its main drawback. The results of continuous monitoring by BINOM3 are documented in the Electric Power Compliance Verification Report. This report is generated automatically at specified intervals (daily, weekly) in a standard format (according to GOST 33073-2014) and stored on the instrument's memory card. In case of abnormal events in the electrical networks, such as voltage dips, interruptions, and surges, the BINOM3 records and stores their parameters (start time, depth, duration, quantity) and current and voltage waveforms (before, during and after the event) on the memory card. BINOM3 reports and waveforms are valid and reliable evidence of power quality deviations occurring at the point of delivery from the supplier to the customer.

The cost of BINOM3 begins with the commercial value of the commercial customer meter. The BINOM3 application provides significant economic benefits over a set of specialized instruments with similar functions (substantiation can be found at http://binom3.ru/files/binom3_technical_description_ru.pdf).

Introduction of such instrumentation in the electric power systems in general would improve observability standards, optimize operations, and increase cost effectiveness, quality of operation and management of the production processes, power transmission, distribution, and consumption.

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