

The Experimental Studies to Improve the Measurements Synchronization Accuracy in the 10 kV Feeder at Zero Crossing by Calculated Compensation of Phase Shift of Voltage

Pavel Zvada, Evgenii Zelenskii, Yury Kononov

*Institute of Electricity, Electronics and Nanotechnologies
North Caucasian Federal University, Stavropol, Russia, pzvada@ncfu.ru, zeg86@ya.ru,
iukononov@ncfu.ru*

Abstract – The article research a low-cost method for synchronization of measurements in distribution networks in terms of a mains' voltage signal zero crossing. In order to improve the accuracy of synchronization it is suggested compensating for the phase shift of voltage in the network nodes using the algorithmic technique relative to the power supply voltage. It calculates the network mode for the positive sequence of the fundamental harmonic to compute the phase shifts.

The experimental field studies have been performed with the operating municipal 10 kV feeder and twelve 10/0.4 kV step-down transformers. The synchronized measurements of the phase voltages and currents have been executed with specially designed experimental 24 bit sigma-delta ADC IED with 10 minute periodicity at 40 ms intervals with a sampling frequency of 16 kHz in low voltage buses of all 12 substations and in the supply center of the feeder. The results of experimental studies have shown that algorithmic compensation of phase shift can improve the accuracy of measurements synchronization up to 0.5-3 microsecond.

Keywords – Synchronization, IED, Phase Shift

I. INTRODUCTION

The implementation of WAMS technologies based on phasors synchronous measurements with PMU [1] in electric power engineering, as well as the use of optical current and voltage transformers and merging units (MU) in digital substations demonstrate the effectiveness of application of high-precision synchronous measurements in power networks. So far, the synchronous measurements has been widely used only in the ultra-high

and high voltage (110 kV and higher) networks due to the high cost of PMU, IED and MU utilized. The available separate research results of synchronized measurements in distribution networks indicate the technical expedience of their application for the traditional tasks of monitoring the modes based on state estimation, and also to address problems pertaining specifically to distribution networks such as quality assessment of power, detection of the sources of distorting effects, identification of topology and parameters of the network elements and detection of the non-technical energy losses [2-6]. However, the practical implementation of these technologies in the distribution networks requires a significant reduction in price of the measuring systems and the transition from the synchronization via satellite navigation systems signals to other noise-immune and reliable synchronization methods [2].

II. TASK SYNCHRONIZATION OPTIONS FOR ITS SOLUTION

There might be alternative methods such as:
– symbol synchronization via communication channels such as standard 1588 protocol [7]);
– synchronization via voltage waveform distortion [8];
– synchronization via the mains voltage signal zero crossing [9].

There is no doubt the symbol synchronization application via communication channels within the framework of implementation of the active-adaptive grid (Smart Grid) concept, which assumes the availability of two-way data exchange between the measuring device (IED) and automated systems, is promising. The drawbacks of this method are the requirement for high-speed communication channels and routers to ensure synchronization accuracy of less than 1 ms.

Synchronization by means of artificial distortion using voltage signal thyristor at the center of power supply of a low-voltage power network [8] in normed constraints of the level of the higher harmonics limits the spread of network feasible for synchronization. Furthermore, there are additional costs for the thyristors and control system involved.

One of the most promising and low-cost methods to synchronize measurements in distribution network, especially low-voltage ones, is the synchronization by a mains voltage signal zero crossing. In [10] the application of this method to synchronize the PLC modems is viewed in detail. Based on experimental measurements of zero crossing transient in rural and urban power networks in Germany and Switzerland, the maximum value of jitter was detected. The mains voltage zero crossings were measured during 28.8 days total in the number of 124.4 million. As a result of the processed research data it has been determined that 99.91% of jitter values are in the range of ± 60 microseconds. The maximum jitter values ranged from -400 to 300 microseconds. The study was carried out for low-voltage networks with lines spread up to 500 meters.

In Smart Grid framework the magnitude of mistiming of measuring devices using the zero crossing for synchronization, can be compensated by modeling the mode of network in DMS they are connected to [11].

This paper studies experimentally the calculation error of the of voltage phase angle relative to the phase angle of the power supply with the 10 kV current feeder as an example for 12 10/0.4 kV transformer substations. The experimental IEDs with 24-bit sigma-delta ADC and GPS/GLONASS synchronization function have been used as a benchmark. 13 of these IEDs were fitted to all 12 transformer substations and at the center of power supply (CPS) as a part of an experimental AMR Energomera, JSC [12].

Section III describes the 10 kV test feeder, IED interconnection circuit and data acquisition.

Section IV describes the methods for processing of the measured data and simulating the feeder modes. The results of experimental studies, calculation errors and their analysis are shown in Section V.

III. DESCRIPTION OF THE 10 KV TEST NETWORK OF AND MEASURING SYSTEM

The field measurements have been fulfilled with an operating 10 kV feeder owned by the municipal networks of the town of Mikhailovsky, Stavropol Territory, Russia. The single-line feeder circuit is shown in Figure 1. The feeder supplies 12 10.0/0.4 kV single-transformer substations under the normal mode.

All Transformer Substations (TS) except TS-12 are fitted with Y/Y_H-12 winding connection circuit. The TS-12 transformer features Δ /Y_H-11 circuit. The parameters

of feeder line sections are shown in Table 1.

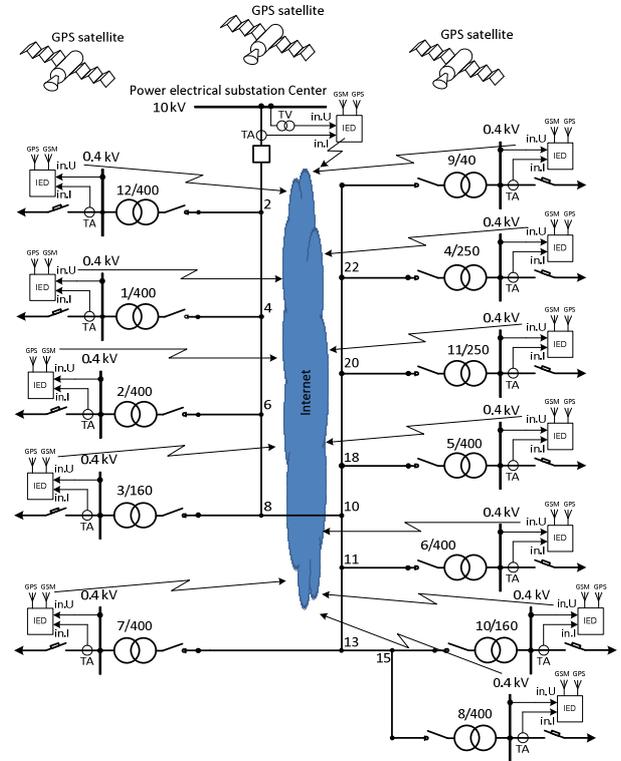


Fig.1. Single-line diagram of the feeder

Table 1. Line Sections Parameters.

Section Number	F, sq. mm	L, m	Section Number	F, sq. mm	L, m
CPS-2	50	64	13-TS7	50	527
2-TS12	50	184	13-15	50	538
2-4	50	211	15-TS10	50	33
4-TS1	35	20	15-TS8	50	1640
4-6	240	681	10-18	50	1352
6-TS2	120	20	18-TS5	50	410
6-8	70	116	18-20	50	399
8-TS3	70	167	20-TS11	50	123
8-10	70	661	20-22	50	307
10-11	70	56	22-TS4	150	65
11-TS6	70	19	22-TS9	70	105
11-13	50	788	-	-	-

The power feeder is supplied by 10 kV 35/10 kV buses. To conduct the studies, three-phase IEDs manufactured by Energomera, JSC, have been installed in all 12 TS and CPS.

The IED technical specifications are shown in Table 2.

Table 2. Three – phase IED specifications.

Parameter	Unit of Measure	Parameter Value
Phase Voltage Measurement Accuracy	δ_u , %	$\pm 0,1$
Phase Currents Measurement Accuracy	δ_i , %	$\pm 0,1$
Power Measurement Accuracy	δ , %	$\pm 0,5$
ADC, Type	-	$\Delta\Sigma$
ADC, Resolution	bit	24
Oscilloscope Time Span	second	0,04
Sample Rate	kHz	16
Operating Temperature Rate	$^{\circ}\text{C}$	$-40 \div +60$

The IEDs' main circuits of 10 / 0.4 kV TS have been attached to a stationary CT; the specifications are shown in Tables 3.

Table 3. CT Technical Specifications.

Voltage Rating, kV	Secondary Current Rating, A	Secondary Load Rating, VA	Precision Rate
0,66	5	5	0,5

The measuring module of the IED is based on ADS131E08 microcircuit [13], incorporating a 24-bit sigma-delta ADC produced by Texas Instruments. A GPS/GLONASS module receiving is used to synchronize measurements and AD9548 the phase-locked loop chip by Analog Devices [14].

The samples of the phase voltages and currents being measured in the range of 40 ms with a preset schedule (at 5 or 10 minutes intervals) have been transmitted to the AMR data collection server via GSM modems.

IV. DESCRIPTION OF THE METHOD FOR PROCESSING OF THE DATA BEING MEASURED AND FEEDER MODES SIMULATION

The measurements were taken during 24 hours on April 16, 2016. The instantaneous values of the phase currents and voltages of all 13 IEDs were downloaded from AMR server database and transformed into a text file prior being processed using specially developed computer programs.

The program algorithm included the following steps for each test period of the network:

1. Computing phase currents phasors and phase voltage phasors at each network node through the Fourier transform.

2. Computing direct sequence of currents and voltages through the method of symmetrical components.

3. Computing the values of three-phase active and reactive power for the direct sequence of all the measured network nodes.

4. Computing a steady-state mode of network by means of the Newton method using the data of nodes' load and main substation voltage. Defining calculated values of the phase angles of voltages at the loaded nodes relative to the phase angle of the main substation.

5. Computing an error of voltages synchronization by the zero-crossing, with and without accounting for the compensation of the estimated value of the phase angle of voltage.

The substitution feeder circuit was designed in advance based on the initial data of line sections parameters and transformer technical specifications data in order to calculate the steady-state mode of the network mentioned above in Step 4. The circuit comprised U-shaped equivalent circuit for the lines and L-shaped for transformers. The length of the sections was defined by means of IEDs geographical coordinates data of the substations and Google Map satellite images. The equivalent circuit parameters were customized with a specially designed computer program in order to define the effect of temperature on the active resistance of line sections and the transformer. The algorithm of the program utilized the method of coordinate-wise descent to minimize the deviation of the measured and calculated parameters of the network mode.

The results of synchronization errors calculation by zero crossing, without taking into account compensation for the estimated value of the phase angle of the voltage are shown in Table 4.

Table 4. TS Measurements Synchronization Accuracy.

TS Number	Non compensated		Compensated	
	Mathematical Expectation, μs	Standard Deviation, μs	Mathematical Expectation, μs	Standard Deviation, μs
1	-0,928	0,516	-0,175	0,190
2	-58,339	15,667	0,530	0,206
3	-47,493	16,049	1,065	0,449
4	-2,690	2,480	-1,386	1,082
5	-29,829	9,438	0,610	0,432
6	-51,026	16,295	-1,672	1,399
7	-59,212	16,514	0,271	0,240
8	-51,980	14,660	0,318	0,382
9	-6,354	1,656	-2,115	0,674
10	-41,223	11,686	0,659	0,195
11	-3,626	1,836	-1,589	0,356
12	-0,704	0,377	-1,269	0,318

As can be seen from the results, at the phase angle compensation the reduction of mathematical expectation of value of mistiming in 2 - 100 times occurs for all TS. The standard deviation of value of mistiming decreased about 20 times for the loaded TS. Maximum effect oc-

curs to TS7 and the minimum effect occurs to underloaded TS12 closely spaced to the Main Substation.

The value of mistiming can be reduced by refining the parameters of the equivalent circuit of the feeder, and a more precise modeling of network modes, subject to the nonlinear dependence of the magnetizing current of the transformers, considering the effect of temperature of wires and cable cores, transformer windings on their active resistance.

V. CONCLUSIONS

Based on the data provided by the IED with the oscilloscope function for simultaneously measured currents and voltages within the performed field studies of municipal network's operating 10 kV feeder the following conclusions can be drawn:

1. The algorithmic compensation of phase shift angle of voltages phasors in the nodes of the network based on the calculation of the steady state mode allows reducing the maximum value of mistiming from 108 μ s to 0.89 μ s for the top loaded TS7. The effectiveness of compensation is less significant for underloaded TS. The minimal effect on improving the accuracy has been recorded for TS 12 spaced closely to the MS. The maximum value of mistiming for that TS decreased from 2.56 μ s to 2.41 μ s.

2. A more accurate simulation of network modes is required to increase the efficiency of algorithmic compensation, including calculation for nonlinear dependence of the magnetizing current of the transformers, and taking into account the effect of temperature of wires and cable cores, transformer windings on their active resistance.

3. The measurements data indicate that the application of the previous period measurements to calculate the steady-state mode of the power mains, results in additional mistiming no greater than $\pm 0,5 \mu$ s (the mean value of standard deviation is 0.044 μ s).

VI. ACKNOWLEDGMENT

This work was supported by the Ministry of Education and Science of the Russian Federation under agreement No. RFMEFI57814X0017.

REFERENCES

- [1] De La Ree, J., Centeno, V., Thorp, J. S., Phadke, A. G., "Synchronized Phasor Measurement Applications in Power Systems," in *IEEE Transactions on Smart Grid*, vol. 1, no. 1, pp. 20-27, June 2010. DOI: 10.1109/TSG.2010.2044815
- [2] Albu, M., Dumitrescu, A. M., "Applicability of synchronised measurements in modern distribution grids. A discussion," Applied Measurements for Power Systems Proceedings (AMPS), 2014 IEEE International Workshop on, Aachen, 2014, pp. 1-6. DOI: 10.1109/AMPS.2014.6947717
- [3] Giustina, D. D., Ferrari, P., Flammini, A., Rinaldi, S., "Experimental characterization of time synchronization over a heterogeneous network for Smart Grids," Applied Measurements for Power Systems (AMPS), 2013 IEEE International Workshop on, Aachen, 2013, pp. 132-137. DOI: 10.1109/AMPS.2013.6656239
- [4] Dumitrescu, A. M., Roman, R., Albu, M., "Synchronized measurements and power quality assesment," PowerTech, 2015 IEEE Eindhoven, Eindhoven, 2015, pp. 1-6. DOI: 10.1109/PTC.2015.7232815
- [5] Vicol, B., Gavrilas, M., Ivanov, O., Neagu, B., Grigoras, G., "Synchrophasor measurement method for overhead line parameters estimation in MV distribution networks," 2014 16th International Conference on Harmonics and Quality of Power (ICHQP), Bucharest, 2014, pp. 862-865. DOI: 10.1109/ICHQP.2014.6842833
- [6] Sánchez-Ayala, G., Agüerc, J. R., Elizondo, D., Lelic, M., "Current trends on applications of PMUs in distribution systems," Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES, Washington, DC, 2013, pp. 1-6. DOI: 10.1109/ISGT.2013.6497923
- [7] *Standard IEEE-1588-2008 "IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems"* (2008) DOI: 10.1109/IEEESTD.2008.4579760
- [8] Grilo, A.P., Pengfei, Gao, Xu, W., de Almeida, M.C., "Load Monitoring Using Distributed Voltage Sensors and Current Estimation Algorithms", IEEE Trans. Smart Grid, vol. 5, n°. 4, pp. 1920-1928, Jul. 2014 DOI: 10.1109/TSG.2014.2304011
- [9] Gaderer, G., Sauter, T., Bumiller, G., "Clock synchronization in powerline networks," International Symposium on Power Line Communications and Its Applications, 2005. pp. 71-75. DOI: 10.1109/ISPLC.2005.1430468
- [10] Kistner, T., Bauer, M., Hetzer, A., Dostert, K., "Analysis of zero crossing synchronization for OFDM-based AMR systems," Power Line Communications and Its Applications, 2008. ISPLC 2008. IEEE International Symposium on, Jeju city, Jeju Island, 2008, pp. 204-208. doi: 10.1109/ISPLC.2008.4510424
- [11] Kononov, Y., Zvada, P., Rudnev, V., "The low cost method of measurements synchronization in the low-voltage network on frequency and the voltage phase," Proceedings XXI IMEKO World Congress, Prague, Czech Republic, 2015.
- [12] CJSC "Electrotechnical factories «Energomera»", Official site, [Online]. Available: <http://www.energomera.ru/en>.
- [13] ADS131E08 [Online]. Available: <http://www.ti.com/product/ADS131E08>
- [14] AD9548 [Online]. Available: <http://www.analog.com/en/products/clock-and-timing/clock-generation-distribution/ad9548.html>