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MONITORING THE UNBALANCE IN POWER MICRO-GRIDS

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Abstract: *Micro-power grids are network components in which the consumers are active entities, i.e. they communicate with distribution network and contribute to the production of electricity, in particular, through renewable energies. Consumer involvement on energy efficiency has positive consequences if their electrical micro-plants are interconnected with the distribution network. But, the interconnections rise many and different quality problems. Unbalanced regime in the three-phase system of voltages and currents of power micro-grids depends on both the degree of unbalance and the harmonic pollution induced by the consumers connected to the grids. The consequences of unbalances have a negative impact on the performances of the network and the consumers too. The paper deals with the analysis of the methods of the unbalance indicators establishing according to the international recommendations. Analysis is useful for calculation of the current through the neutral and the active and reactive power losses. Based on the parameters of consumers – the phase voltages and currents and their phase difference - a simulation program in LABVIEW is proposed, which allows the establishment of the specific unbalance indicators. The simulation is validated by experimental measurements.*

Keywords: *electrical micro-plants, active entities, energy efficiency, electrical unbalance, low-voltage electrical grid, quality indicator of electrical energy, unbalance factor.*

1. INTRODUCTION

Three-phase systems whose waveform voltage and current are periodically with the period *T*, is balanced if the waveform is equal in magnitude and are time-shifted to each other by *T*/3. Otherwise, the three-phase system is unbalanced. The balance definition refers not only to the wave form; therefore the system may be balanced even in the presence of distorted wave forms.

The study of the combined effects of the distorted and unbalanced wave forms in the three-phase systems with neutral provides useful information for designing the neutral conductor. An ideal operation of a three phase system has the form of voltage and current sinusoidal wave and balanced so that the three phases are equally charged and neutral current is zero. This condition is usually taken as reference for dimensioning phase conductors. For the neutral conductor, some regulations allow its reduced sizing as compared to the phase conductors. In power micro-grids with neutral the quality of electrical energy is affected by the unbalanced and non-linear consumers which lead to relatively high currents in the neutral [4].

Analysis of the power systems in non-sinusoidal operation is particularly important, the specialized recent literature bringing many contributions on the concepts and definitions related to the system variables [6,1].

The effects of the unbalance in the power system and the distortion of the wave forms were approached in several articles. The measurements of the currents and the voltages on the neutral have been presented in [10,7,8,2], for practical cases, with different types of distorted loads.

It is necessary that these unbalances should be monitored especially due to the emergence of intelligent networks, with distributed generation (GD). With the advent of intelligent electrical networks (Smart Grids) with distributed generation (GD) capacity is considered a good opportunity in terms of monitoring power quality.

An important aspect of these networks is the bidirectional circulation of electrical energy, in which consumers are active entities, because the production of electricity in particular renewable energy is very close to the consumer. For this purpose it is necessary the monitoring of these micro-networks unbalance. In this paper we propose a system of continuous monitoring of voltage and current form for the three phases and of voltage and current unbalance factor.

In this paper a continuous monitoring system of phase voltage and currents wave forms is proposed which give the information on unbalance indicators.

2 UNBALANCED REGIME

For the analysis of unbalanced regimes several methods are used, such as component system networks introduced by Clarke and Stanley Park, or the symmetrical components introduced by Stokvis-Fortescue [5]. The symmetrical components method is most advantageous for the study of symmetrical or asymmetrical connection of consumers without or with harmonic pollution.

2.1. Unbalance in sinusoidal regime. Unbalanced current modeling in a micro-grids are based on Stokvis-Fortescue theorem, which states that a three-phase sinusoidal system in a particular case - the current three-phase system - can be decomposed into three symmetrical systems: positive, negative and zero.

The phase unbalanced current can be determined using symmetrical components relationship:

$$\left[\underline{I}\right] = \left[\underline{T}\right] \cdot \left[\underline{I}_{sim}\right] \qquad (1)$$

where:

- the column matrix of currents unbalanced system is:

$$\left[\underline{I}\right] = \left[\underline{I}_R \quad \underline{I}_S \quad \underline{I}_T\right]^t \qquad (2)$$

- the column matrix of symmetrical components is:

$$\left[\underline{I}_{sim}\right] = \left[\underline{I}_0 \quad \underline{I}_1 \quad \underline{I}_2\right]^t \qquad (3)$$

- the exponent t refers to matrix transposition,

- $[T] = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix}$ is the transformation matrix

The symmetrical components of the phase currents can be written as follows:

$$\left[\underline{I}_{sim}\right] = \left[\underline{T}\right]^{-1} \cdot \left[\underline{I}\right] \qquad (4)$$

where:

- $\left[\underline{T}\right]^{-1} = \frac{1}{3} \cdot \begin{vmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{vmatrix}$ is the inverse transformation matrix in which $a = e^{j \cdot \left(\frac{2 \cdot \pi}{3}\right)}$ is the rotation operator [5].

Symmetrical current systems are characterized by the absence of negative and zero sequence components.

2.2. Unbalance in non-sinusoidal regime. In power micro-grids the voltage harmonics are insignificant, so that only currents harmonics presence os take into account.

In a matrices' representation of complex current vector $\underline{I}$, for each harmonics of k order a colon complex vector of phase current is defined:

$$\left|\underline{I}^k\right| = \left|\underline{I}_R^k \qquad \underline{I}_S^k \qquad \underline{I}_T^k\right|^t \qquad (5)$$

The symmetrical components of the k harmonic of the phase currents can be written as follows:

$$\left|\underline{I}_{sim}^{k}\right| = T^{-1} \cdot \underline{I}^{k} \quad (6)$$

where the symmetric components are:

$$\left|\underline{I}_{sim}^{k}\right| = \left|\underline{I}_{1}^{k} \quad \underline{I}_{2}^{k} \quad \underline{I}_{0}^{k}\right|^{t} \quad (7)$$

A distinction is possible between balanced and unbalanced phase current of fundamental components:

$$I_{p}^{b1} = I_{p}^{u1} \quad (8)$$

A distinction is also possible for distortion phase current:

$$I_{p}^{d} = \sqrt{\sum_{k=2}^{\infty} \left(I_{1}^{k}\right)^{2} + \left(I_{2}^{k}\right)^{2} + \left(I_{0}^{k}\right)^{2}} \quad (9)$$

Usual the unbalance indicators are defined taking in account only the characteristics of fundamental phase current.

2.3. Indicators of unbalanced regime. Calculation of zero, positive and negative sequence components in the case of unbalanced voltages and currents system is presented in [9,3,11].

Phase voltage unbalance rate (PVUR) is proposed by IEEE standards [12], defined by the relationship:

$$PVUR\ [\%] = \left|\frac{U_{f\,med} - U_{f\,\max}}{U_{f\,med}}\right| \cdot 100 \quad (10)$$

where: $U_{f\,med}$ represents arithmetic average of the rms phase voltages; $U_{f\,\max}$ is the highest value of measured phase voltage.

Voltage unbalance factor (VUF) is another indicator proposed by the IEC standards [13], defined with symmetrical components method by the relation:

$$VUF\ [\%] = \left|\frac{\underline{U}_2}{\underline{U}_1}\right| \cdot 100 = \left|\frac{\underline{U}_R + a^2 \cdot \underline{U}_S + a \cdot \underline{U}_T}{\underline{U}_R + a \cdot \underline{U}_S + a^2 \cdot \underline{U}_T}\right| \cdot 100 \quad (11)$$

where: U_1 is the positive sequence voltage, U_2 is the negative sequence voltage, and $\underline{U}_R$, $\underline{U}_S$, $\underline{U}_T$ signify the measured rms values of the fundamental phase voltages, and a is the transformer operator.

Similarly are determined unbalance current factor. According to IEC and IEEE standards, the unbalance voltage and current factors are usually denoted by K_U, respectively, K_I

3. UNBALANCE MONITORING

The paper proposes an analysis of the procedure monitoring and the indicators evaluation into a power micro-grid in which different types of regimes exists: unbalanced, distorted or combined - unbalanced-distorted operation. The aim is to establish the measures to eliminate or reduce the energy losses.

3.1. Description of analyzed micro-grid. A power micro-grid with active consumers was considered, which is supplied from a PT X transformer point of 6.0/0.4 kV.

Passive consumers are lighting, induction motors, computers, fans, converters, inverters and laboratory equipments. In the majority these are controlled by electronic equipment, having the nonlinear voltage-current characteristics, being the sources of disturbances through the generation of harmonics in the network. Thus, the waveforms of voltages and currents are differently distorted on the three phases. Power system studied is shown in Fig. 1.

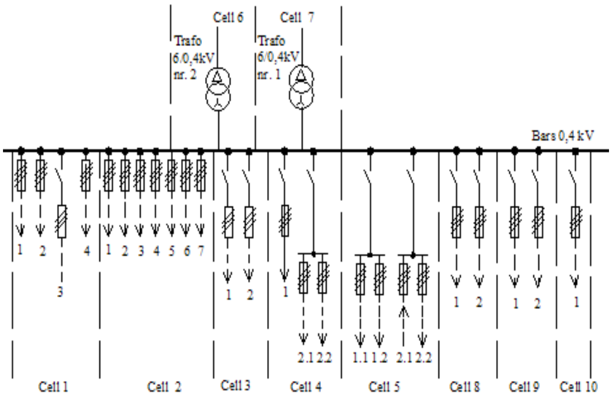

Fig. 1. Single-phase scheme of the supplying of PT-X transformer point 6.0/0.4 kV

The transformer point PT-X consists in 10 distribution cells G-P1...G-P10 with a single bar system, the working supply is ensured from the transformer number 2 in the cell P6 and the reserve supply is ensured from the transformer number 1 in the cell P7 without AAR-type automation. In the cell P5 on the circuit 2.1 is supplied from the photovoltaic panels.

3.2. Monitoring system. To achieve security and stability of micro-grid is necessary to monitor these parameters, particularly the unbalance parameters.

The paper proposes a system of continuous monitoring system of voltage and current form on the three phases and voltage unbalance voltage and current factor (Fig.2).

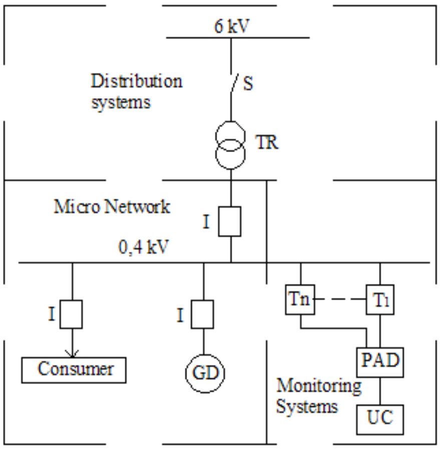

Fig.2. Monitoring system of power micro-grid unbalance

In Fig. 2 there are: S – separator; TR - 20.0/0.4 kV transformer, I – switch gear, DG - distributed generation, T1 - transducers, PAD - data acquisition card, UC – central unit.

Through transducers, data acquisition card collects information from the micro-grid (current, voltage, power, frequency) and transmits to the central unit where the information are stored and processed. A complex system of control, protection and power quality monitoring is obtained. The tool developed can be used to monitor micro-grids unbalance in sinusoidal and non0sinusuidal regimes.

3.3. LabVIEW programming software. The central unit (CU) uses a LabVIEW graphical programming software for data acquisition and proceeding and for using the virtual instruments for measuring and control devices. One of its advantages compared to conventional devices is the ability to be easily transformed by changing or replacement program. The front panel of the application is presented in Fig. 3.

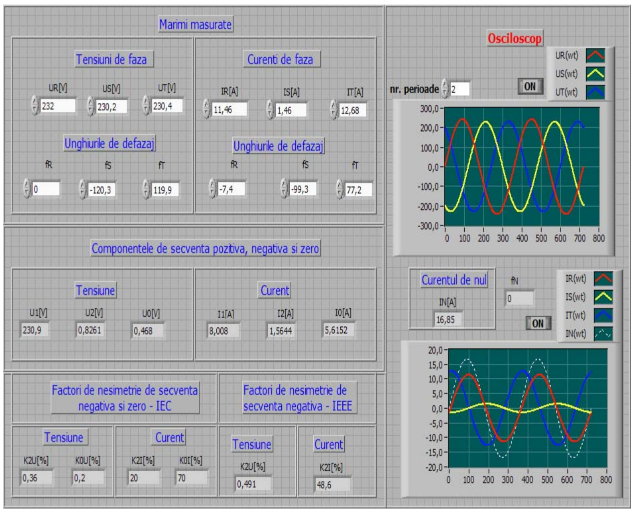

Fig. 3. The front panel of the application

The front panel is structured in following blocks:

- Measured values of voltages, currents and phase ongles;
- Neutral current;
- Components of positive, negative and zero sequence voltage and currents;
- Negative and zero voltage and current unbalance factors;
- Two oscilloscopes for phase voltages, currents and neutral current waveforms.

In the measured values block there are recorded the rms values of phase voltages and currents and their phase angles. In neutral conductor block is set the effective value of calculated/measured neutral current.

The values obtained for the positive, negative and zero sequence components, are compared with permissible levels and are shown.

In unbalance factor block is calculated and displayed levels of negative and zero sequence unbalance factors.

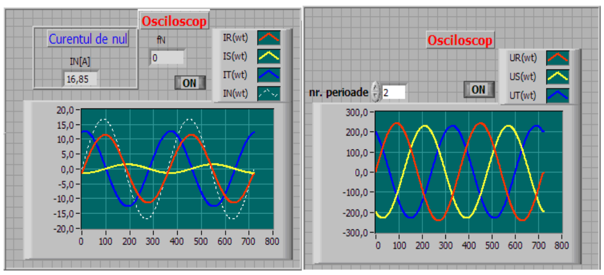

Fig. 4. Waveforms of phase voltages and currents

Oscilloscope block (Fig.4.) is used for viewing:

- waveforms of the phase voltages by consumers;
- waveform of phase currents by consumers;
- waveform of neutral current.

The developed tool can be used to monitor micro-grids because the consumers can be drastically affected under the influence of a high voltage unbalance.

3.4. Experimental data and results. With the proposed software the parameters of micro-grid supplied from PT X transformer point 6.0 / 0.4 kV with 10 minute periods have been monitored. For one week of monitoring, a large amount of information was obtained, and to obtain meaningful data, an aggregation of measured parameters was performed.

The levels of voltage and current unbalance negative factor obtained with the proposed software are presented in Fig. 5 and Fig. 6.

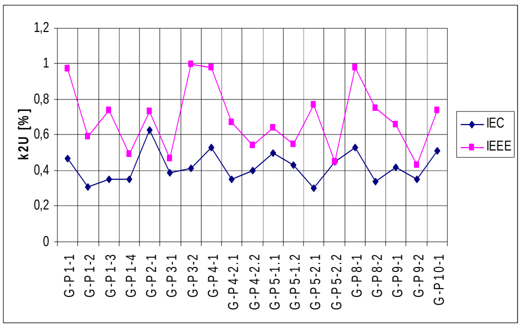

Fig. 5. Voltage unbalance negative factor K2U for the issues from „PT-X”

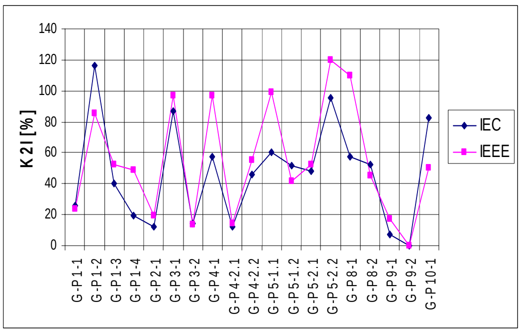

Fig. 6. Current unbalance negative factor K2I for the issues from „PT-X”

Some observations can be underlined:
- Voltage unbalance negative factor is within the limits imposed by current standards;
- Current unbalance negative factor exceeds the maximum value imposed by standards;
- For the low values of unbalance, the unbalance factor can be calculated with the relationship given by the IEEE;
- Definitions proposed by the IEC and IEEE give almost identical results, where the zero sequence components is below the limit permitted by the regulations. When the zero sequence components is greater than the limit, both definitions may overestimate or underestimate the level of unbalance.

4. CONCLUSIONS

Due to the increasing number of single-phase loads with nonlinear nature and due of the development of power electronics that produce unbalances, the unbalance regimes increase and a continuous monitoring system is required to estimate the level of voltage waveforms deformation and of voltage unbalance degree, and to evaluate the unbalance factors.

Definitions proposed by the IEC and IEEE standards give almost identical results, where the zero sequence component is below the limit permitted by the regulations. When the zero sequence component is greater both definitions may overestimate or underestimate the level of unbalance.

The proposed monitoring system is useful in analysis of power micro-grid unbalance, contributing to the increasing of the performance of micro-grid and reducing he power consumption.

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