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NEW WAY TO IDENTIFY AND ASSESS VOLTAGE UNBALANCE EMISSION SOURCES IN THREE-PHASE THREE-WIRE ELECTRICAL NETWORK

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Abstract: The identification of voltage unbalance sources and assessment of their impact onto power quality are important matters of disagreement between a utility and a customer. The standard methods on power quality measurement impose additional restrictions on a problem solution. As a result, the existing methods for voltage unbalance emission identification and assessment are valid only for the cases with a single dominating disturbing source. This paper proposes a new way to solve the problem based on the basic time interval for power quality measurement. It is a simple method with high accuracy and has no limitations as regards number and power rate of disturbing sources connected to a considered point of evaluation.

1. INTRODUCTION

Voltage unbalance sources identification and assessment in electrical network is a topical billing problem for utilities and customers [1-4]. It draws a lot of attention if low electric power quality (PQ) results in financial losses. Among others power quality parameters, the voltage unbalance is a one of the most important phenomenon causing sufficient economical losses to both utilities and consumers.

The majority of modern voltage unbalance emission identification and assessment methods applies Thevenin and Norton equivalent circuits [5]. The methods differ as regards ways to determine parameters of these circuits. The determination of equivalent circuit parameters on the basis of the basic measurement time interval prescribed by IEC 61000-4-30 [6] encounters obstacles sufficiently limiting the capabilities of the mentioned above methods. In addition, the CIGRE working group C4.109 [7] proposes the comparison of the pre-existing emission level with the total disturbance level after connection of a new installation a basic way of voltage unbalance emission identification and assessment [8-10].

In the presented paper a new way to identify and assess voltage unbalance emission sources at a point of evaluation (POE) is considered for the case of three-phase three-wire network. The method is highly adopted to the standard procedures of PQ measurement and evaluation.

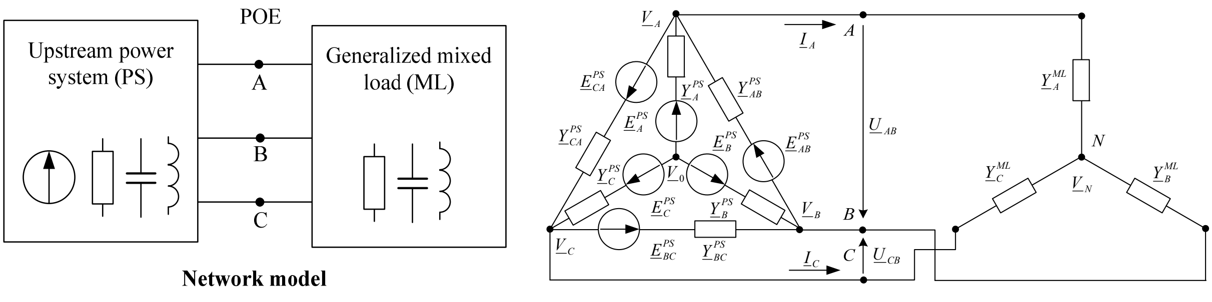
This paper is organized as follows. Section 2 presents conditions and assumptions for the solving task. Section 3 gives ideas how was chosen the equivalent circuit for a network model in a relation to POE. Section 4 describes the determination of the equivalent circuit parameters for different network components. Section 5 presents the fundamentals of the proposed mathematical model. Section 6 discusses the error of the proposed method.

2. BASIC CONDITIONS AND ASSUMPIONS FOR THE SOLVING TASK

According to IEC 61000-4-30 [6], the basic time interval must be 10 cycles for PQ measurement in 50 Hz power system. This time windows is also applied in the presented method of the identification and assessment of voltage unbalance emission sources. It is supposed that network operational state aggregated during 10 cycles may be treated as a steady one. The network state over each basic time interval are considered to be different. The high frequncy components of the measured voltages and currents are neglected. The network operational state is measured only in two phases. All components of the equivalent circuit are supposed to be linear. The proposed identification and assessment method is originally developed in phase coordinates.

3. EQUIVALENT CIRCUIT FOR POWER SUPPLY SYSTEM

Let us coniser three-phae three-wire power supply system (PSS) in relation to a POE located between an upstream power system (PS) and a generalized mixed load (ML) (Fig. 1, *a*). The upstream power system can be presented with a set of arbitrarily interconnected passive and active components. The same approach is used for the mixed load equivalnt circuit, but the last one includes no active components.



a) b)

Fig. 1. The equivalent circuit of a power supply system with separately presented POE nodes in phase coordinates: a) common diagram, b) detailed model with configurations of the upstream power system and generalized mixed load rquivalnet circuits

A common schematic diagramm of network with separetly presented POE is shown in Fig. 1, *b*. The upstream power system is presented with six passive ($\underline{Y}_{AB}^{PS}$, $\underline{Y}_{BC}^{PS}$, $\underline{Y}_{CA}^{PS}$, $\underline{Y}_{A}^{PS}$, $\underline{Y}_{B}^{PS}$ and $\underline{Y}_{C}^{PS}$) and six active ($\underline{E}_{AB}^{PS}$, $\underline{E}_{BC}^{PS}$, $\underline{E}_{CA}^{PS}$, $\underline{E}_{A}^{PS}$, $\underline{E}_{B}^{PS}$ and $\underline{E}_{C}^{PS}$) components, at the same time the generalized mixed load contains only three passive components ($\underline{Y}_{A}^{ML}$, $\underline{Y}_{B}^{ML}$ and $\underline{Y}_{C}^{ML}$). This diagram is a basis for our method to identify voltage unbalance emission sources and assess their impact on PQ at a POE.

4. DETYERMINATION OF EQUIVALENT CIRCUIT PARAMETERS

Let us consider how to determine the parameters of PS and ML equivalent circuit components on the basis of the basic measurment time interval.

The PS equivalnet circuit components are related to the operational state parameters measured at the POE by means of the following equations:

$$\begin{cases} \underline{U}_A^{PS} \cdot \underline{Y}_A^{PS} + \underline{U}_{AB} \cdot \underline{Y}_{AB}^{PS} + \left(\underline{U}_{AB} - \underline{U}_{CB}\right) \cdot \underline{Y}_{AC}^{PS} = \underline{E}_{CA}^{PS} \cdot \underline{Y}_{CA}^{PS} + \underline{E}_A^{PS} \cdot \underline{Y}_A^{PS} - \underline{E}_{AB}^{PS} \cdot \underline{Y}_{AB}^{PS} - \underline{I}_A; \\ \underline{U}_B^{PS} \cdot \underline{Y}_B^{PS} - \underline{U}_{AB} \cdot \underline{Y}_{AB}^{PS} - \underline{U}_{CB} \cdot \underline{Y}_{BC}^{PS} = \underline{E}_{AB}^{PS} \cdot \underline{Y}_{AB}^{PS} + \underline{E}_B^{PS} \cdot \underline{Y}_B^{PS} + \left(\underline{I}_A + \underline{I}_C\right) - \underline{E}_{BC}^{PS} \cdot \underline{Y}_{BC}^{PS}; \\ \underline{U}_C^{PS} \cdot \underline{Y}_C^{PS} + \underline{U}_{CB} \cdot \underline{Y}_{BC}^{PS} - \left(\underline{U}_{AB} - \underline{U}_{CB}\right) \cdot \underline{Y}_{AC}^{PS} = \underline{E}_{BC}^{PS} \cdot \underline{Y}_{BC}^{PS} + \underline{E}_C^{PS} \cdot \underline{Y}_C^{PS} - \underline{E}_{CA}^{PS} \cdot \underline{Y}_{CA}^{PS} - \underline{I}_C, \end{cases} \quad (1)$$

where $\underline{U}_A^{PS}$, $\underline{U}_B^{PS}$ and $\underline{U}_C^{PS}$ are POE node potentials in relation to reference point of zero potential $\underline{V}_0$ of PS equivalent circuit (Fig. 1, *b*).

The set of equations (1) contains three equations with 15 unknown quianities, namely six active components ($\underline{E}_{AB}^{PS}$, $\underline{E}_{BC}^{PS}$, $\underline{E}_{CA}^{PS}$, $\underline{E}_A^{PS}$, $\underline{E}_B^{PS}$ and $\underline{E}_C^{PS}$), six passive components ($\underline{Y}_{AB}^{PS}$, $\underline{Y}_{BC}^{PS}$, $\underline{Y}_{CA}^{PS}$, $\underline{Y}_A^{PS}$, $\underline{Y}_B^{PS}$ and $\underline{Y}_C^{PS}$) and three phase to ground voltages ($\underline{U}_A^{PS}$, $\underline{U}_B^{PS}$ and $\underline{U}_C^{PS}$). It means (1) may be solved only by means of the measured POE voltages and currents. To sovle this uncertanty, of the matrix transformation of network electrical circuit is used. This transformation requires values of slack bus voltages, as well as the configuration and parameters of upstream power system componets between the slack bus and the POE like overhead lines, cables, transformers etc. This task can be solved on the basis of Smart Grid techology and concepts [11], [12].

The interrelations between the ML equivalent circuit components and the votlages and currents measured at the POE are described by the following equations:

$$\begin{cases} \underline{U}_{AB} \cdot \left[\dfrac{\underline{Y}_A^{ML} + \underline{Y}_B^{ML} + \underline{Y}_C^{ML}}{\underline{Y}_A^{ML} \cdot \underline{Y}_B^{ML}} \right] + \left(\underline{U}_{AB} - \underline{U}_{CB}\right) \cdot \left[\dfrac{\underline{Y}_A^{ML} + \underline{Y}_B^{ML} + \underline{Y}_C^{ML}}{\underline{Y}_C^{ML} \cdot \underline{Y}_A^{ML}} \right] = \underline{I}_A; \\ -\underline{U}_{AB} \cdot \left[\dfrac{\underline{Y}_A^{ML} + \underline{Y}_B^{ML} + \underline{Y}_C^{ML}}{\underline{Y}_A^{ML} \cdot \underline{Y}_B^{ML}} \right] - \underline{U}_{CB} \cdot \left[\dfrac{\underline{Y}_A^{ML} + \underline{Y}_B^{ML} + \underline{Y}_C^{ML}}{\underline{Y}_B^{ML} \cdot \underline{Y}_C^{ML}} \right] = -\left(\underline{I}_A + \underline{I}_C\right), \end{cases} \quad (2)$$

where $\underline{U}_{AB}$, $\underline{U}_{CB}$, $\underline{I}_A$ and $\underline{I}_C$ are the voltages and currents measured at the POE.

The set of two equations (2) contains three unknown quantities ($\underline{Y}_A^{ML}$, $\underline{Y}_B^{ML}$ and $\underline{Y}_C^{ML}$). It is impossible to solve this set of equations on the basis of a single basic measurement time interval. It is also incorrect to use the data from the previous time interval because it generally corresponds to other steady state of the network as it was mention in Section 2. Nevertheless, the ML equivalent circuit parameteres can be approximately determined as follows:

$$\underline{Y}_{ph}^{ML\approx} = \underline{I}_{ph} \Big/ \underline{U}_{ph}^{ML\approx}, \quad (3)$$

where $\underline{U}_{ph}^{ML\approx}$ is the appoximate POE voltage between a phase with the index *ph*=*A*, *B*, *C* and node *N* of ML equivalnet circuit (Fig. 1, *b*) that can be found on the basis of phase-to-phase votlages in the following way:

$$\begin{cases} \underline{U}_A^{ML\approx} = \left(\underline{U}_{AB1} \cdot e^{-j30} + \underline{U}_{AB2} \cdot e^{j30}\right) \Big/ \sqrt{3}; \\ \underline{U}_B^{ML\approx} = \underline{U}_{BA} + \underline{U}_A^{ML\approx}; \\ \underline{U}_C^{ML\approx} = \underline{U}_{CB} + \underline{U}_B^{ML\approx}, \end{cases} \quad (4)$$

where $\underline{U}_{AB1}$ and $\underline{U}_{AB2}$ are the positive and negative sequence components of POE voltage.

As a result, the unknown parameters of ML equivalent circuit ($\underline{Y}_{ph}^{ML}$) can be determined with an error:

$$\delta\underline{Y}_{ph}^{ML} = \underline{Y}_{ph}^{ML} - \underline{Y}_{ph}^{ML\approx} = \underline{Y}_{ph}^{ML} \cdot \Delta\underline{V} \big/ \underline{U}_{ph}^{ML\approx}, \tag{5}$$

where the error is found with the next expression

$$\Delta\underline{V} = \left(\underline{V}_A + \underline{V}_B + \underline{V}_C - 3\cdot\underline{V}_N\right)\big/3. \tag{6}$$

5. MATHEMATICAL MODEL FOR IDENTIFICATION AND ASSESSMENT OF VOLTAGE UNBALANCE EMISSION SOURCES

This novel method is based on the separation of three-phase asymmetrical components into non-disturbing (symmetrical) and disturbing (asymmetrical) parts in each phase (Fig. 2). Due to assumed linear nature of considered network model, the disturbing parts of equivalent circuit can be presented as disturbing sources causing voltage unbalance. The component separation into disturbing and non-disturbing parts may be carried out by means of symmetrical decompostion. This procedure for active components (Fig. 2, *a*) is performed as follows:

$$\begin{cases} \underline{E}_A^{nondis} = \left(\underline{E}_A + a\cdot\underline{E}_B + a^2\cdot\underline{E}_C\right)\big/3; \\ \underline{E}_A^{dis} = \underline{E}_A - \underline{E}_A^{nondis}; \quad \underline{E}_B^{dis} = \underline{E}_B - a^2\cdot\underline{E}_A^{nondis}; \quad \underline{E}_C^{dis} = \underline{E}_C - a\cdot\underline{E}_A^{nondis}, \end{cases} \tag{7}$$

where $a = e^{j2\pi/3}$ is the operator rotating a phasor counterclockwise by 120°.

The passive components of an equivalnet circuit (Fig. 2, *b*) are separated this way

$$\begin{cases} \underline{Y}_{ph}^{nondis} = \left(\underline{Y}_A + \underline{Y}_B + \underline{Y}_C\right)\big/3; \\ \underline{Y}_{ph}^{dis} = \underline{Y}_{ph} - \underline{Y}_{ph}^{nondis}, \end{cases} \tag{8}$$

where *ph*=*A*, *B* and *C* is the phase index.

Fig. 2. Separation of the components into nondisturbing and disturbing parts

After separating the original components (Fig. 1, *b*) into non-disturbing and disturbing parts (Fig. 2), the state of network equivalent circuit cab be described by means of node voltage method:

$$\left(\mathbf{Y}^{nondis} + \sum_{i=1}^{M}\mathbf{Y}_i^{dis}\right)\cdot\vec{\mathbf{V}} = \vec{\mathbf{I}}^{nondis} + \sum_{j=1}^{N}\vec{\mathbf{I}}_j^{dis}, \tag{9}$$

where *M* is the number of passive components containing disturbing parts; *N* is the number of active components containing disturbing parts; $\mathbf{Y}^{nondis}$ is a nodal admittance matrix for the non-disturbing passive parts of the network equivalent circuit; $\mathbf{Y}_i^{dis}$ is a nodal admittance matrix for disturbing passive parts of the network equivalent circuit for the disturbing source *i*; $\vec{\mathbf{I}}^{nondis}$ is the column vectors of nodal currents of the non-disturbing active parts of the network equivalent circuit; $\vec{\mathbf{I}}_j^{dis}$ is the column vectors of nodal currents of the disturbing active parts of the network equivalent circuit for the disturbing source *j*.

To solve set of matrix equation (9) and obtain column vectors of the node potentials $\vec{\mathbf{V}}$, it is necessary to convert passive entries of the matrix $\mathbf{Y}_i^{dis}$ into current sources in accordance with Substitution Theorem. After that, the matrix equation (9) can be transformed by applying Superposition Theorem

$$\vec{\mathbf{V}} = \vec{\mathbf{V}}^{undis} + \sum_{k=1}^{L} \vec{\mathbf{V}}_k^{dis} = \left(\mathbf{Y}^{nondis}\right)^{-1} \cdot \left(\vec{\mathbf{I}}^{nondis} + \sum_{k=1}^{L} \vec{\mathbf{I}}_k^{dis} \right), \tag{10}$$

where $L = M + N$ is the total number of the disturbing sources in the network; $\vec{\mathbf{V}}^{undis}$ is the column vectors of undisturbed parts of node potentials; $\vec{\mathbf{V}}_k^{dis}$ is the column vectors of node potential disturbed parts due to the impact disturbing voltage source *k*.

The disturbed parts of the POE voltages can be found on the basis of node potential equation

$$\sum_{k=1}^{L} \vec{\mathbf{V}}_k^{dis} = \mathbf{T} \cdot \left(\mathbf{Y}^{nondis}\right)^{-1} \cdot \sum_{k=1}^{L} \vec{\mathbf{I}}_k^{dis}, \tag{10}$$

as presented below:

$$\sum_{k=1}^{L} \vec{\mathbf{U}}_{sym.k}^{dis} = \frac{1}{3} \begin{pmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{pmatrix} \cdot \begin{pmatrix} 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ -1 & 0 & 1 & 0 \end{pmatrix} \cdot \left(\mathbf{Y}^{nondis}\right)^{-1} \cdot \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \\ -3 & 0 & 0 \end{pmatrix} \cdot \sum_{k=1}^{L} \vec{\mathbf{I}}_{sym,k}^{dis}, \tag{11}$$

where $\vec{\mathbf{U}}_{sym,k}^{dis}$ is the symmetrical components at the *k*th node.

The measured negative sequence voltage at the POE can be expressed from (11):

$$\underline{U}_2 = \sum_{k=1}^{L} \underline{U}_{2,k}^{dis} = \underline{z}_2 \cdot \sum_{k=1}^{L} \underline{I}_{2,k}^{dis}, \tag{12}$$

where $\underline{I}_{2,k}^{dis}$ is a nodal disturbing current of negative sequence, $\underline{z}_2$ is a proportionality coefficient between negative sequence voltage and nodal disturbing current of negative sequence in ohms. Parameter $\underline{z}_2$ and negative sequence nodal disturbing current $\underline{I}_{2,k}^{dis}$ are determined as follows:

$$\underline{z}_2 = \frac{1}{3} \cdot (a-1) \cdot \begin{bmatrix} \left(\mathbf{Y}^{nondis}\right)_{2,1}^{-1} + \left(\mathbf{Y}^{nondis}\right)_{2,3}^{-1} + \left(\mathbf{Y}^{nondis}\right)_{3,1}^{-1} - \\ -\left(\left(\mathbf{Y}^{nondis}\right)_{1,1}^{-1} + \left(\mathbf{Y}^{nondis}\right)_{2,2}^{-1} + \left(\mathbf{Y}^{nondis}\right)_{3,3}^{-1} \right) \end{bmatrix}. \tag{13}$$

$$\underline{I}_{2,k}^{dis} = \frac{1}{3} \cdot \left(\underline{I}_{A,k}^{dis} + a^2 \cdot \underline{I}_{B,k}^{dis} + a \cdot \underline{I}_{C,k}^{dis} \right), \tag{14}$$

where $\underline{I}_{A,k}^{dis}$, $\underline{I}_{B,k}^{dis}$ and $\underline{I}_{C,k}^{dis}$ are nodal disturbing currents in phases *A*, *B* and *C* originating from voltage disturbing source *k*; the node numbers *1*, *2* and *3* of the nodal admittance matrix $\mathbf{Y}^{nondis}$ corresponds to nodes *A*, *B* and *C* of phase potentials in Fig. 1, *b*.

Let us analyze the obtain results. First, the expression (12) offers a new criterion for the identification of a voltage unbalance emission and assessment of its impact on the voltage unbalance at a POE:

$$\underline{I}_{2,k}^{dis} \begin{cases} = 0 \Rightarrow \text{nondisturbing installation} \\ \neq 0 \Rightarrow \text{disturbing installation} \end{cases} \tag{15}$$

$$\underline{U}_{2,k}^{dis} = \underline{z}_2 \cdot \underline{I}_{2,k}^{dis}. \tag{16}$$

Second, expression (12) determines a corrected network equivalent circuit (Fig. 3) for solving the considered task in symmetrical components. In contrast to Thevenin and Norton equivalent circuits, there is a single impedance $\underline{z}_2$ in common for the both ML and PS sides. Parameter $\underline{z}_2$ may not be decomposed into a sum of the terms corresponding to utility and each customer tied to the POE. It is clearly seen from (13), where the parameter $\underline{z}_2$ depends on the entries of the inverse nodal admittance matrix contributed from the whole equivalent circuit of the considered network.

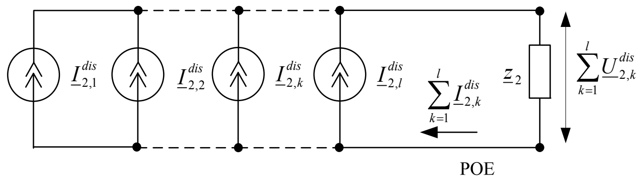


Fig. 3. The equivalent circuit of a power supply system for the negative sequence components

6. ERROR ANALYSIS

The main errors of the method are errors from defining $\underline{Y}_{ph}^{ML}$ and $\underline{z}_2$. Let us evaluate the impact of these errors onto voltage unbalance emission source identification criterion (15) and the assessment of its contribution into POE voltage unbalance (16).

The exact value for the voltage unbalance emission source identification criterion on the customer side $\underline{I}_2^{ML,dis}$ and its absolute error $\delta\underline{I}_2^{Ml,иск}$ caused by $\delta\underline{Y}_{ph}^{ML}$ (5) can be found using following expressions:

$$\underline{I}_2^{ML,dis} = -\left(\frac{\underline{U}_1 \cdot e^{-j30}}{\sqrt{3}} \cdot \underline{Y}_1 + \Delta\underline{V} \cdot \underline{Y}_2\right); \tag{20}$$

$$\delta\underline{I}_2^{ML,dis} \cong -\Delta\underline{V} \cdot \frac{\underline{U}_2 \cdot e^{j30}}{\underline{U}_1 \cdot e^{-j30}} \cdot \left(\underline{Y}_1 + \frac{\underline{U}_2 \cdot e^{j30}}{\underline{U}_1 \cdot e^{-j30}} \cdot \underline{Y}_{ph}^{nondis}\right), \tag{21}$$

where $\underline{U}_1$ and $\underline{U}_2$ are positive and negative sequence of the voltages measured at the POE; $\underline{Y}_1$ are $\underline{Y}_2$ admittances of ML equivalent circuit in symmetrical components that can be found on the basis of the ML admittances in phase coordinates:

$$\left.\begin{aligned} \underline{Y}_1 &= \left(\underline{Y}_A^{ML} + a \cdot \underline{Y}_B^{ML} + a^2 \cdot \underline{Y}_C^{ML}\right)/3; \\ \underline{Y}_2 &= \left(\underline{Y}_A^{ML} + a^2 \cdot \underline{Y}_B^{ML} + a \cdot \underline{Y}_C^{ML}\right)/3. \end{aligned}\right\} \tag{22}$$

The study of $\delta\underline{I}_2^{ML,dis}$ behavior demonstrated that if there is non-disturbing mixed load with neutral potential $\Delta\underline{V} = 0$ then it will be identified as non-disturbing ML with methodological error being equal to zero. If a ML is asymmetrical then the error $\delta\underline{I}_2^{ML,dis}$ is not equal to zero. To investigate the error impact, a worst case scenario with negative sequence voltage u_{2*} = 4 % and neutral potential being equal to positive sequence voltage $|\Delta\underline{V}| = |\underline{U}_1|$ was observed. Fig. 4 shows the relative error $\Delta\underline{I}_2^{ML,dis} = \left|\delta\underline{I}_2^{ML,dis}\right| / \left|\underline{I}_2^{ML,dis}\right| \cdot 100$ % loci depending on values of Y_1 and Y_2. If there is a non-disturbing (symmetrical) ML then $\underline{Y}_1 \to 0$, $\underline{Y}_2 \to 0$ and $\underline{I}_2^{ML,dis} \to 0$. As a result, as the relative error is maximal $\Delta\underline{I}_2^{ML,dis} \to 100\%$. The higher the asymmetry of a ML ($\underline{Y}_1 \uparrow$ and $\underline{Y}_2 \uparrow$), the lower the relative error $\Delta\underline{I}_2^{ML,dis}$. In real network cases, the neutal potentail there is $|\Delta\underline{V}| << |\underline{U}_1|$ and when $\underline{I}_2^{ML,dis} \to 0$ and $\Delta\underline{V} \to 0$ the relative error loci $\Delta\underline{I}_2^{ML,dis}$ will be of remarkably less diameter. That means the proposed identification method has high accuracy at the levels of ML asymmetry that take place in real cases.

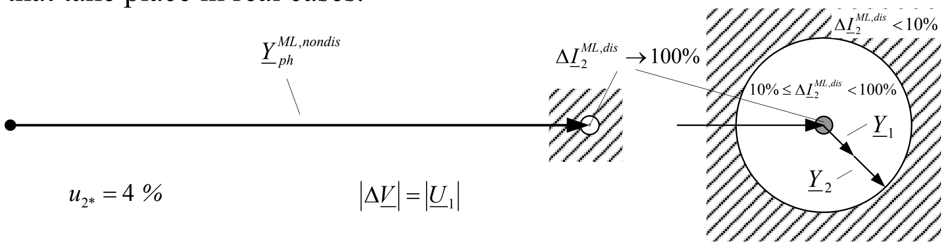


Fig. 4. Relative error for the identification of a voltage unbalance emission source

When we talk about the assessment of disturbing installation contribution into POE voltage unbalance $\underline{U}_{2,k}^{dis}$ (16) then the methodological error mainly depends on error $\delta \underline{z}_2$, i.e. how accurate is value of $\underline{z}_2$. The error $\delta \underline{z}_2$ can be found on the basis of (13):

$$\delta \underline{z}_2 = \frac{1}{3} \cdot (a-1) \cdot \left[\left(\delta \mathbf{H}_{2,1}^{nondis} + \delta \mathbf{H}_{2,3}^{nondis} + \delta \mathbf{H}_{3,1}^{nondis} \right) - \left(\delta \mathbf{H}_{1,1}^{nondis} + \delta \mathbf{H}_{2,2}^{nondis} + \delta \mathbf{H}_{3,3}^{nondis} \right) \right] \quad (23)$$

The entries of matrix $\delta \mathbf{H}^{nondis}$ in (23) reflects the separation of inverse nodal admittance matix into disturbing and non-disturbing parts:

$$\delta \mathbf{H}^{nondis} = -\left[\mathbf{Y}^{nondis} + \mathbf{Y}^{nondis} \cdot \left(\delta \mathbf{Y}^{nondis} \right)^{-1} \cdot \mathbf{Y}^{nondis} \right]^{-1}, \quad (24)$$

where $\delta \mathbf{Y}^{nondis}$ is the matrix taking into account inaccurate evaluation of network component parameters, e.g. line and transformer impedances.

The error $\delta \underline{z}_2$ has to be evaluated in each real case. We have to simulate the considered network and to prescribe to each modeled network component some random errors. Applying numerous random sets of errors to network components we can observe maximum limit of resulting error for $\delta \underline{z}_2$.

7. CONCLUSIONS

It can be stated that there is still no methodologically correct and practically applicable tool for the identification of voltage unbalance emission sources and the assessment of their contributions into PQ deterioration at a POE. The authors have proposed such a method that can be used even with multiple voltage unbalance emission sources. In this paper is presented application of the method to a three-phase three-wire electrical network based on voltage and current measurements in two phases at a single POE and the specification data for PSS installations.

The method includes an original way to model network components. First, each installation is separated into disturbing and non-disturbing parts in phase coordinates. Second, the disturbing passive parts are substituted with current sources and the equivalent circuit is transformed from pahse coordinates into symmetrical components. The obtained model differs from Thevenin and Norton equivalent circuits that are not suitable for the case of multiple disturbing sources. The used equivalent model contains multiple nodal disturbing current sources and a single impedance $\underline{z}_2$ that is common for all installation connected to a POE.

The criterion for the identification of a voltage unbalance emission sources is a negative sequence nodal current. An installation producing no such a current is non-disturbing one. Otherwise, the considered installation can be treated as a disturbing source.

The proposed method directly calculates the contributions into the voltage unbalance level at a POE from involved parties in contrast to methods using power flow direction or impedance increments. In the considered case of a three-phase three-wire network, the contribution of each disturbing source into POE voltage unbalance is calculated as a product of nodal disturbing current and impedance that is the same for all installations. The method has errors caused by simplifications and the uncertainty of the parameters of the network components. The resulting error is at an acceptable level for the practical cases.

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