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THE COMPARATIVE ANALYSIS OF UNSYMMETRICAL STATE ASSESSING METHODS

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ABSTRACT

For electrical network energetically states analysis is adopting the following initial hypothesis: the system sources determine in terminals a voltage symmetrical system and the asymmetry, in different nodes of the network, is determined by the unequal loads over the system phases due to the unbalanced consumers or by the different impedances over the electrical energy transport and distribution network phases. In this way, even in case of an unbalanced consumer, the energy transfer over the energetically system lines, leads to the unsymmetrical states appearance.
Were used in the study the following calculus relations for unsymmetrical state: Stokvis-Fortescue, Amounts iterative method, The maximum deviation reported to the medium value, GOST, GOST with error, Robert-Marquet and Geometrically method.
Is important to mention that the all of the calculus was made considered the case of homopolar component being equal with zero.
Keywords: unsymmetrical state, symmetrical components, asymmetry coefficient

1. THE CALCULUS METHODS FOR SYMMETRICAL COMPONENTS

1.1. Iterative calculus method

The symmetrical components are calculated using the Stokvis-Fortescue theorem.

$$\underline{Y_d} = \frac{1}{3}\cdot\left(\underline{Y_1} + a\cdot\underline{Y_2} + a^2\cdot\underline{Y_3}\right);\ \underline{Y_i} = \frac{1}{3}\cdot\left(\underline{Y_1} + a^2\cdot\underline{Y_2} + a\cdot\underline{Y_3}\right);\ \underline{Y_h} = \frac{1}{3}\cdot\left(\underline{Y_1} + \underline{Y_2} + \underline{Y_3}\right) \quad (1)$$

Developing tis relations and starting from **a** and $\mathbf{a^2}$ operators, separating the real and imaginary parts, for ***direct succession components*** $\underline{\mathbf{Y_d}}$ is obtaining, first, in complex, the next relations:

$$\underline{Y_d} = \frac{1}{3}\cdot\left[\sum_{k=1}^{3} Y_k\cdot\cos\left(\varphi_k + \frac{2\pi}{3}\cdot(k-1)\right) + j\cdot\sum_{k=1}^{3} Y_k\cdot\sin\left(\varphi_k + \frac{2\pi}{3}\cdot(k-1)\right)\right] \quad (2)$$

From which is follows the Y_d modulus:

$$Y_d = \frac{1}{3}\cdot\left\{\left[\sum_{k=1}^{3} Y_k\cdot\cos\left(\varphi_k + \frac{2\pi}{3}\cdot(k-1)\right)\right]^2 + \left[\sum_{k=1}^{3} Y_k\cdot\sin\left(\varphi_k + \frac{2\pi}{3}\cdot(k-1)\right)\right]^2\right\}^{1/2} \quad (3)$$

Simillary, using a calculus contrivance, was deduced the relations for ***inverse succesion components (negative):***

$$Y_i = \frac{1}{3}\cdot\left\{\left[\sum_{k=1}^{3} Y_k \cdot \cos\left(\varphi_k + \frac{2\pi}{3}\cdot(4-k)\right)\right]^2 + \left[\sum_{k=1}^{3} Y_k \cdot \sin\left(\varphi_k + \frac{2\pi}{3}\cdot(4-k)\right)\right]^2\right\}^{1/2} \quad (4)$$

as well as the ***homopolar components (zero sequence)***:

$$Y_h = \frac{1}{3}\cdot\left\{\left[\sum_{k=1}^{3} Y_k \cdot \cos\varphi_k\right]^2 + \left[\sum_{k=1}^{3} Y_k \cdot \sin\varphi_k\right]^2\right\}^{1/2} \quad (5)$$

1.2. Geometrically method

As it was already specified, there are other calculus methods for symmetrical components. First it is necessary to be mentioned is the so-called geometric method, because it is based on solving triangles (Napoleon) which highlights the construction of symmetrical components. In the first form, valid if the homopolar component (zero sequence) is non-zero, the geometrically method offers the next relations:

$$Y_d = \sqrt{\frac{Y_{L2} + \sqrt{3Y_{L2}^2 - 6Y_{L4}}}{18}}\ ;\ Y_i = \sqrt{\frac{Y_{L2} - \sqrt{3Y_{L2}^2 - 6Y_{L4}}}{18}} \quad (6)$$

In which we considered the next notations:

$Y_{L2} = Y_{12}^2 + Y_{23}^2 + Y_{31}^2$; $Y_{L4} = Y_{12}^4 + Y_{23}^4 + Y_{31}^4$, $\underline{Y}_{12} = \underline{Y}_1 - \underline{Y}_2$, $\underline{Y}_{23} = \underline{Y}_2 - \underline{Y}_3$; $\underline{Y}_{31} = \underline{Y}_3 - \underline{Y}_1$

In case of homopolar component equal with zero, the proposed calculus relations are follows:

$$Y_d = \sqrt{\frac{Y_{f2} + \sqrt{3Y_{f2}^2 - 6Y_{f4}}}{6}}\ ;\ Y_i = \sqrt{\frac{Y_{f2} - \sqrt{3Y_{f2}^2 - 6Y_{f4}}}{6}} \quad (7)$$

1.3. Robert-Marquet relation

Identical results with geometric method provide relationship Robert-Marquet, directly for the calculation of the ratio of direct and inverse component (applicable if $Y_h = 0$):

$$\frac{Y_d}{Y_i} = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}}\ ;\ \beta = \frac{Y_1^4 + Y_2^4 + Y_3^4}{\left(Y_1^2 + Y_2^2 + Y_3^2\right)} \quad (8)$$

1.4. GOST method

The term derives from the name of the method (GOST) designates the Russian standards, as is proposed in this paper. First reported the following calculation relationship of inverse (negative sequence), to be applied in case of component homopolar void (Yh = 0, for example in the case of line voltages):

$$Y_i = \sqrt{\frac{1}{12}\left\{\left[\sqrt{3}Y_1 - \sqrt{4Y_2} - \left(\frac{Y_2^2 - Y_3^2}{Y_1} + Y_1\right)^2\right]^2 + \left(\frac{Y_2^2 - Y_3^2}{Y_1}\right)^2\right\}} \quad (9)$$

1.5. Simplified relations

GOST with error relation, indicates, first, inverse succession component calculus relation, when the homopolar component is zero, and the homopolar component of phase voltage:

$$Y_i = 0.62\left(Y_{Max} - Y_{min}\right);\ U_h = 0.62\left(U_{fMax} - U_{f\,min}\right) \quad (10)$$

1.6. MAXIMUM DEVIATION REPORTED TO THE MEDIUM VALUE, reported the difference between the highest and the lowest value to the arithmetic mean of the three sizes, in accordance with the next relation:

$$k_{nes} = \frac{Y_{max} - Y_{min}}{Y_{med}}\ ;\ Y_{med} = \frac{Y_1 + Y_2 + Y_3}{3} \quad (11)$$

2. THE COMPARATIVE ANALYSIS

A comparative analysis on the application of computational components and unsymmetrical system indicators is shown in the table below, where dΦi is the variable angle φ and notation by cY1, cY2 cY3 and has noted the size of system phasors (Y1, Y2, Y3); symmetrical components are designated by Y_d and Y_h, Y_i, and the K_{id} is the coefficient of asymmetry. It is important to note that all calculations have been made where the homopolar sequence equal to zero (Yh = 0). From the analysis of the obtained results, it is noted that only the relationship according to Stokvis-Fortescue theorem and the form of iterative amounts lead to accurate results, the whole field of variation of negative asymmetry coefficient. Robert-Marquet method is identical to the geometric Method and GOST method, for values of asymmetry factor less than 0.771. Also, the first two methods mentioned above are perfectly identical on the interval of interest. On this interval GOST method with error close results in the field of specified error. Note that for values of the negative asymmetry factor, Kid > 0.781 relevant column Stokvis-Fortescue theorem, the methods mentioned above, which provide for the direct calculation of the sequence components and reverse an inversion of their value, which is a flaw. As regards the maximum deviation method with values in the columns relating to the appliance in SATEC-PM295 which design is implemented, this constitutes a weak correlation with the level of asymmetry with negative asymmetry factor values of the fixed, so no relevance in the correct characterization of the asymmetric state.

Table 1. Results about calculus relation checking of symmetrical components

Nr. Crt.	**The unsymmetrical measures generation**				**Stokvis-Fortescue**				**Amounts iterative method**			
	dΦi	**cY1**	**cY2**	**cY3**	**Yd**	**Yi**	**Yh**	**kid**	**Yd**	**Yi**	**Yh**	**kid**
1	-2.094	100+0i	-50-86.6i	-50+86.6i	100.0	0.0	0	0.000	100.0	0.0	0	0.000
2	-1.885	100+0i	-19.1-58.8i	-80.9+58.8i	85.8	24.0	0	0.280	85.8	24.0	0	0.280
3	-1.676	100+0i	-2.2-20.8i	-97.8+20.8i	67.8	46.9	0	0.692	67.8	46.9	0	0.692
4	-1.466	100+0i	-2.2+20.8i	-97.8-20.8i	60.9	53.9	0	0.886	60.9	53.9	0	0.886
5	-1.257	100+0i	-19.1+58.8i	-80.9-58.8i	65.2	44.6	0	0.684	65.2	44.6	0	0.684
6	-1.047	100+0i	-50+86.6i	-50-86.6i	66.6	33.3	0	0.500	66.6	33.3	0	0.500
7	-0.838	100+0i	-89.5+99.5i	-10.5-99.5i	65.2	20.6	0	0.316	65.2	20.6	0	0.316
8	-0.628	100+0i	-130.9+95.1i	30.9-95.1i	60.9	6.9	0	0.114	60.9	6.9	0	0.114
9	-0.419	100+0i	-166.9+74.3i	66.9-74.3i	53.9	6.9	0	0.129	53.9	6.9	0	0.129
10	-0.209	100+0i	-191.4+40.7i	91.4-40.7i	44.6	20.6	0	0.462	44.6	20.6	0	0.462
11	0	100+0i	-	-	-	-	-	-	-	-	-	-
12	0.209	100+0i	-191.4-40.7i	91.4+40.7i	20.6	44.6	0	2.165	20.6	44.6	0	2.165
13	0.419	100+0i	-166.9-74.3i	66.9+74.3i	6.9	53.9	0	7.740	6.9	53.9	0	7.740
14	0.628	100+0i	-130.9-95.1i	30.9+95.1i	6.9	60.9	0	8.740	6.9	60.9	0	8.740
15	0.838	100+0i	-89.5-99.5i	-10.5+99.5i	20.6	65.2	0	3.165	20.6	65.2	0	3.165
16	1.047	100+0i	-50-86.6i	-50+86.6i	33.3	66.6	0	2.000	33.3	66.6	0	2.000
17	1.257	100+0i	-19.1-58.8i	-80.9+58.8i	44.6	65.2	0	1.462	44.6	65.2	0	1.462
18	1.466	100+0i	-2.2-20.8i	-97.8+20.8i	53.9	60.9	0	1.129	53.9	60.9	0	1.129
19	1.676	100+0i	-2.2+20.8i	-97.8-20.8i	46.9	67.8	0	1.445	46.9	67.8	0	1.445
20	1.885	100+0i	-19.1+58.8i	-80.9-58.8i	24.0	85.8	0	3.574	24.0	85.8	0	3.574
21	2.094	100+0i	-50+86.6i	-50-86.6i	0.0	100.0	0	-	0.0	100.0	0	-

Maximum deviation /Medium value		**GOST**		**GOST with error**		**Robert-Marquet**		**Geometrically method**		
Ymed	**Knes**	**Yi**	**Kid**	**Yi**	**Kid**	**β**	**Kid**	**Yd**	**Yi**	**Kid**
100.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	100.000	0.000	0.000
87.268	0.438	24.008	0.280	23.682	0.276	0.378	0.280	85.811	24.008	0.280
73.635	1.074	46.966	0.692	49.038	0.723	0.479	0.692	67.872	46.966	0.692
73.635	1.074	46.966	0.771	49.038	0.805	0.479	0.692	67.872	46.966	0.692
87.268	0.438	24.008	0.368	23.682	0.363	0.378	0.280	85.811	24.008	0.280
100.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	100.000	0.000	0.000
111.275	0.304	24.008	0.368	20.972	0.322	0.362	0.219	109.819	24.008	0.219
120.601	0.512	46.966	0.771	38.318	0.629	0.415	0.409	114.837	46.966	0.409
127.570	0.648	67.872	1.258	51.280	0.951	0.461	0.591	114.837	67.872	0.591
131.877	0.725	85.811	1.924	59.290	1.329	0.490	0.781	109.819	85.811	0.781
-	-	-	-	-	-	-	-	-	-	-
131.877	0.725	85.811	4.165	59.290	2.878	0.490	0.781	109.819	85.811	0.781
127.570	0.648	67.872	9.740	51.280	7.359	0.461	0.591	114.837	67.872	0.591
120.601	0.512	46.966	6.740	38.318	5.499	0.415	0.409	114.837	46.966	0.409
111.275	0.304	24.008	1.165	20.972	1.018	0.362	0.219	109.819	24.008	0.219
100.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	100.000	0.000	0.000
87.268	0.438	24.008	0.538	23.682	0.531	0.378	0.280	85.811	24.008	0.280
73.635	1.074	46.966	0.871	49.038	0.909	0.479	0.692	67.872	46.966	0.692
73.635	1.074	46.966	1.000	49.038	1.044	0.479	0.692	67.872	46.966	0.692
87.268	0.438	24.008	1.000	23.682	0.986	0.378	0.280	85.811	24.008	0.280
100.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	100.000	0.000	0.000

When the homopolar succession component is different by zero ($Y_h \neq 0$), only few relations are still available. In this case are simulating also the unsymmetrical states, modifying the next parameters:

- ratios between system phasors amplitude, with values in [0,1] interval;
- phase shift angle (φ) will have constant values: 0, -2π/3 respective 4π/3.

Table 2. Results about calculus relation checking using the Stokvis-Fortescue theorem and maximum deviation reported to the medium value

Y1	Y2/Y1	Y3/Y1	Angle			Stokvis-Fortescue					Maximum deviation /Medium value	
			φ1	φ2	φ3	Yd	Yi	Yh	kid	khd	Ymed	Knes
100	0.0	0.8	0	-120	-240	60.00	30.55	30.55	0.509	0.509	60.000	0.491
100	0.0	0.9	0	-120	-240	63.33	31.80	31.80	0.502	0.502	63.333	0.498
100	0.0	1.0	0	-120	-240	66.67	33.33	33.33	0.500	0.500	66.667	0.500
100	0.1	0.5	0	-120	-240	53.33	26.03	26.03	0.488	0.488	53.333	0.512
100	0.2	0.3	0	-120	-240	50.00	25.17	25.17	0.503	0.503	50.000	0.497
100	0.3	0.2	0	-120	-240	50.00	25.17	25.17	0.503	0.503	50.000	0.497
100	0.5	0.1	0	-120	-240	53.33	26.03	26.03	0.488	0.488	53.333	0.512
100	0.8	0	0	-120	-240	60.00	30.55	30.55	0.509	0.509	60.000	0.491
100	0.9	0	0	-120	-240	63.33	31.80	31.80	0.502	0.502	63.333	0.498
100	1.0	0	0	-120	-240	66.67	33.33	33.33	0.500	0.500	66.667	0.500

Note that there is some symmetry between the values of the negative asymmetry factor and phasors ratio, this being highlighted in the following figure:

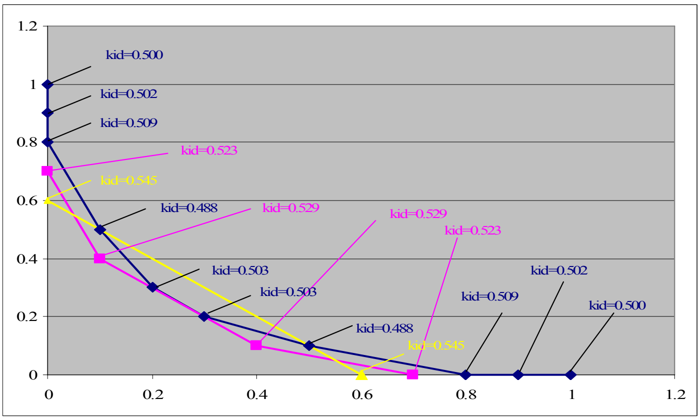

Figure 1. Corelations between ratios Y_2/Y_1 and Y_3/Y_1 for which K_{nes} given by the maximum deviation/medium value is approaching by the K_{id} values, calculated using the Stokvis-Fortescue theorem

3. CONCLUSIONS

The unsymmetrical system phasors generation is made simple and efficient using the proposed method. The simplicity derived from the single variable utilisation, namely the φ angle between two consecutive phasors and the efficiency is sustained by complete codomain coverage, from zero to plus infinite, for both of unsymmetrical state indicators.

4. REFERENCES

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