THE VARIATION OF THE UNSIMMETRY FACTORS IN THE LOW VOLTAGE POWER SUPLIES IN SINUSOIDAL REGIME

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Abstract **– In this work a mathematical model is presented designed for the calculation of the unsymmetrical coefficients afferent to the load currents in the low voltage distribution power supplies. Based on the presented mathematical model, among other things the load of the null lead can be calculated in harmonic regime (associated to the fundamental). The work contains study cases, the unsymmetrical regime caused by the unbalance of the load (of the consumer) wired up to the distribution power supply is analyzed. Within the study cases, the variations of the unsymmetrical factors and their phases were set out.**

Keywords: *unsymmetrical regime, unbalance of the load, unsymmetrical factors.*

1. INTRODUCTION

The apparition of unbalanced phenomena can be explain because of unequal loading of the phases of three-phased electric network as well as the different electric parameters of the three phases. Especially in the low voltage network, the unbalanced phenomena can lead to important differences in amplitude of the values corresponding to the three phases and also differences of passing through zero moments for characteristic curves.

Therefore it is necessary to proper evaluate of this type of disturbances and then taking some decisions regarding the limitation of damages caused by the values of unbalanced which are exceeding the acceptable ones.

The evaluation methods used in the sinusoidal mode and in the balanced networks (with equal electric parameters in all three phases) through decomposition in symmetrical components (method agreed by CEI), offer coherent information about these phenomena, taking into consideration the amplitude unbalanced as well as the unbalance.

The apparition on the market of some equipments of unbalance evaluation based on the IEEE definition of unbalance which consider only the amplitude unbalance offers information which are not in line with those indicated by the equipments set due to CEI recommendations.

The presence in the electric network of consumers with non-linear characteristic and obtaining of some disturbed voltage and current waveforms bring to the apparition of difficulties and unclearness in the evaluation of unbalance level.

For the evaluation based on the CEI recommendations, the utilization of symmetric components can be took into consideration only for the harmonic values analyzed, first of all for the fundamental harmonic, and for the IEEE definition are took into consideration the effective values of the

In this way, for the non sinusoidal mode, curves of different forms can be considered symmetric if there are met the symmetric condition

The visual evaluation of non symmetric electric three-phase values is no longer possible.

2. THE MATHEMATICAL MODEL

For the three phased distribution power supply having a work null lead, for which the following hypotheses are valid:

- The supply voltages $\underline{V}_A;\underline{V}_B;\underline{V}_C$, are symmetrical

$$\underline{V}_A = V;\ \underline{V}_B = a^2 \cdot \underline{V}_A = a^2 \cdot V;\ \underline{V}_C = a \cdot \underline{V}_A = a \cdot V \qquad (1)$$

In which *a* and a^2 are the complex cubical roots of the unit (*Steinmetz*);

$\underline{V}_A;\underline{V}_B;\underline{V}_C$ - the real values of the voltages on the fundamental;

V - the real values of the voltage the fundamental on the phase.

- The complex expressions of the load currents $\underline{I}_A;\underline{I}_A;\underline{I}_A$, in sinusoidal regime, are:

$$\underline{I}_A = I_A \cdot (\cos\varphi_A + j \cdot \sin\varphi_A) \qquad (2)$$

$$\underline{I}_B = I_B \cdot (\cos\varphi_B + j \cdot \sin\varphi_B) \qquad (3)$$

$$\underline{I}_C = I_C \cdot (\cos\varphi_C + j \cdot \sin\varphi_C) \qquad (4)$$

Where:

$\underline{I}_A;\underline{I}_A;\underline{I}_A$ - are the real values of the currents on the fundamental; $\underline{\varphi}_A;\underline{\varphi}_A;\underline{\varphi}_A$ - the initial phase differences

of the fundamental currents, defined in respect to a single phase (by example, the voltage of the phase *A*, as in fig. 1).
The symmetrical components $\underline{I}^o, \underline{I}^+, \underline{I}^-$, afferent to the phase currents in the relations (2) ÷ (4), are in the biunique relation, as shown in the work [3].
The measures $\underline{I}^o, \underline{I}^+, \underline{I}^-$ are the sequence components named in the specialized technical literature as follows:

- **(o) –** ***null*** *sequence;*
- **(+) –** ***positive*** *sequence;*
- **(-) –** ***reversed*** *sequence.*

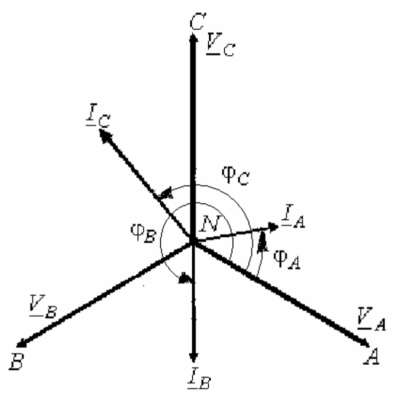

Figure 1. The phase diagram – example

The complex measures $\underline{I}_A, \underline{I}_B, \underline{I}_C$ are representing the currents of the phases {A, B, C}, „*seen*" as the initial data and defined by the relations (2) ÷ (4).
Under these conditions, the real values of the sequence currents $\underline{I}^o, \underline{I}^+, \underline{I}^-$ they can be written depending on the phase currents $\underline{I}_A, \underline{I}_B, \underline{I}_C$ expressed in the relations (2) ÷ (4).
The calculation relations of the modules of the symmetrical components are:

- The null sequence (***homopolar***) I^o

$$9 \cdot \left(I^o\right)^2 = I_A^2 + I_B^2 + I_C^2 + 2 \cdot I_A \cdot I_B \cdot \cos\varphi_{AB} + 2 \cdot I_B \cdot I_C \cdot \cos\varphi_{BC} + 2 \cdot I_C \cdot I_A \cdot \cos\varphi_{CA} \quad (5)$$

- The positive sequence (***direct***) I^+

$$\begin{aligned} 9 \cdot \left(I^+\right)^2 &= I_A^2 + I_B^2 + I_C^2 + \\ &+ 2 \cdot I_A \cdot I_B \cdot \cos(\varphi_{AB} + 2 \cdot \pi/3) + \\ &+ 2 \cdot I_B \cdot I_C \cdot \cos(\varphi_{BC} + 2 \cdot \pi/3) + \\ &+ 2 \cdot I_C \cdot I_A \cdot \cos(\varphi_{CA} + 2 \cdot \pi/3) \end{aligned} \quad (6)$$

- The negative sequence (***reverse***) I^-

$$\begin{aligned} 9 \cdot \left(I^-\right)^2 &= I_A^2 + I_B^2 + I_C^2 + \\ &+ 2 \cdot I_A \cdot I_B \cdot \cos(\varphi_{AB} - 2 \cdot \pi/3) + \\ &+ 2 \cdot I_B \cdot I_C \cdot \cos(\varphi_{BC} - 2 \cdot \pi/3) + \\ &+ 2 \cdot I_C \cdot I_A \cdot \cos(\varphi_{CA} - 2 \cdot \pi/3) \end{aligned} \quad (7)$$

The angles $\varphi_{AB}, \varphi_{BC}, \varphi_{CA}$, in the relations (7) ÷ (9) are defined by the relations:

$$\begin{aligned} \varphi_{AB} &= \varphi_A - \varphi_B ; \\ \varphi_{BC} &= \varphi_B - \varphi_C ; \\ \varphi_{CA} &= \varphi_C - \varphi_A \end{aligned} \quad (8)$$

For the phases $\varphi^o, \varphi^+, \varphi^-$, of the currents of the symmetrical components the following relations are valid:

- Null sequence (***homopolar***) φ^o

$$\tan\varphi^o = \frac{I_A \cdot \sin\varphi_A + I_B \cdot \sin\varphi_B + I_C \cdot \sin\varphi_C}{I_A \cdot \cos\varphi_A + I_B \cdot \cos\varphi_B + I_C \cdot \cos\varphi_C} \quad (9)$$

- The positive sequence (***direct***) φ^+

$$\tan\varphi^+ = \frac{I_A \cdot \sin\varphi_A + I_B \cdot \sin(\varphi_B + 2\pi/3) + I_C \cdot \sin(\varphi_C + 4\pi/3)}{I_A \cdot \cos\varphi_A + I_B \cdot \cos(\varphi_B + 2\pi/3) + I_C \cdot \cos(\varphi_C + 4\pi/3)} \quad (10)$$

- The negative sequence (*reverse*) φ^-

$$\tan\varphi^- = \frac{I_A \cdot \sin\varphi_A + I_B \cdot \sin(\varphi_B + 4\pi/3) + I_C \cdot \sin(\varphi_C + 2\pi/3)}{I_A \cdot \cos\varphi_A + I_B \cdot \cos(\varphi_B + 4\pi/3) + I_C \cdot \cos(\varphi_C + 2\pi/3)} \quad (11)$$

The quality of the absorbed current can be characterized by the indicators:

- Negative unsymmetrical factor $\underline{k}_I^-$:

$$\underline{k}_I^- = \frac{\underline{I}^-}{\underline{I}^+} \quad (12)$$

- Zero unsymmetrical factor $\underline{k}_I^o$:

$$\underline{k}_I^o = \frac{\underline{I}^o}{\underline{I}^+} \quad (13)$$

In the previous relations, the measures have the meaning:

$$\underline{I}^o = I^o \cdot \left(\cos\varphi^o + j \cdot \sin\varphi^o\right) \quad (14)$$

$$\underline{I}^+ = I^+ \cdot \left(\cos\varphi^+ + j \cdot \sin\varphi^+\right) \quad (15)$$

$$\underline{I}^- = I^- \cdot \left(\cos\varphi^- + j \cdot \sin\varphi^-\right) \quad (16)$$

Where the measures have the meaning given in the relations (5 ÷ 11).
The currents which are circulating on the phases of the low voltage power supply can be expressed by using the unsymmetrical factors defined by the

relations 12, 13 and by the symmetrical component with the relations:
The current of the phase A:

$$\underline{I}_A = \left(1 + \underline{k}^o + \underline{k}^-\right)\cdot \underline{I}^+ \qquad (17)$$

The current of the phase B:

$$\underline{I}_B = \left(a^2 + \underline{k}^o + a\cdot \underline{k}^-\right)\cdot \underline{I}^+ \qquad (18)$$

The current of the phase C:

$$\underline{I}_C = \left(a + \underline{k}^o + a^2\cdot \underline{k}^+\right)\cdot \underline{I}^+ \qquad (19)$$

If it is considered that the definition of the current in the null lead for the operation of a low voltage power supply, from the following relation:

$$\underline{I}_N = \underline{I}_A + \underline{I}_B + \underline{I}_C \qquad (20)$$

Which considering the symmetrical components, becomes:

$$\underline{I}_N = 3\cdot \underline{I}^o \qquad (21)$$

Which depending on the negative unsymmetrical factor $\underline{k}_I^o$, can be expressed by the relation:

$$\underline{I}_N = 3\cdot \underline{k}^o \cdot \underline{I}^+ \qquad (22)$$

The unsymmetrical factors defined previously (***k***$^-$ end ***k***^{o}) can be used in the calculation of the unsymmetrical regimes, by example in the calculation of the losses in the active and reactive power of the low voltage power supply.
In the literature [2], usually, the modules of the unsymmetrical factors are defined, in 1% (defined in the relations (12 ÷ 13)). With the relations defined previously, in the next paragraph of the work the symmetric components of the load currents connected to distribution low voltage power supply.

3. CASE STUDIES

For a load defined by the currents according to the relations (2) – (4), the following two situations were considered (cases):

- **case 1 – equal** real values of the currents on the phases

a) the real values of the currents absorbed on each phase equal in module

$$I_A = I_B = I_C \qquad (25)$$

an application was done for:

$$I_A = I_B = I_C = 10[A] \qquad (26)$$

b) the phases of the currents, generally different;

$$\varphi_A \neq \varphi_B \neq \varphi_C \qquad (27)$$

c) The domain of their values is

$$\varphi_A \in \left[0^o; +90^o\right] \cup \left[270^o; 360^o\right]; \quad \varphi_B \in \left[150^o; 330^o\right]; \ \varphi_C \in \left[30^o; 210^o\right] \qquad (28)$$

The results of the calculation of the symmetrical components, of the unsymmetrical factor and of the phases afferent were expressed in the following tables as follows: table 1 – maximal values; table 2 – minimal values; table 3 – medium values.

I^o	I^+	I^-	k^-	k^o	φ^o	φ^+	φ^-	φ^o-φ^+	φ^--φ^+
A	A	A			o	o	o	o	o
9	10	9	273	273	90	63	90	124	124
9	10	9	265	265	90	71	90	120	120
8	10	8	254	254	87	75	90	129	129
8	10	8	239	239	90	80	90	141	141
9	10	9	273	273	90	90	90	120	120
9	10	9	265	265	90	60	90	130	139
8	10	8	254	254	89	61	90	142	145
8	10	8	239	239	90	66	90	145	147
9	10	9	273	273	90	90	90	158	158

Tab 1 – Max value for the case $I_A = I_B = I_C = 10[A]$

I^0	I^+	I^-	k^-	k^0	φ^0	φ^+	φ^-	φ^0-φ^+	φ^--φ^+
A	A	A			o	o	o	o	o
0	3	0	0	0	-87	-63	-87	-124	-124
0	3	0	0	0	-85	-60	-87	-130	-130
0	5	3	27	27	-23	-61	-22	-98	-98
0	4	2	18	18	-15	-66	-15	-95	-95
0	3	0	0	0	72	90	-81	-18	-171
0	6	3	38	38	-60	-71	-60	-120	-120
0	5	3	27	27	-68	-75	-68	-129	-129
0	3	0	0	0	-90	-80	-90	-141	-141
0	3	0	0	0	-90	-90	-76	-120	-120

Tab 2 – Max values for the case $I_A = I_B = I_C = 10[A]$

I^0	I^+	I^-	k^-	k^0	φ^0	φ^+	φ^-	φ^0-φ^+	φ^--φ^+
A	A	A			o	o	o	o	o
4	8	4	55	58	3	-2	4	5	7
4	8	4	62	63	11	9	7	2	-2
4	7	7	68	68	10	15	7	-5	-8
5	7	7	80	78	9	20	1	-11	-19
5	7	6	113	106	-15	30	-16	-46	-46
4	7	8	57	60	-4	-14	-1	11	14
4	7	7	63	65	-10	-20	-4	10	16
4	7	4	72	74	-7	-26	-1	19	24
5	6	5	102	100	14	-31	21	44	52

Tab 3 – Max values for the case $I_A = I_B = I_C = 10[A]$

- **case 2 – unequal** real values of the currents on the phases

d) the real values of the absorbed currents on each phase different in module

$$I_A \neq I_B \neq I_C \qquad (29)$$

in this case an application was made for the values

$$I_A = 15[A]; \; I_B = 20[A]; \; I_C = 25[A] \qquad (30)$$

e) the phases of the currents, generally different, see the relation (19);

f) The field of their values is the same as the relation (20)

The results of the calculation of the symmetrical components, of the unsymmetrical factor and of the phases afferent were expressed in the following tables as follows: table 4 – maximal values; table 5 – minimal values; table 6 – medium values

I^0	I^+	I^-	k^-	k^0	φ^0	φ^+	φ^-	φ^0-φ^+	φ^--φ^+
A	A	A			o	o	o	o	o
18	20	18	342	342	87	72	90	132	143
18	20	17	290	400	90	76	88	132	145
17	20	17	266	427	88	79	89	139	152
17	20	16	320	447	90	83	90	148	174
18	20	18	427	427	90	90	90	167	66
17	20	18	400	290	89	71	89	145	152
17	20	17	427	266	89	73	90	141	141
16	20	17	447	320	90	77	90	152	156
18	20	18	427	427	90	90	90	172	142

Tab 4 – Max values for the case
$I_A = 15[A]; I_B = 20[A]; I_C = 25[A]$

I^0	I^+	I^-	k^-	k^0	φ^0	φ^+	φ^-	φ^0-φ^+	φ^--φ^+
A	A	A			o	o	o	o	o
1	5	1	5	5	-86	-72	-87	-143	-132
1	4	1	5	5	-89	-71	-89	-152	-141
1	12	6	34	24	-62	-73	-39	-141	-118
1	11	5	26	17	-72	-77	-39	-154	13
3	10	3	14	14	60	90	-83	-30	-173
1	13	6	32	42	-74	-76	-60	-117	-131
1	12	4	24	34	-79	-79	-66	-152	-139
1	11	3	17	26	-85	-83	-72	-162	-148
1	10	13	14	14	60	90	-83	-30	-173

Tab 5 – Max values for the case
$I_A = 15[A]; I_B = 20[A]; I_C = 25[A]$

I^0	I^+	I^-	k^-	k^0	φ^0	φ^+	φ^-	φ^0-φ^+	φ^--φ^+
A	A	A			o	o	o	o	o
8	16	8	64	65	11	-3	-9	14	-6
9	15	8	68	73	16	5	-9	10	-14
9	15	15	72	76	10	10	-7	0	-16
10	15	14	81	85	9	13	-7	-4	-16
11	15	12	107	106	-5	20	-11	-26	-32
8	16	15	66	64	6	-12	-15	-18	-3
8	15	15	72	68	3	-16	-7	19	9
9	15	14	80	74	5	-20	-3	25	17
9	15	13	102	93	7	-22	6	29	29

Tab 6 – Max values for the case
$I_A = 15[A]; I_B = 20[A]; I_C = 25[A]$

4. RESEARCH RESULTS

In the definition relations of the symmetrical components as well as in the case studies, the following are noticed:

- ➢ The unsymmetrical factors depend on the measures which are defining the status measures:
- - The real values of the currents;
- - Their phase differences in respect to the reference selected conventionally.
- ➢ For the **case 1** ($I_A = I_B = I_C = 10[A]$)
- ▪ The maximal values of the unsymmetrical factors exceed the usual values at the SEN level, as follows:
- - The modules of the real values are contained in the field (239 ÷ 273)% both for the negative unsymmetrical factors, respectively null;
- - The afferent phases are contained in the field (120 ÷ 158)°, both for the negative unsymmetrical factors, respectively null ones.
- ▪ The medium values of the unsymmetrical factors exceed the usual values, as follows:
- - The modules of the real values are contained in the field (55 ÷ 113)% for the negative unsymmetrical component and in the field (58 ÷ 106)% for the null unsymmetrical factor;
- - The afferent phases are contained in the field (-46 ÷ 44)° for the negative unsymmetrical factors and in the field (-46 ÷ 52)° for the null unsymmetrical factor.
- ▪ The minimal values of the unsymmetrical factors exceed the usual values, as follows:
- - The modules of the real values are contained in the field (0 ÷ 38)%, both for the negative unsymmetrical factors, respectively null ones;
- - The afferent phases are (-95 ÷ -141)° for the negative unsymmetrical factors (-95 ÷ -171)° namely null ones.
- ➢ For the **case 2** $I_A = 15[A]; I_B = 20[A]; \quad I_C = 25[A]$
- ▪ The maximal values of the unsymmetrical factors exceed the usual values, as follows:
- - The modules of the real values are contained in the field (266 ÷ 447)% both for the negative unsymmetrical factors, respectively null ones;
- - The afferent phases are contained in the field (132 ÷ 172)° for the negative unsymmetrical factors and in the field (66 ÷ 174)° for the null unsymmetrical factor.
- ▪ The medium values of the unsymmetrical factors exceed the usual values, as follows:
- - The modules of the real values are contained in the field (64 ÷ 107)% for the negative unsymmetrical factors and in the field (64 ÷ 106)% for the null unsymmetrical factor;
- - The afferent phases are contained in the fields (-26 ÷ 29)° and (-32 ÷ 29)° for the negative and for the null unsymmetrical factors.

- The minimal values of the unsymmetrical factors exceed the usual values, as follows:
- The real values modules are contained in the field (5 ÷ 32)% for the negative unsymmetrical factor, namely (5 ÷ 42)% for the null unsymmetrical factor;
- The afferent phases are contained in the field (-30 ÷ -162)° for the negative unsymmetrical factors and (13 ÷ -173)°, for the null sequence factor.

5. CONCLUSIONS

The limiting of the asymmetries determined by the unbalanced consumers is possible, basically two solutions [1]:

- the reconfiguration of the supply scheme of the consumer's receivers to ensure a rendering of the load symmetrical;
- the use of special schemes for the rendering of the load symmetrical.

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