INVESTIGATION OF NONSYMMETRICAL LOAD INFLUENCE TO THE THREE-PHASE GRID VOLTAGE

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Abstract

The results of investigation of nonsymmetrical load influence to the power grid voltage are presented. A different point of view is presented and the relationship between three-phase current magnitudes and phase angles and distribution transformer supply voltage is explored.

1. INTRODUCTION

There are high trend of development of some large electrical power consumers – such as big resorts Pamporovo and Sunny Beach. The high dynamic of the distribution and the development of the smaller electrical power consumers, into one city or one district exists – such as small manufacturing enterprises, malls and others.

Some power supplying problems are created by the fast variation of consumed power. The power quality problem is one of them. Of course, the fast consumed power alternation is only one of reasons witch cause the power quality problems. The large number of different type power loads using one phase supplying is other one. The next one is non-linear power loads using – office equipment, computers, power drive systems, and others.

The results of investigation of nonsymmetrical load influence to the power grid voltage are presented. A different point of view is presented and the relationship between three-phase current magnitudes and phase angles and distribution transformer supply voltage is explored.

2. EXPOSITION

It is common researchers practice to replace the real supplying grid, including middle voltage (MV) grid, distribution transformer and low voltage (LV) grid and they [2] use a more simplified one-phase equivalent circuit (Figure.1).

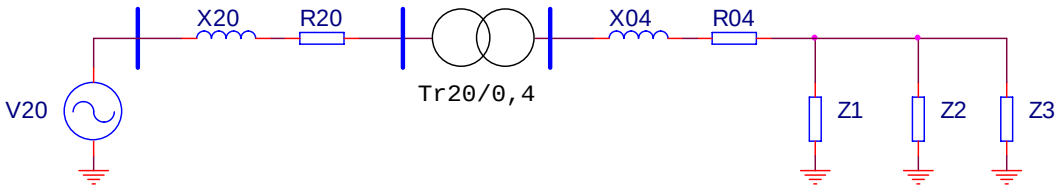

Figure 1.

The MV and LV networks equivalent parameters are used - Z20, R20, X20 (Z20=R20+jX20) and Z04, R04, X04 (Z04=R04+jX04) respectively, neglecting the capacitive leakage current (B20 →∞). Usually, the core type distribution transformer is changed with T-type or L-type equivalent circuit. In these models the phases couple cross-influence is neglected, and every phase works for himself

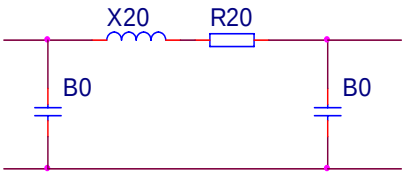

Figure 2a.

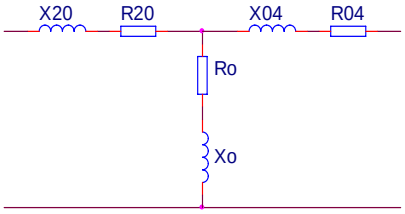

Figure 2b.

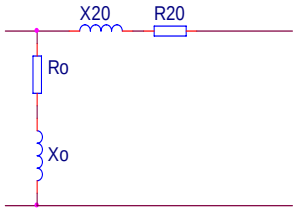

Figure 2c.

In reality, the power consumers are not uniformly distributed. Therefore current non-symmetry always exist. The Bulgarian and European standards limited the maximal voltage non-symmetry – 2% [1,3].

For non-symmetrical equipment behavior studying, the symmetric component method (Fortescue transformation) is very useful.

For the purpose of this investigation, let assume:

- three phase loads are supplied by three phase symmetrical voltage source (V20 in Figure 1) via the ideal distribution transformer and real symmetrical network;

- the coefficient of the transformer is equal to 1;
- three phase resistive loads are non-symmetrical and they are at steady –state.

The MV grid parameters and transformer primary coils parameters are reduced to the secondary voltage.

Case 1.

Core type distribution transformer with D/y connection is under consideration. The neutral wire of the star-connected secondary winding is isolated.

If we assume that phase current (phase A) is less than other phase currents (phases B and C) and:

$$i_{a,*} = \frac{I_{a,1}}{I_a}; \qquad i_{b,*} = \frac{I_b}{I_a}; \qquad i_{c,*} = \frac{I_c}{I_a};$$

$$i_{AB,*} = \frac{I_{AB,1}}{I_{AB}}; \qquad i_{BC,*} = \frac{I_{BC,1}}{I_{BC}}; \qquad i_{CA,*} = \frac{I_{CA,1}}{I_{CA}}$$

where I_a, I_b, I_c are phase currents, I_{AB}, I_{BC}, I_{CA} - line currents, I_a - basic current.

For this studying case, $I_{a,1} < I_a = I_b = I_c$ and ia,* < ib,* = ic,* .

The currents phasor diagram is shown in Figure 3. As seen in Figure 3 the current Ia decreasing will change the lag between the currents. It is not a reactive type loads result. It is causes of that the neutral point of the star-connected secondary winding is isolated. And something typical - $\dot{I}_b$ will go at δ ahead and $\dot{I}_c$ - at δ behind the corresponding vectors at symmetrical load. The line currents (MV grid currents) are changed too. Two of them are shifted – IAB will go at δ1 ahead and $\dot{I}_c$ - at δ1 behind the corresponding symmetrical vectors. The line magnitudes of currents are changed – IBC is increasing and IAB and ICA are decreased.

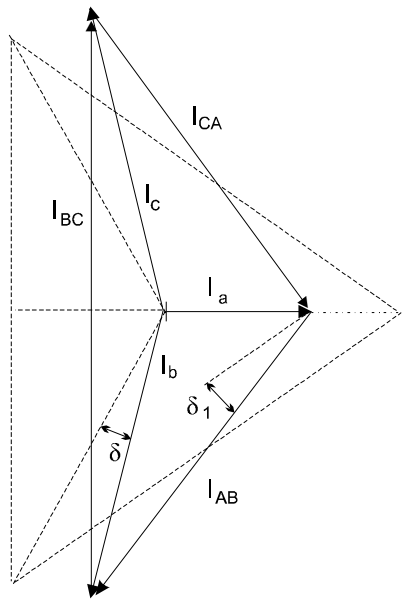

Figure 3.

$$\delta = \pm\left(arccos\frac{i_{a,*}}{2} - \frac{\pi}{3} \right) \tag{1}$$

$$\delta_1 = \pm\left[arccos\left(\frac{3}{2}\frac{i_{a,*}}{\sqrt{1+2.i_{a,*}^2}} \right) - \frac{\pi}{6} \right] \tag{2}$$

$$i_{AB,*} = i_{CA,*} = \sqrt{1+2.i_{a,*}^2} \tag{3}$$

$$i_{BC,*} = \sqrt{4-i_{a,*}^2} \tag{4}$$

The shifting angle +δ (term 1) means that the phasor current I_b leads the symmetrical component and the angle -δ means that phasor I_c lags. The signs +/- before δ_1 are related with phasors I_{AB} and I_{CA} respectively. If the current of phase A is bigger than other phase currents ($i_{a,*} > i_{b,*} = i_{c,*}$), we can use the same relationships for additional shifting angles - (1), (2) and currents altering - (3) and (4), but reciprocal signs of the phase and line currents shifting angels must be taken.

Case 2.

Assume that the neutral wire of the star-connected secondary winding is grounded and phase current (phase A) is less than other phase currents (phases B and C) – ia,* < ib,* = ic,*. The current phasor diagram is shown in Figure 4. Because of this the

transformer neutral point is grounded, the current Ia changing reduce two line currents IAB and ICA. The magnitudes and additional shifting angles are calculated with:

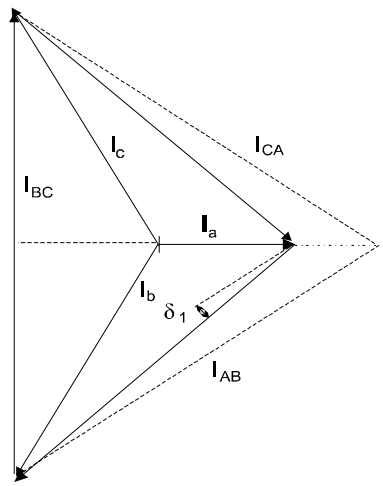

Figure 4

$$\delta_1 = \pm\left[arccos\left(\frac{\sqrt{3}}{1+2.i_{a,*}^2}\right)-\frac{\pi}{6}\right] \tag{5}$$

$$i_{AB,*} = i_{CA,*} = \sqrt{1+i_{a,*}+i_{a,*}^2} \tag{6}$$

and δ =0 и $i_{BC,*} = \sqrt{3}$.

The sign + before δ1 is used with current IAB and the sign - with ICA.

If the phase current (phase A) is bigger than others the signs before δ1 are reciprocal for both currents.

As a conclusion, three-phase load non-symmetry creates distribution transformer currents non-symmetry.

The transformer primary voltages are equal to:

$$\begin{aligned}
\dot{U}_{AB} &= \dot{E}_{AB} - Z_{20}.\dot{I}_{AB} = \dot{E}_{AB}.\left(1-\frac{Z_{20}.\dot{I}_{AB}}{\dot{E}_{AB}}\right)\\
\dot{U}_{BC} &= \dot{E}_{BC} - Z_{20}.\dot{I}_{BC} = \dot{E}_{BC}.\left(1-\frac{Z_{20}.\dot{I}_{BC}}{\dot{E}_{BC}}\right)\\
\dot{U}_{CA} &= \dot{E}_{CA} - Z_{20}.\dot{I}_{CA} = \dot{E}_{CA}.\left(1-\frac{Z_{20}.\dot{I}_{CA}}{\dot{E}_{CA}}\right)
\end{aligned} \tag{7}$$

If we assume that

$$\dot{u}_{\Delta} = Z_{20} \frac{\dot{I}_{AB}}{\dot{E}_{AB}} \tag{8}$$

$$\varphi_{20} = arctg \frac{X_{20}}{R_{20}} \tag{9}$$

$$\dot{d} = d\angle\delta_1 = \left(\frac{\dot{I}_{AB}}{\sqrt{3}} . i_{a,*} \right) \angle\delta_1 \tag{10}$$

Because of the assumption the MV grid is symmetrical and the parameters of the grid phases are equal, three phase voltage drops will be equals and will have the same phase angles φ20 for symmetrical currents.

By replacing (8), (9) and (10) in (7), we have

$$\begin{aligned} \dot{U}_{AB} &= \dot{E}_{AB} . \left(1 - u_{\Delta}\angle\varphi_{20} \ .d\angle + \delta_1\right) \\ \dot{U}_{BC} &= \dot{E}_{BC} . \left(1 - u_{\Delta}\angle\varphi_{20} .. d\angle + 2\delta_1\right) \\ \dot{U}_{CA} &= \dot{E}_{CA} . \left(1 - u_{\Delta}\angle\varphi_{20} \ .d\angle + \delta_1\right) \end{aligned} \tag{11}$$

After some calculation, the transformer primary voltage UAB, will be equal to:

$$\dot{U}_{AB} = \dot{E}_{AB} . \left(1 - u_{\Delta} . d\right) . \sqrt{1 + 2 . u_{\Delta} . d . \frac{1 - cos\ \left(\varphi_{20} + \delta_1\right)}{\left(1 - u_{\Delta} . d\right)^2}} \tag{12}$$

$$arctg\delta_2 = \frac{u_{\Delta} . d . sin\left(\varphi_{20} + \delta_1\right)}{1 - u_{\Delta} . d . cos\left(\varphi_{20} + \delta_1\right)} \tag{13}$$

where δ_2 is voltage shifting angle, due to LV load non-symmetry.

The term for two other voltages UBC, UCA, are similar - the shifting angle is the same for UCA and the - 2δ1 for UBC .

From terms (12) and (13) can conclude that the primary voltage supplying the distribution transformer depends on MV lines drop uΔ, relative current value d, phase angle φ20 for symmetrical systems and shifting angle δ1.

The typical values of the phase resistance, the phase reactance and phase admittance are:

r_{20}=0,31 Ω/*km*; x_{20}=0,38 Ω/*km*; b_{20}=3,04 *μS/km*.

These values alter depending of the conductor material – aluminum or copper, network type – cable or overhead of and some other factors. The phase angle of the three-wire copper cable and of the overhead aluminum-steel wire are presented in fig.5.

We can see constant trend for MV lines decreasing in our country. If the cross-section of MV or LV wires is selected using the admissible voltage drop ($0,1.U_{rate}$) it means that the phase angle φ_{20} will decrease too. On the other hand, a bigger part of power consumers are concentrated in urban district of our country, where we use mostly cable lines. It means that we use power lines with less phase angle φ_{20}. But if the phase angle φ_{20} is decreased it will cause the shifting angle influence increasing.

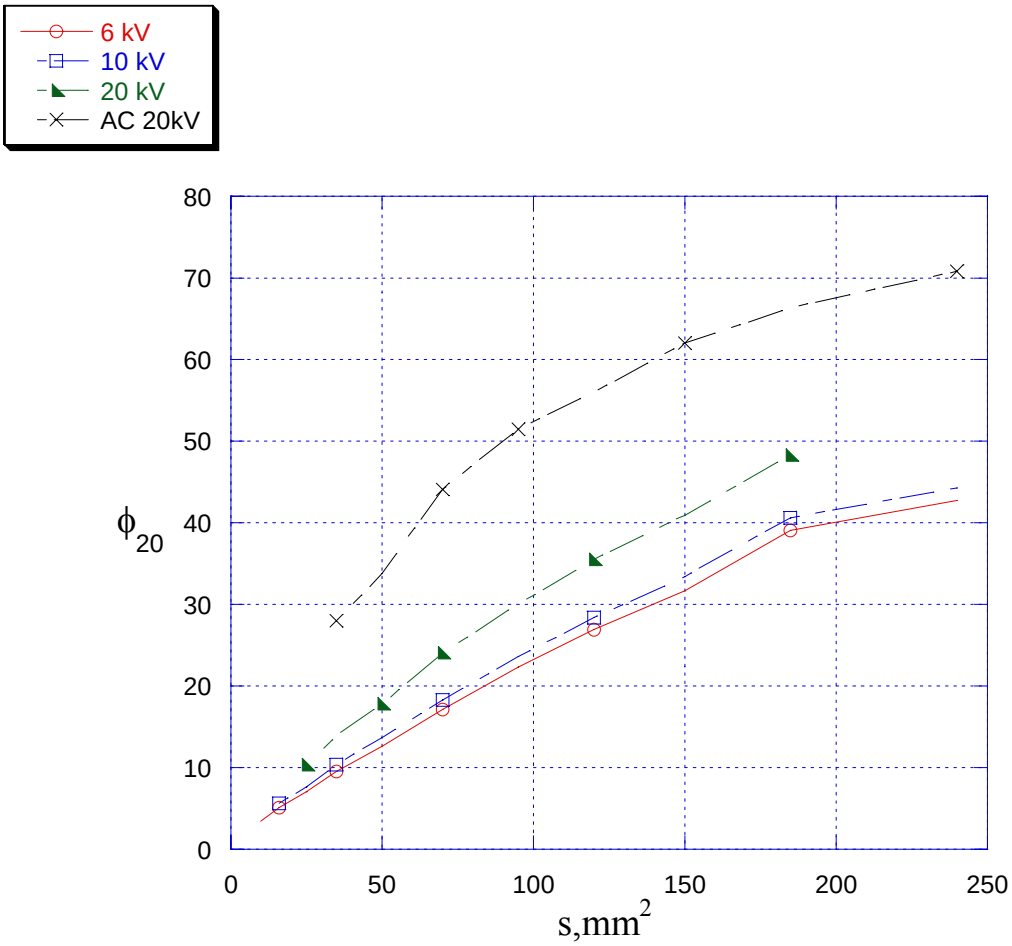

Figure 5.

3. EXPERIMENTAL RESULTS

Series of experiments are made to verify the theoretical analysis of the load non-symmetry influence. Three-phase transformer TT16002 with ratings as follows is used: Sr=1200VA, winding's connection D/y, isolated Y-center of the secondary winding. Power quality analyzer CA8332 (manufactored by Chouven Arnoux - France) is used to carry out the measurements. Three-phase resistive load is connected to the secondary winding of the transformer. The experiments include symmetric load Ir and next one of the currents is altered - 0,5.Ir and 1,5.Ir. The phasor diagrams in Fig. 6,7,8 show the currents measured in the transformer's secondary and primary winding at variation of the load non-symmetry. At a symmetrical load (Fig. 6a) the lag between currents is equal to 120°. Diagrams in the next two figures (Figs. 7a, and 8a) show the change of the secondary current's lag, caused by the reduction of the load current I1. Diagrams in the next figures (Figs.6b, 7b and 8b) show the change of the primary current's lag. Although the load is resistive, it is non-symmetry increases the current's lag proportionally to the non-symmetry increase.

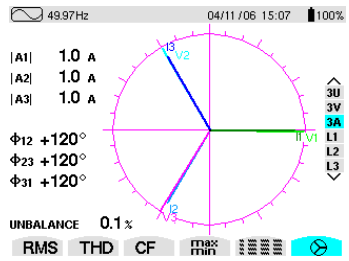

Figure 6a

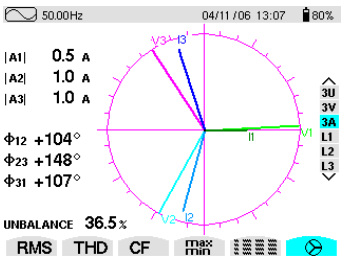

Figure 7a

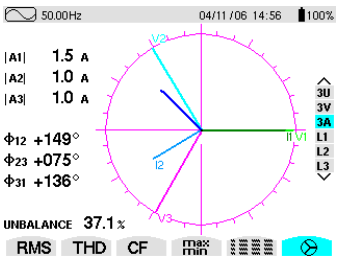

Figure 8a

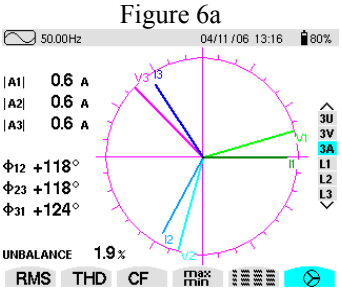

Figure 6b

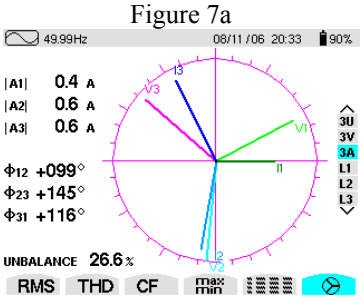

Figure 7b

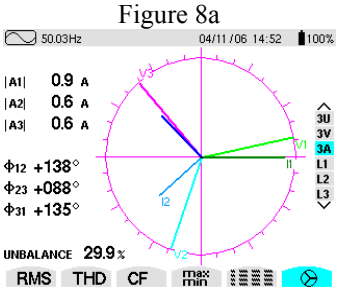

Figure 8b

In Table 1 we can compare the calculated and the measured values of the phase shifting angles for studying non-symmetrical cases.

Table 1.

				Secondary currents			Primary currents		
$i_{b,*} = i_{c,*}$	$i_{a,*}$	Fig.							
1	1.0	6	Cal.	I_a **0**	I_b **0**	I_c **0**	I_1 **0**	I_2 **0**	I_3 **0**
			Meas.	I_1 **0**	I_2 **0**	I_3 **0**	I_1 **2**	I_2 **2**	I_3 **4**
	0,5	7	Cal.	I_a **16**	I_b **16**	I_c **32**	I_1 **22**	I_2 **22**	I_3 **44**
			Meas.	I_1 **16**	I_2 **15**	I_3 **28**	I_1 **4**	I_2 **11**	I_3 **25**
	1,5	8	Cal.	I_a **18**	I_b **18**	I_c **36**	I_1 **14**	I_2 **14**	I_3 **28**
			Meas.	I_1 **29**	I_2 **16**	I_3 **45**	I_1 **15**	I_2 **2**	I_3 **32**

4. CONCLUSION

The non-symmetrical load connected to the secondary winding causes change in the phase currents lag. It depends on the values and the proportion between the currents and the neutral wire grounding.

The non-symmetry of the load currents causes also lag change of the currents in the primary winding and non-symmetry of the transformer's supply voltage.

The non-symmetry of the transformer's primary voltage increases the non-symmetry of the secondary voltage, supplying three phase loads.

REFERENCES

[1] EN 61 000. Electromagnetic compatibililty. 1998.
[2] Ivanov-Smolenski A.V., Electrical Mashines, Moskow, 1980 (rus).
[3] BS EN 50160, Voltage Characteristics of Electricity Supplied by Public Distribution Systems .