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IMPROVING THE POWER FACTOR AT UNBALANCED CONSUMERS

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Abstract: Unbalanced consumers have led to power quality problems. It is therefore necessary to have on hand solutions and equipment capable of improving the power quality. This paper provides a comparison on improving the power factor at unbalanced consumers by using two methods the installation of a capacitor in the PCC (point of common coupling) – analysis made through analytical method; and installation of a shunt active power filter in the PCC – analysis made through simulation using Matlab/Simulink software.

Keywords: power quality, power factor, active power filter, unbalance.

1. INTRODUCTION

The economic impacts caused by operation with low power factor must be taken into account in determining electricity price, seeking to compensate for energy losses determined by this operating mode. The main problem for the existing compensation methods, those witch use only one phase as reference, is that the consumers are not balanced, a large quantity of current flow through the neutral wire. Therefore the classical method of installation the condenser blanks isn't a viable one.

2. POWER FACTOR

Defined as the ratio between active power P and apparent power S, the power factor PF is a size variable in time (as the two powers that define it):

$$(1)\quad PF = \frac{P}{S}$$

The limits of the average power factor are 0.92 for the inductive power factor and 1 for a capacitive power factor.

For an average power factor achieved less than 0.92 but higher than 0.65, the consumer will pay the difference between the recorded reactive energy and the corresponding power factor limit set by the ANRE (Romanian Energy Regulatory Authority), at the tariff value in force.

If the consumer reaches a power factor below 0.65, it will pay the difference between the recorded reactive energy and the corresponding power factor limit set by ANRE, three times the price in force.

3. UNBALANCE

The analysis of the unbalance of a sinusoidal three phase system is based on Fortescue theorem, which allows the decomposition of an unbalanced sinusoidal three phase system UA, UB, UC in three independent single phase systems U^+, U^- and U^0, of a

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positive, negative and zero sequence, thus taking into account both the module unbalance and the angle unbalance.

- Negative unbalance factor, k_s^-

$$(2)\quad k_s^- = \frac{|U^-|}{|U^+|}$$

- Zero unbalance factor, k_s^0

$$(3)\quad k_s^0 = \frac{|U^0|}{|U^+|}$$

IEEE recommendations for the unbalance assessment take into account only the module unbalance based on the relation:

$$(4)\quad k_s = \frac{\text{max dev from avg value}}{\text{avg value}}$$

where, the average value results as an arithmetic average of the three considered dimensions.

4. DEFINITION OF THE ANALYZED CONSUMER

The study was conducted with an industrial consumer, where there were made measurements at the connection point of the power distribution system during one week.

In Table 1 there are presented the average values of the main electric quantities that characterize the analyzed consumer, while Fig. 1 and 2 show load curves.

Table 1Features of the analyzed consumer

Cosumer type	f [Hz]	Urms [V]	Vrms [V]	Arms [A]	P [kW]	Q [kVAR]	S [kVA]	PF	k_{si}
Industrial	49.9	413	238	34.4	23.7	7.2	25.8	0.89	0.5

where:
- Urms – is the rms value of line voltage;
- Vrms – is the rms value of voltage phase;
- Arms – is the rms value of current;
- P, Q, S – are the values of active, reactive and apparent power;
- PF – is the value of power factor;
- ksi – is the value of unbalanced current factor based on the IEEE definition.

One can notice from the load curves that there is an unbalance between the phases and, at the same time, a cyclical evolution over the period of analysis. Therefore, the calculations will be made over a period of one day, considered as a standard from the point of view of the consumer activities. Fig. 3 and 4 show the evolution of active power consumption and the variation of the power factor for that day.

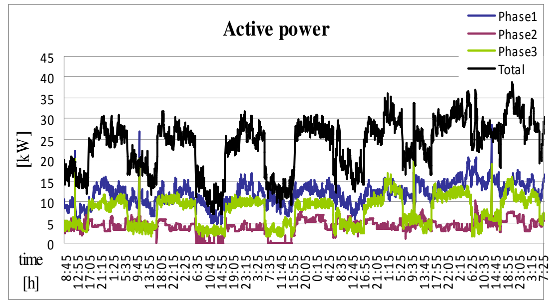

Fig.1. Active power load curve

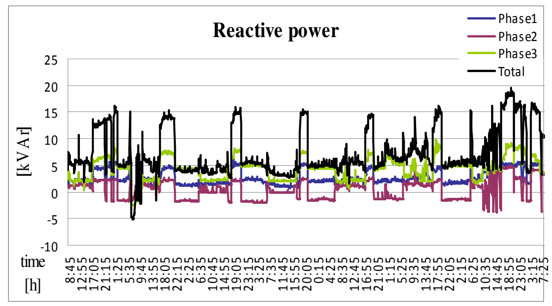

Fig.2. Reactive power load curve

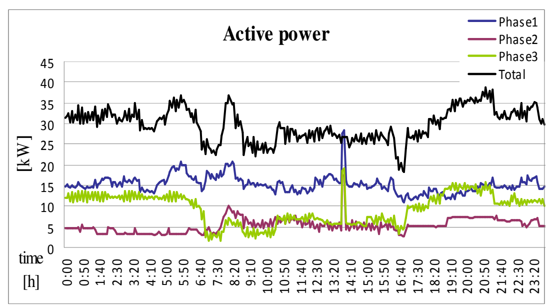

Fig.3. Active power load curve at the level of the standard day

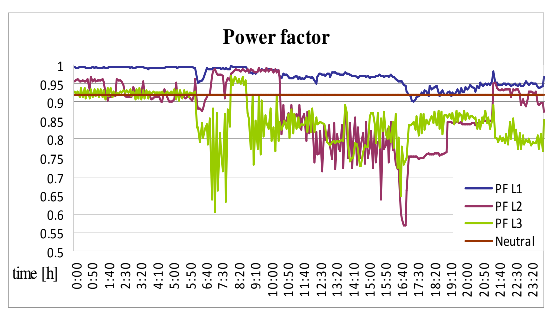

Fig.4. Evolution of power factor in the analyzed day

5. ANALYSIS RESULTS FOR THE CONSIDERED CASE STUDY

Two methods for the power factor improvement were considered for the analysis:

- the installation of a capacitor in the PCC (point of common coupling) – analysis made through analytical method;

- the installation of a synchronous compensator in the PCC – analysis made through simulation using Matlab/Simulink software.

A. Installation of capacitor in the PCC

Since automatic capacitor use as reference only one phase, the study was made by sizing compensation systems considering each phase as reference. Then with the same active power consume and part of reactive power (because the other part of reactive power came from the capacitor bank) we calculate the value of PF if these compensators are installed in the system, results presented in Fig. 5, 6 and 7.

$$(5)\ \ S=\sqrt{P^2+(Q_r-Q_c)^2}$$

where Q_r is the reactive power absorbed from the network, when the compensation system don’t exist, and Q_c is the reactive power injected in the system by the compensation system.

To improve the existing power factor ($\cos\varphi_1$) to an imposed value $\cos\varphi_2 \geq 0.92$:

$$(6)\ \ Q_c = P\cdot\left(\tan\varphi_1 - \tan\varphi_2\right)$$

The results for compensator steps needed are presented in Table 2, where first line – “Present” – represents the situation when no compensation system exists.

Table 2 Used steps of the capacitor

Analysis type	Step 1 [kVAR]	Step 2 [kVAR]	Step 3 [kVAR]	Step 4 [kVAR]	Step 5 [kVAR]	Step 6 [kVAR]	Step 7 [kVAR]	Step 8 [kVAR]	Step 9 [kVAR]
Present	0	0	0	0	0	0	0	0	0
Phase 1 Reference	1	1.5	0	0	0	0	0	0	0
Phase 2 Reference	1	1.5	2	2.5	3	0	0	0	0
Phase 3 Reference	1	1.5	2	2.5	3	3.5	4	4.5	5

Fig. 5, 6 and 7 describe the total power factor curve for each case.

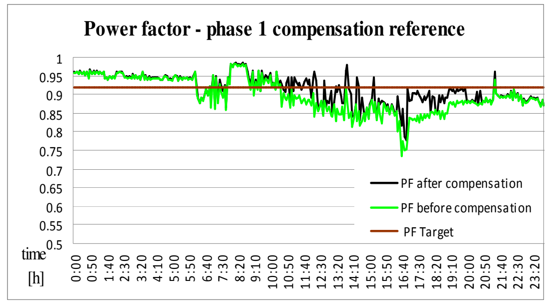

Fig.5. Power factor curve with phase 1 as reference

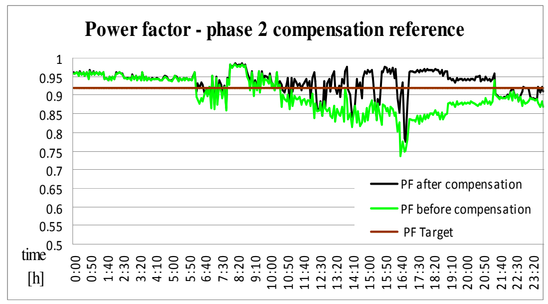

Fig.6. Power factor curve with phase 2 as reference

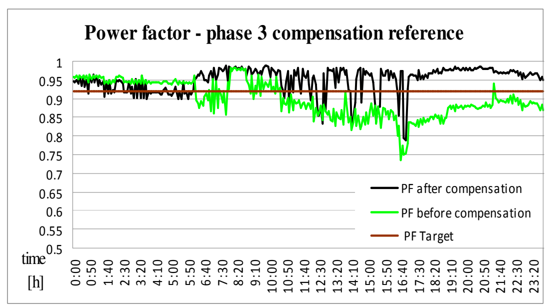

Fig.7. Power factor curve with phase 3 as reference

Table 3 contains the average values of characteristic dates for the studied cases.

Table 3 Average values table

Analysis type	Phase 1					Phase 2					Phase 3					Total PF
	P [kW]	Q [kVAR] L	Q [kVAR] C	S [kVA]	PF	P [kW]	Q [kVAR] L	Q [kVAR] C	S [kVA]	PF	P [kW]	Q [kVAR] L	Q [kVAR] C	S [kVA]	PF	
Present	15.2	3.42	0	15.71	0.96	5.33	1.7	-0.65	6.11	0.87	9.38	5.27	0	10.86	0.85	0.89
Phase 1 Reference	15.2	3.29	0	15.71	0.97	5.33	1.57	-0.65	6.11	0.90	9.38	5.14	0	10.86	0.86	0.914
Phase 2 Reference	15.2	2.76	0	15.71	0.98	5.33	1.03	-0.65	6.11	0.94	9.38	4.16	0	10.86	0.88	0.93
Phase 3 Reference	15.2	1.28	-0.01	15.71	0.99	5.33	0.41	-1.52	6.11	0.9	9.38	3.12	0	10.86	0.94	0.95

B. Installation of active power filter in PCC

Active filter model was implemented in Matlab/Simulink on the structure of a three phase three wire parallel active filter (Fig. 8) controlled by indirect control method (Fig. 9). [4]

The structure of the implemented model consists of:

- Power supply, three phase c.a. source;
- The unbalanced consumer is the one presented above, designed as an unbalanced value using the data from Table 1;
- Active power filter consisting of:
- Control;
- Voltage converter with IGBT;
- Storage capacitor in c.c., C = 30mF;
- Inductive filter (Lf= 18mH);
- Measure unit.

In Fig. 10, 12 and 14 are presented the voltage and current signals obtained (by simulation method) before coupling of the compensator and the Fig. 11, 13 and 15 are the result obtained after the installation of active filter.

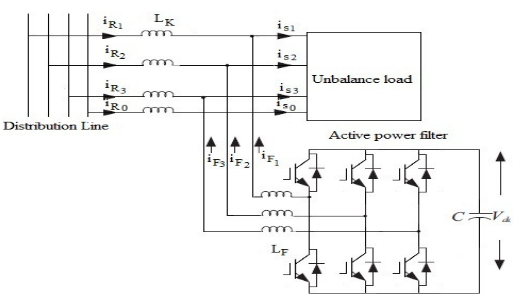

Fig.8. Active power filter

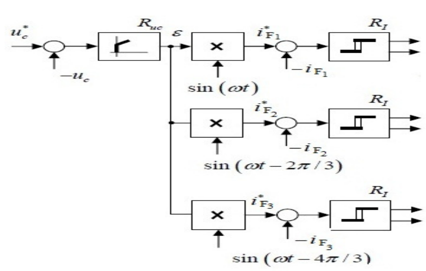

Fig.9. Indirect control strategy

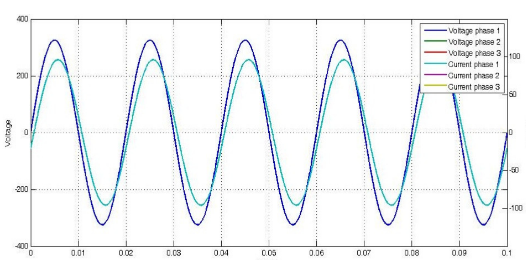

Fig.10. Current and voltage signals for phase 1 before compensation

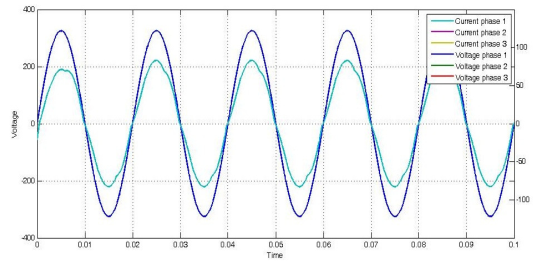

Fig.11. Current and voltage signals for phase 1 after compensation

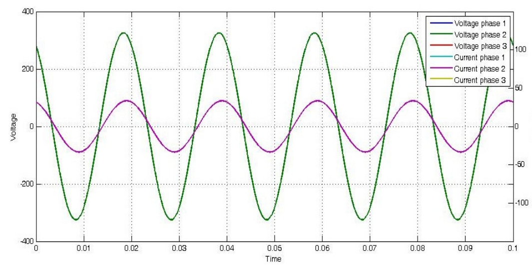

Fig.12. Current and voltage signals for phase 2 before compensation

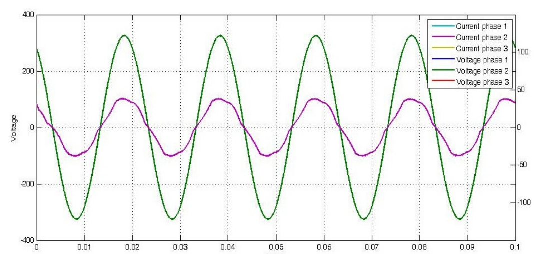

Fig.13. Current and voltage signals for phase 2 after compensation

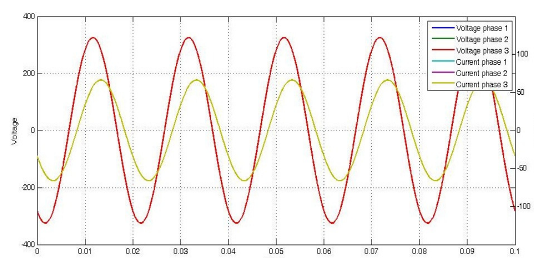

Fig.14. Current and voltage signals for phase 3 before compensation

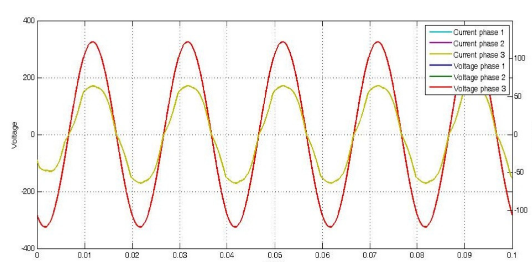

Fig.15. Current and voltage signals for phase 3 after compensation

6. CONCLUSION

For the above-presented case, the only acceptable solutions are:

- installation of capacitor bank and setting phase 2 as reference, because if phase 1 would be used results a global power factor compensation below the neutral, and if phase 3 would be used results an overcompensation compared to the neutral factor.

- the use of power electronics by using an active power filter. This device, as can be seen in Fig. 11, 13 and 15, is able to minimize the phase shift between current and voltage on each phase of the three phase electrical system analyzed above.

On the basis of this study the main conclusion is to install compensators for reactive power consumption in unbalanced systems which use information acquired from all three phases.

7. ACKNOWLEDGMENT

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