ECONOMICS REASONS TO USE SHUNT ACTIVE POWER FILTERS

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The economics reasons to use shunt active power filters are considered from the point of view of the consumer and producer of electrical power. 3-D diagrams, that give the relationship between load parameters and saving for the consumer and producer of electrical power, are carried out. Experimental results with an estimated saving are given.

Keywords: active power filter, economics benefit.

1. INTRODUCTION

The consumption of electrical power has been recently increased for industrial application as well as for living standards. This consumption, as well as the increase of the world population determines faster depletion of sources used to produce electrical power.

Scientific workings out of worldwide importance to search alternative power sources, and to use power more efficiently, are made. Active power filters (APF) are prospective way [1] [2] for more efficient use of the electrical power in already existing consumers.

APF are shunt (fig.1.A), series (fig.1.B), a combination of shunt and series, and a combination of active and passive filters (hybrid filter) [1]. Shunt filters are used both to eliminate harmonics in the consumed current (to compensate the distortion power) and to compensate the consumed reactive power. Series filters are used to eliminate harmonics in the source voltage and its notch changes, i.e. to improve quality of the network source voltage. A combination of a shunt and a series APF is called "unified power quality conditioner", as the combination performs both functions of the series and shunt filters. APFs are applied under single-phase consumers, as well as under three-phase consumers with three or four wired source voltages. APF might be combined with UPS of a sensitive consumer to perform both functions of APF and UPS.

Single-phase shunt and series active power filters, a combination of both, as well as hybrid filters have been studied with different types of load. These kinds of APF are also studied with different algorithms to form the control signals for power devices of these filters [2] [3] [4]. To form the reference signal to control power switches, methods using one or several current transformers are known [4] [5] [6].

In addition, different control strategies for three-phase active power filters are known. The method with 3-D vector control has been scrutinized in [7]. Other algorithms for controlling devices of three-phase APF have been examined in [8] [9] [10] [11] [12].

The paper aim is to demonstrate economics benefit for a final consumer and a producer of electrical power using shunt active power filter. For better understanding, 3D graphics displaying this benefit are carried out. A real example is provided.

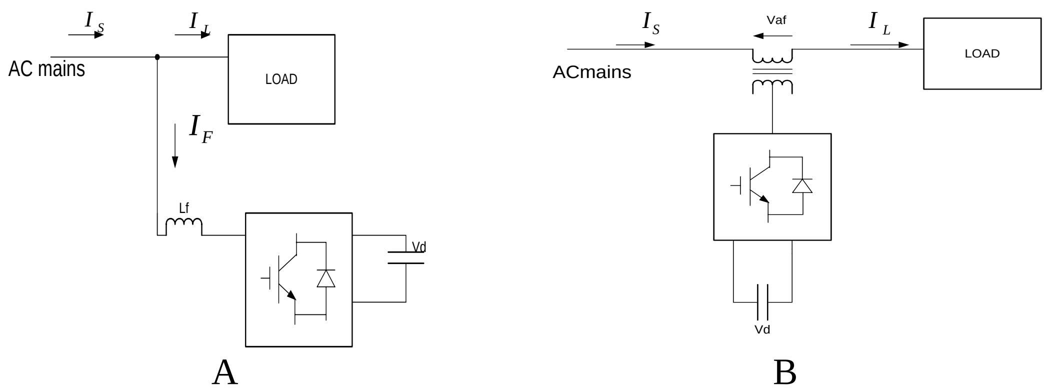


Fig.1. Block shematic of a shunt and series APF

2. ECONOMICS BENEFIT OF USING APF

2.1 Case of Linear Load

In more countries, in the case of linear load, industrial consumers pay not only for the consumed active power but also for the reactive power (for example Bulgaria).

Let C_{NAPF} is the expense of an industrial consumer. It defines as:

(1) $C_{NAPF} = P_L \cdot C_P + Q_L \cdot C_Q$,

where C_P, C_Q, P_L and Q_L are the price of the active power, the price of the reactive power, the required price to pay for active and reactive power, respectively.

Let mark with K_{PQ}, $K_{PQ} = \dfrac{C_P}{C_Q}$, the ratio between the prices of the active and the reactive power, and consider the expression $Q_L = P_L \cdot tg\varphi_{NAPF}$, where φ_{NAPF} is the phase difference between the source voltage and the first harmonic of the consumed current. The following is valid:

(2) $C_{NAPF} = P_L \cdot C_P \cdot \left(1 + \dfrac{tg\varphi_{NAPF}}{K_{PQ}}\right)$.

When APF is connected to this consumer, consumed active and reactive powers change. The active power increase with ΔP dependent of the losses in the filter, on the other hand, the reactive power decreases. The following expressions are derived:

(3) $P'_L = P_L + \Delta P = P_L + P_L\left(\dfrac{1}{\eta} - 1\right) = \dfrac{P_L}{\eta}$

(4) $Q'_L = P'_L \cdot tg\varphi_{APF}$.

In this way, the consumer is going to pay:

(5) $$C_{APF} = P_L' \cdot C_P + Q_L' \cdot C_Q = \frac{P_L}{\eta} \cdot C_P \cdot \left(1 + \frac{tg\varphi_{APF}}{K_{PQ}}\right).$$

The ratio between the difference of the price, which the consumer has to pay without and with the presence of the filter, and the price which the consumer has to pay without the presence of the filter, is showing in percents measured in corresponding currency the economy made using APF.

(6) $$Sav = \frac{C_{NAPF} - C_{APF}}{C_{NAPF}}.100,\%$$

Substitution of (1) and (5) in (6) and treatment, derives:

(7) $$Sav = \left(1 - \frac{1}{\eta} \cdot \frac{1 + \frac{tg\varphi_{APF}}{K_{PQ}}}{1 + \frac{tg\varphi_{NAPF}}{K_{PQ}}}\right)100,\%$$

Connecting APF, the phase difference between the source voltage and the consumed current in ideal case is 0 ($\varphi_{APF} = 0$). Thus for Sav is valid:

(8) $$Sav = \left(1 - \frac{1}{\eta} \cdot \frac{1}{1 + \frac{tg\varphi_{NAPF}}{K_{PQ}}}\right)100,\%.$$

Let see the relationship between $\cos\varphi$ and $tg\varphi$:

(9) $$\frac{1}{\cos\varphi} = \sqrt{1 + tg^2\varphi},$$

the following expression for Sav is obtained:

(10) $$Sav = \left(1 - \frac{1}{\eta} \cdot \frac{1}{1 + \frac{\sqrt{\frac{1}{\cos^2\varphi_{NAPF}} - 1}}{K_{PQ}}}\right)100,\%$$

The ratio between the price of the active power and the price of the reactive one is known for every country, for example in Bulgaria $K_{PQ} = 20$.

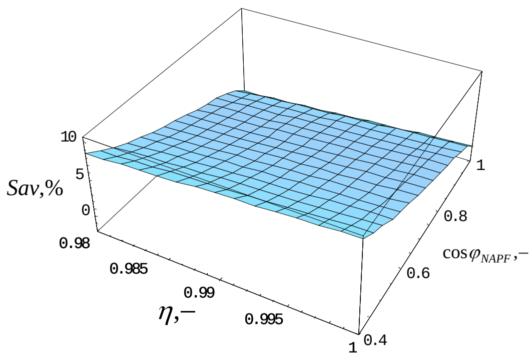


Figure 2.

Using Matemathica4.1 software, graphical representation of the relationship among the filter's efficient coefficient, the phase difference between source voltage and consumed current, before the connection of APF, and Sav is obtained and presented at fig.3.

2.2 Case of Nonlinear Load

In the case of nonlinear load, consideration by analogy to the case of linear load can be made. Let mark with C_{NAPF} the expense of an industrial consumer, and register:

(11) $C_{NAPF} = P_L \cdot C_P + S_L \cdot C_S$,

where C_P, C_S, P_L and S_L are the price of the active power, the price of the total power, the required active power to be paid and the required total power to be paid, respectively.

Let mark the ratio between the price of the active power and the price of the total power with K_{PS}, $K_{PS} = \dfrac{C_P}{C_S}$, take into consideration the expression $K_{PNAPF} = \dfrac{P_L}{S_L}$. Thus, the following expression for C_{NAPF} is derived:

(12) $C_{NAPF} = P_L \cdot C_P \cdot \left(1 + \dfrac{1}{K_{PS} \cdot K_{P\,NAPF}}\right)$

When APF is connected to this consumer, consumed active and total powers change. The active power increases with ΔP dependent of the losses in the filter, on the other hand, the total power has to be equal to the active power consumed without filter. The following expressions are derived:

(13) $P'_L = P_L + \Delta P = P_L + P_L\left(\dfrac{1}{\eta} - 1\right) = \dfrac{P_L}{\eta}$

(14) $P'_L = K_{P_{APF}} \cdot S'_L$.

Thus, the consumer is going to pay:

(15) $C_{APF} = P'_L \cdot C_P + S'_L \cdot C_S = \dfrac{P_L}{\eta} \cdot C_P \cdot \left(1 + \dfrac{1}{K_{PS} \cdot K_{P_{APF}}}\right)$.

The economy made using APF is:

(16) $Sav = \dfrac{C_{NAPF} - C_{APF}}{C_{NAPF}}.100,\%$

Substitution of (12) and (15) in (16) and treatment, derives:

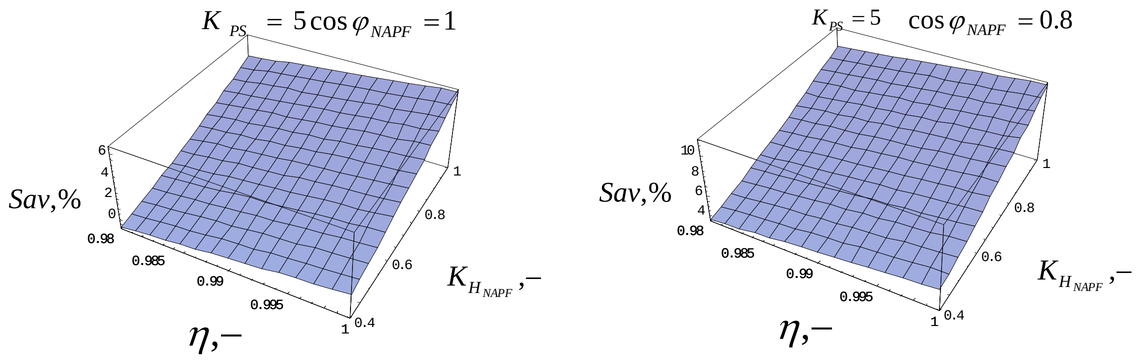
(17) $Sav = \left(1 - \dfrac{1}{\eta} \cdot \dfrac{1 + \dfrac{1}{K_{PS} \cdot K_{P_{APF}}}}{1 + \dfrac{1}{K_{PS} \cdot K_{P_{NAPF}}}}\right)100,\%$.

Substitution in (17) with the expression of the power factor $K_{P_{NAF}} = \nu \cdot \cos\varphi_{NAF} = \frac{1}{\sqrt{1+K_{H_{NAF}}^2}} \cdot \cos\varphi_{NAF}$ and consider that $K_{H_{APF}} \approx 0$ and $\cos\varphi_{APF} \approx 1$, the following expression for Sav is derived:

$$(18)\quad Sav = \left(1 - \frac{1}{\eta} \cdot \frac{1+\dfrac{1}{K_{PS}}}{1+\dfrac{\sqrt{1+K_{H_{NAPF}}^2}}{K_{PS}\cdot\cos\varphi_{NAPF}}} \right) 100,\%$$

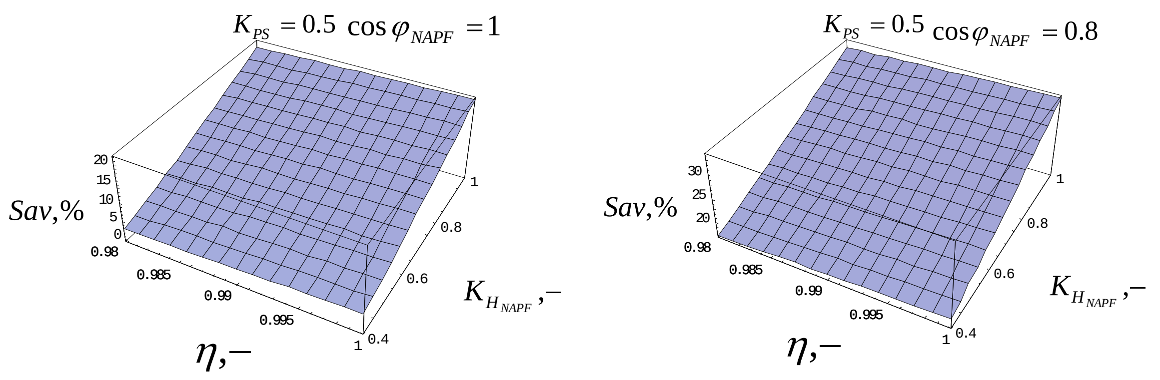
From the consumer's point of view, let assume that this ratio is $K_{PS} = 5$. Fig.3.A. and fig.3.B. display relationships among Sav, η and $K_{H_{NAPF}}$, for $\cos\varphi_{NAPF} = 1$ and $\cos\varphi_{NAPF} = 0.8$, respectively.

For the producer of electrical power the ratio between the price of the active power and the price of the total power is below 1. Fig.4.A and fig.4.B display the relationships among Sav, η and $K_{H_{NAPF}}$, for $\cos\varphi_{NAPF} = 1$ and $\cos\varphi_{NAPF} = 0.8$, respectively, when $K_{PS} = 0.5$.



A **B**

Figure 3. Economics saving from the point of view of the consumer



A B

Figure 4. Economics saving from the point of view of the producer of electrical power

In different countries, this ratio is varying. The smaller and closer to 1 this ratio is, the bigger economics effect from the consumer's point of view appears. From the producer's point of view, the less is this ratio, the bigger economics effect appears.

3. Experimental Study and Results

Experimental pattern of a parallel APF is made. To control this filter, a method described in [13] is used. The results from the work of the APF together with an uncontrollable rectifier are shown at fig.5. Saving for the example given at fig.5 may be calculated from (17) and it is available when $K_{PS} < 4.16$.

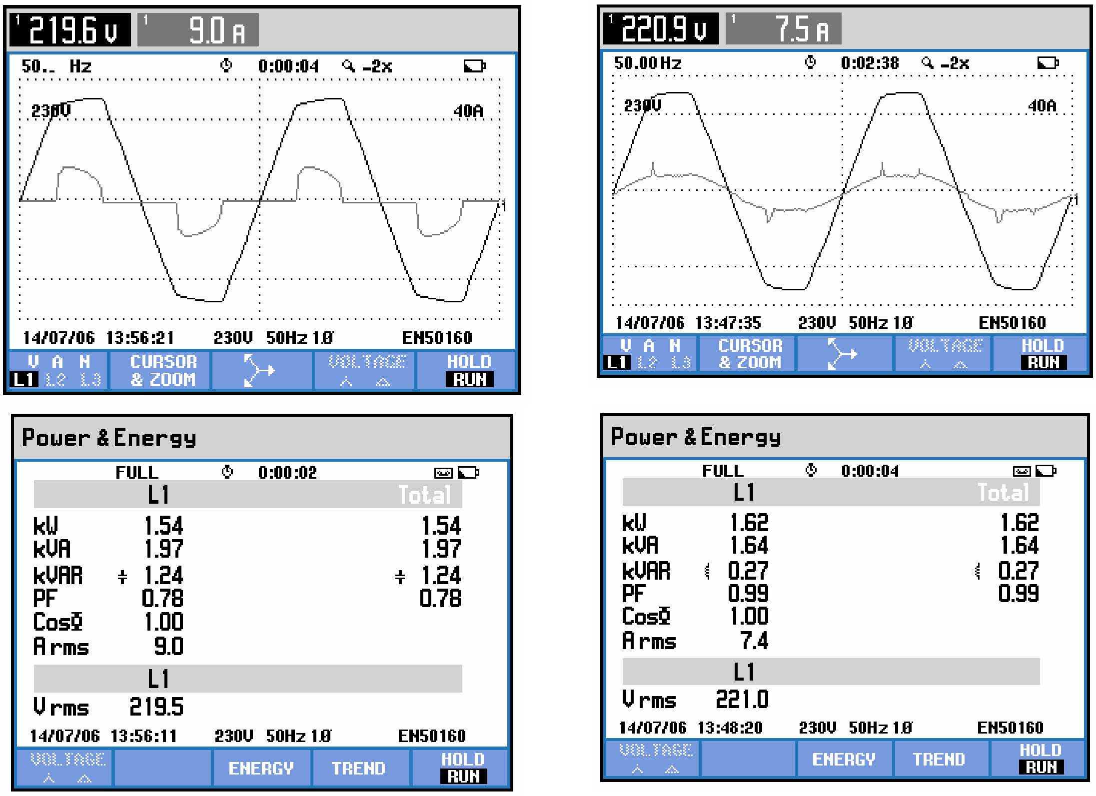


Fig.5. On the left side are the results from the operation of the uncontrollable rectifier, on the right – from the joint operation of the same rectifier and shunt APF

This paper does not comment the problem connected with the economics effect of the improvement of power factor and decrease of total harmonic coefficient of source current upon the distribution network. Problems with meeting international standards EN61000-3-2 and EN61000-3-4 are also not included.

4. Conclusion

A valuation of the financial benefit using shunt active power filter connected to the system network source – load from the consumer's and producer's of electrical power point of view is made. 3-D diagrams that give the relationship between load parameters and saving for a consumer and producer of electrical power are carried out. These diagrams are made for linear and non-linear loads. Experimental study used to calculate saving are enclosed.

5. ACKNOWLEDGMENT

The study carried out in this work is made in connection with Contract VU – TN – 116, between (RDS) TU – Sofia and Ministry of Education and Science Bulgaria .

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