SPECIAL OPERATION FEATURES OF THE OUTPUT TRANSFORMER OF SERIES ACTIVE POWER FILTERS

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This paper examines several special operation features of the output transformer included in the schematic of a series active power filter. Results enabling to found an output data to design the transformer are included. Also, graphics from a computer simulation and ocsilograms from experimental study of a laboratory model are presented.

Keywords: series active power filters, output transformer

1. INTRODUCTION

Series active power filters (SAPF) are modern means, extremely efficient ones, to increase the quality of the source network voltage supplying a critical consumers, such as computer systems, communication tools, etc. [1-5]. It is known the probability to implement these filters also in distributed generation system [6, 7].

Fig.1 displays a block scheme of single-phase SAPF [8, 9]. It consists of the following blocks:

- Power part – a voltage inverter, formed by transistors T1÷T4, a low pass frequency filter (C_f - L_f), an output transformer Tr and a source of DC voltage (U_d - C_d);
- Control system.

Based on the data of the feedbacks for the input voltage of the load U_L and the source voltage U_S (their waveforms and their amplitudes), the control system generates control signals for the power part [8]. By appropriate drivers, these signals acts upon the transistors gates in such a way, that the output inverter voltage, after has passed through a low pass frequency filter and the output transformer and has summed with the real voltage of the network, gives an ideal sinusoidal voltage applied to the load.

In accordance with the international standard EN50160 the harmonics of the source voltage are supervised till 39th one. These harmonics have to be compensated by SAPF. This means that the waveforms and the harmonic spectrum of the voltage and the current of the output of the SAPF are extremely complex and leads to quite a

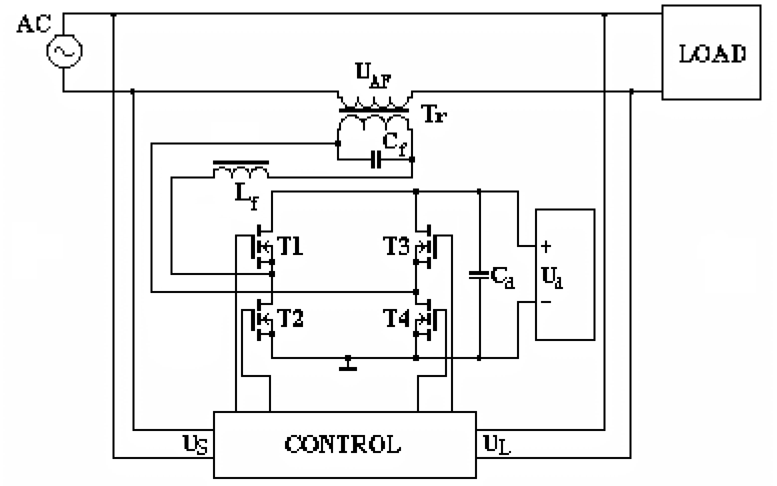

Fig.1. Series active power filter

specific operation of the output transformer in contrast to the conventional network transformers implemented into practice.

However, in many cases, it is required not only a filtering as it has already been described, but also a stabilization of the amplitude of the voltage supplying the load to a certain value. In this case besides the compensation of the undesired harmonic components it is required to add a voltage with a frequency of the first voltage harmonic to be able to stabilize its amplitude.

These special operation features of the filter are related to the operation of the output transformer with a great importance. The proposed paper is devoted to study the specific character of the operation of the output transformer with the purpose of founding a necessary data for its design.

2. MATHEMATICAL DESCRIPTION

When installing SAPF it is primary necessary to study distortions in the source voltage waveform. One of the frequently met distortions is the limitation of its maximum value, which is connected with a propagation of consumers without power factor correction, containing uncontrolled rectifiers with active-capacitive load. This explains why in the proposed mathematic description the approximation of the source voltage waveform is made with a trapezium function (see Fig.2). The altitude of the trapezium h is equal to the maximum value of the source voltage - U_m. The angle at the base α determines the value of the first derivative at the moment of crossing the X-axes, i.e. when x=0.

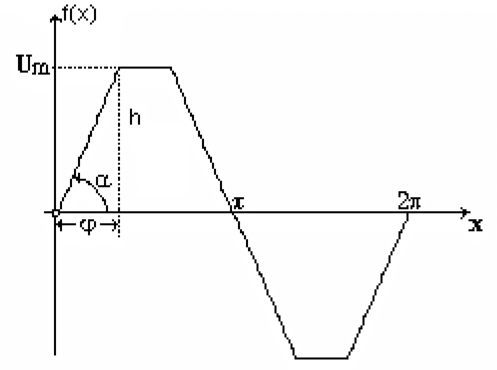

Fig.2. Trapezium approximation of the source voltage

Fourier decomposition of such a function is well known and it is:

$$f(x)=\frac{4\cdot h}{\pi\cdot\varphi}\sum_{k=1}^{\infty}\frac{1}{(2k-1)^2}\sin(2k-1)\cdot\varphi\cdot\sin(2k-1)\cdot x \qquad (1)$$

The fundamental harmonic component can be separated from the higher harmonics:

$$f(x)=\frac{4\cdot h}{\pi\cdot\varphi}\sin(\varphi)\sin(x)+\frac{4\cdot h}{\pi\cdot\varphi}\sum_{k=2}^{\infty}\frac{1}{(2k-1)^2}\sin(2k-1)\cdot\varphi.\sin(2k-1)\cdot x \qquad (2)$$

From equation (2) total harmonic distortion coefficient is derived:

$$K_H=\frac{\sqrt{\sum\limits_{k=2}^{\infty}\frac{1}{(2k-1)^4}\sin^2(2k-1)\cdot\varphi}}{\sin\varphi} \qquad (3)$$

It is obvious from equation (3) that this coefficient depends on the parameter φ. The nomographic chart based on the equation (3) is shown at Fig.3.

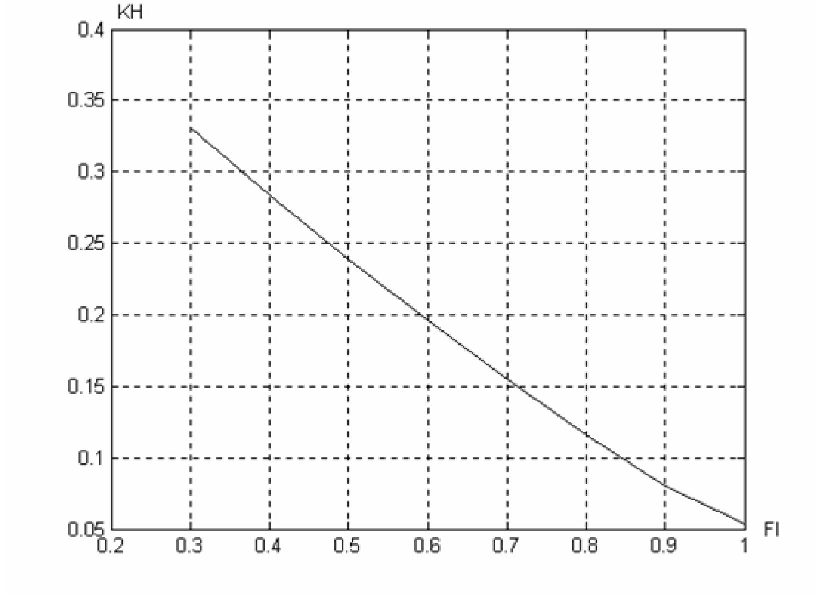

Fig.3. Nomographic chart presents relationship (3)

Thus, the amplitude values of the voltage harmonics in the output transformers of the SAPF can be determined:

$$U_{km} = \frac{4 \cdot h}{\pi \cdot \varphi} \cdot \frac{1}{(2k-1)^2} \sin(2k-1)\varphi. \tag{4}$$

The maximum value of the current through the capacitor C_f of the low pass filter for each harmonic component:

$$I_{Ckm} = U_{km} \cdot k \cdot \omega \cdot C \tag{5}$$

Equation (5) leads to the effective value of the current through the capacitor, taking into consideration all harmonic components, and it is:

$$I_{Cf} = \frac{4Ch\omega\sqrt{2}}{\pi} \sqrt{\sum_{k=2}^{\infty} \frac{1}{(2k-1)^4} \cdot \sin^2(2k-1)\sin\varphi} \tag{6}$$

Finally, data making probable the design of the output transformer is found.

The design can be performed in the following way:

- By the means of Fig.3, corresponding to equation (3), when the harmonic coefficient of the source voltage is chosen, the angle φ is determined and then using equation (4) the values of all higher harmonics that will be included into the transformer voltage are calculated and with a sufficient accuracy for the practice it can be taken only the 3rd 5th 7th and the 9th harmonics for a single-phase filter and the 5th 7th 11th and the 13th harmonics for a three-phase filter.
- If there is need of a stabilization of the input load voltage to a reference value, a first harmonic component is added to the higher harmonics and its value is equal to the difference between the reference and the defined with the first component at the right side of equation (2) values.
- The current through the transformer is determined mainly from the load current (see Fig.1), and it can be linear or nonlinear and also it is preliminarily known of measurements or data of the consumer.
- The coefficient of the transformation depends on the chosen value of the voltage U_d and on the attenuation of the harmonics in the output of the inverter introduced by the filter $L_f\ C_f$.

3. COMPUTER SIMULATION

A computer simulation is made with the purpose of obtaining the waveform of the current through and the voltage across the output transformer of the single-phase SAPF. The simulation scheme is shown at Fig.4 and the results of the study at Fig.5.

A trapezium form of the source voltage U_{SOURCE} is used, as the input voltage of the load (uncontrolled bridge rectifier with active capacitive load) is generated only by filtering.

The simulation is made through software Orcad10.5. The operation of the SAPF performed with a bridge inverter is simulated. The control system uses the method of the sliding-mode control [8, 9]. The lower diagrams at Fig.6 show the operation conditions of the output transformer.

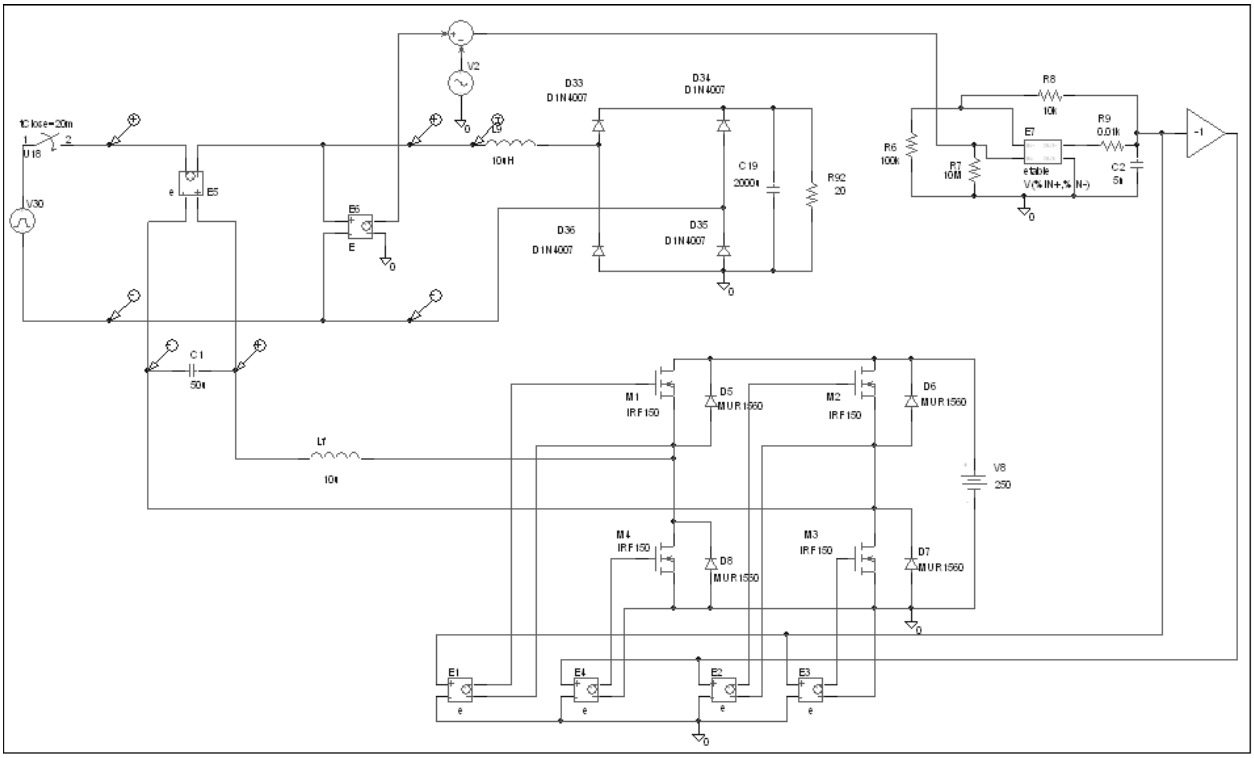

Fig.4.Computer simulation scheme

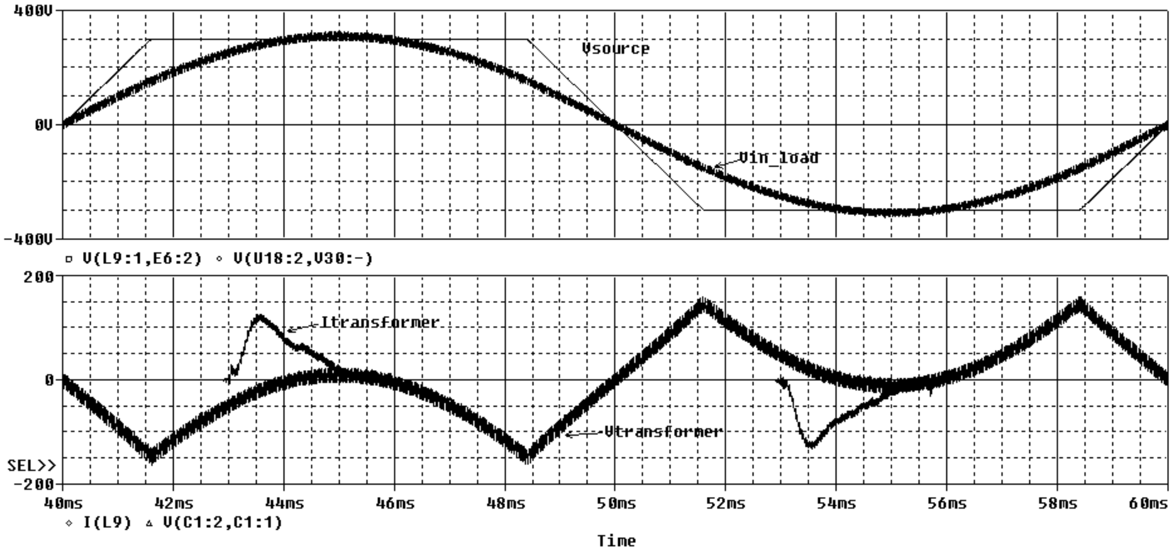

Fig.5. Computer simulation results. At the upper diagram – the input load voltage without and with filter, and, at the lower diagram – the voltage across and the current through the output transformer.

4. EXPERIMENTAL STUDY

Experimental results obtained through measurements of the laboratory model are shown at Fig.6 and Fig.7. Improvement in the waveform of the voltage supplying the load after the connection of SAPF is proved.

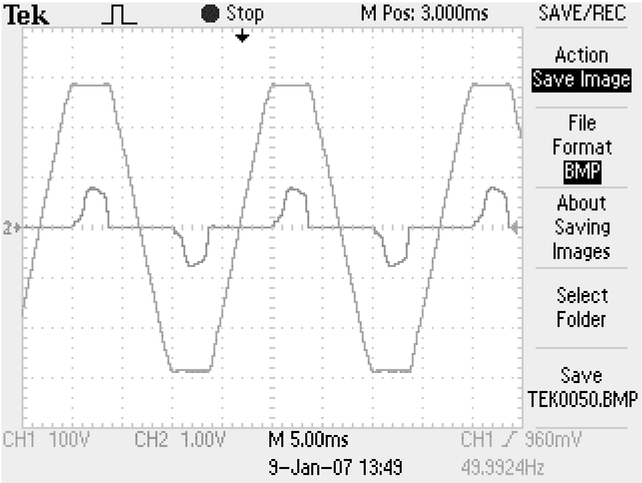

Fig.7. The source voltage and current of a nonlinear load when SAPF is not connected.

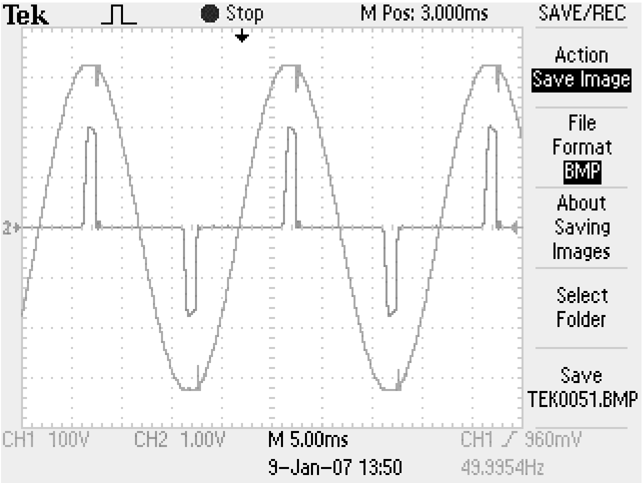

Fig.8. The source voltage and current of a nonlinear load when SAPF is connected.

5. CONCLUSIONS

Analytic equations are found and the data to design the output transformer of a series active power filter is proposed. Data can be used not only when a filtering is needed but also when both a filtering and stabilization of the voltage is required.

6. ACKNOLEDGMENT

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