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Parallel Active Power Filter using A Resonant Converter

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***Abstract**— The paper deals with a new concept for a parallel active power filter, which uses a converter with a resonant intermediate circuit. The described active power filter is connected in parallel to the power supply network. Such a connected parallel active power filter compensates for unwanted current harmonics of the supply network generated by nonlinear electrical consumers. Since the switches of the active filter with a resonant converter operate at zero-voltage switching moments, some disadvantages of the previously used hard-switching converter are suppressed. This concept brings advantages both by significantly reducing switching losses and, compared to conventional types of active power filters, by a lower level of electromagnetic interference. The presented results – outputs of computer simulations in the PS pice program – form the basis for the practical implementation of a physical model of a parallel active power filter with a parallel resonant intermediate circuit.*

***Keywords**— Data compression, Huffman coding, LZW, FFT, Optical fiber, OptiSystem, Multimedia communication.*

I. INTRODUCTION

Problems caused by the influence of harmonic network current can be varied. "Pollution" of the power supply network by current harmonics most often manifests itself through increased losses in components in distribution systems caused by the skin effect in conductors, increased iron losses in transformers, malfunctioning of control systems, the occurrence of unwanted resonances, electromagnetic radiation into telecommunications systems, deformation of the power supply voltage waveform, undesirable changes in power factor, thus disrupting the electromagnetic compatibility of electrical systems. The paper deals with the implementation of soft switching in the application of a parallel active power filter, which is intended especially for compensating the feedback effects of nonlinear and unbalanced loads powered from the distribution network. The parallel active power filter performs current harmonic correction by injecting the same spectrum of currents. harmonics, but with opposite phase. In our solution, the parallel active power filter contains a converter with a resonant intermediate circuit, which generates suitable voltage pulses for harmonic compensation, whose magnitude and polarity create the necessary compensating current on the coupling inductance relative to the connection point of a nonlinear load. A filter designed this way then operates, for example, with linear current control, PWM regulation, or hysteresis control. To achieve correct operation of the control circuits, most methods require the use of a very fast system with a digital signal processor (DSP) and fast A/D converters. In the presented type of application, a special hysteresis control is used, because the converter is implemented in the structure of a new type of parallel active power filter. It must be synchronized with the operation of the resonant intermediate circuit. The resonant circuit is placed between the direct current (DC) source and the power switches of the converter's three-phase bridge. The disadvantages of a conventionally hard-switched converter (the power switches are exposed to voltage stress from overvoltage pulses, and the switching losses of the device increase linearly with the switching frequency) are minimized because the power switches of the filter converter are turned on and off at zero-voltage points, and the slope of the transient edges is significantly lower. The resonant intermediate circuit is identical to that of a class E inverter type. The addressed parallel active power filter, which contains a converter with a resonant intermediate circuit, is a new solution option for parallel active power filters. This filter can be used to compensate for a large group of nonlinear devices in both AC and DC networks.

II. FILTER CONCEPT, PRINCIPLE OF OPERATION

The parallel active power filter analyzes the actual current of the power grid in real time. Signals of the network currents, and possibly voltages, are measured, evaluated, and digitized for further processing.

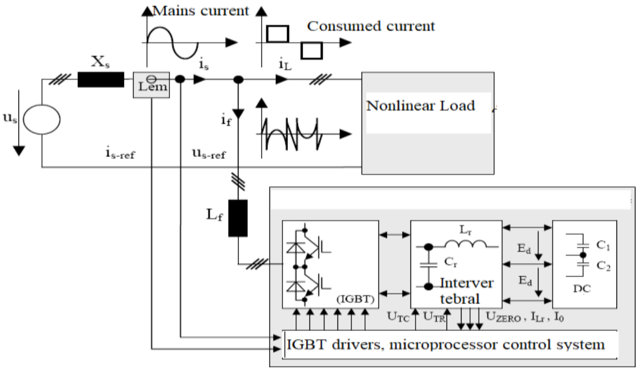

Fig. 1. Parallel active power filter using a converter with a resonant intermediate circuit.

The basic circuit concept of a parallel active power filter, which uses a converter with a resonant intermediate circuit, is shown in Fig. 1. A nonlinear load can generally consist of a parallel connection of a larger number of nonlinear devices. To achieve sufficient compensation of current harmonics at any moment during the period, the instantaneous value of the resonant pulse voltage at any moment must be greater than the instantaneous value of the AC voltage (including its amplitude) in the compensated phase of the power network.

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In the practical implementation of the physical filter model, a high-performance control system with a signal microprocessor will be used for this purpose. This control system must be capable of performing, during the resonance pulses generated in the intermediate circuit by the Lf and C f elements, not only calculations of the magnitudes of instantaneous values of phase compensation currents, but especially the calculation of the optimal magnitude of the initial energy of the resonance pulse depending on the magnitude of the compensation current. For proper operation, the resonant intermediate circuit must function in such a way that unnecessary energy losses in the resonant elements of the intermediate circuit are avoided, while ensuring completely stable operation, i.e., preventing the damping of the resonance pulses of the intermediate circuit and thereby avoiding the termination of the soft switching of the converter. The output of the IGBT power switches connected in a voltage inverter bridge consists of resonant voltage pulses, whose maximum value is limited by the so-called clamp circuit (see Fig.2). These pulses induce, at individual discrete moments, the required compensating filter currents if in the output filter inductors Lf. In this way, the compensating spectrum of currents is created.

harmonics, which have an opposite phase compared to the individual order harmonics of the current generated by the load. The basic effect of using a filter is thus the elimination of the observed current harmonics generated into the power grid, ideally resulting in a purely sinusoidal current waveform drawn from the grid.

III. CIRCUIT CONCEPT OF THE RESONANT INTERCIRCUIT.

The following figure (Fig. 2) shows the overall concept of the resonant intermediate circuit solution using a circuit for limiting resonant voltage pulses, the so-called clamp circuit. This active clamp circuit limits the value of resonant voltage pulses to the required voltage level. The result of the proper operation of the active clamp circuit is shown in detail in Fig. 3. Without the use of the active clamp circuit function, or in the case of its deactivation, the peak values of resonant voltage pulses can theoretically reach twice the voltage of the DC energy source of the filter (DC source, see Fig.2).

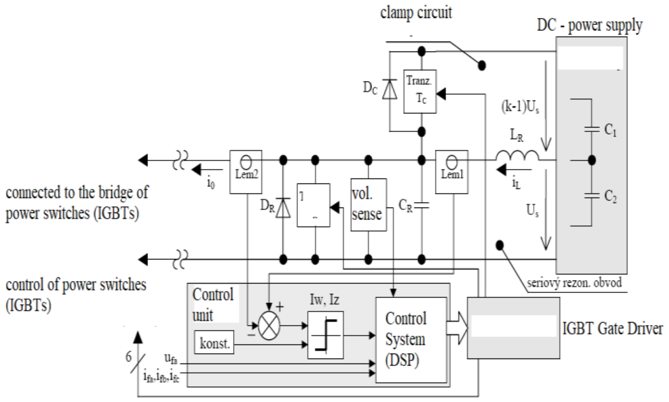

Fig. 2. Block diagram of the circuit concept of the resonant intermediate circuit solution.

An important factor of an active clamp circuit is the so-called clamp coefficient k, which is closely related to the so-called tank period Tk and the value of the resonant frequency $\overline{w_0} = \sqrt{LC}$.

$$\frac{f_0}{f_k} = T_k w_0 = 2\left[\cos^{-1}(1-k) + \frac{\sqrt{(2-k)}}{k-1}\right] \tag{1}$$

It is clear that for a constant value of the factor k and the period time Tk, the parameters of the resonant intermediate circuit can be determined. Thus, for an unchanged value of k=1.5je.

$$\mathrm{T_k} = 7.65\sqrt{\mathrm{LC}} \tag{2}$$

The limiting circuit plays a very important role during the four-quadrant operation of the converter, when the load current reverses polarity, i.e., when the average current through the freewheeling diodes of the switching bridge is greater than the current through the IGBT switches. The capacitor of the limiting circuit is charged by this current. If this condition is not managed, it could lead to an excessive increase in the voltage in the DC link and, consequently, to excessive amplitude of resonant pulses. To ensure sufficient stability, the C1 capacitor of the limiting circuit must have a corresponding circuit capacity, if applicable, must be supplemented with a circuit for conversion or dissipation of its energy.

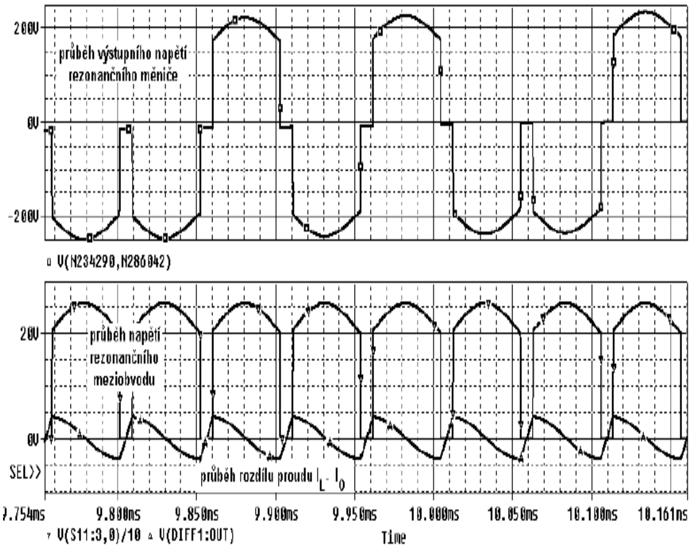

Fig. 3. Voltage and current waveforms in the resonant intermediate circuit.

(Fig. 3) above shows the voltage and current waveforms in the resonant tank. At the top is the waveform of the output resonant voltage pulses of the converter filter. The polarity of individual pulses is determined by the requirements of the control system. The moments of zero voltage in the resonant tank are very clearly visible. In the lower part of the figure, both the periodic waveform of the voltage across the resonant capacitor CR (for clarity, its scale is adjusted to 1:10) and the periodic waveform of the current difference IL - I0 are shown. Information about this differential current value is provided to the control system, which sets the maximum and minimum values of the resonant current.

IV. RESULTS ACHIEVED FROM SIMULATIONS.

For the analysis of the task using computer simulations, the PSpice simulation program version 9.0 was used. Figure 4 shows the waveforms obtained from the simulation of the parallel active filter. At the top, we can see the waveform of the input current i_L to the compensated device with an undesirable nonlinear current draw from the power supply network (harmonics: $I_1 = 0.8A$; $I_3 = 0.2A$; $I_9 = 0.2A$). In the middle, the compensated waveform of the phase current from the power supply network is shown. At the bottom, the waveform of the filter's output current is presented.

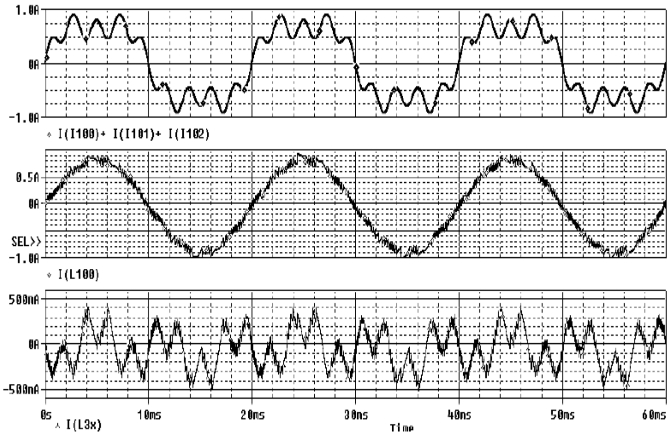

Fig. 4. Waveforms obtained from the simulation of a parallel active power filter using a converter with a resonant intermediate circuit.

In the next figure (Fig. 5), there are analogous waveforms for a different spectrum of nonlinear load. At the top, the waveform of the input current I_L into the compensated device with undesirable nonlinear current draw from the power network is shown (harmonics:
($I_1 = 0.8$ A; $I_3 = 0.2$ A; $I_9 = 0.1$ A). In the middle, the compensated waveform of the phase current of the power network is displayed. At the bottom, the waveform of the output current of the filter is shown.

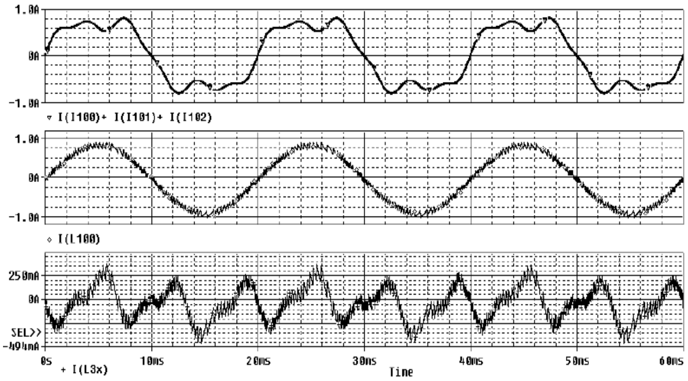

Fig. 5. Waveforms obtained from the simulation of a parallel active power filter using a converter with a resonant DC link.

(Fig.6) shows the simulation waveforms in the individual phases. At the top, the waveform of the input current in phase U to the compensated device is shown, as well as the waveform of the compensated current in phase U of the power supply network. Below, analogous waveforms of the remaining phases are presented.

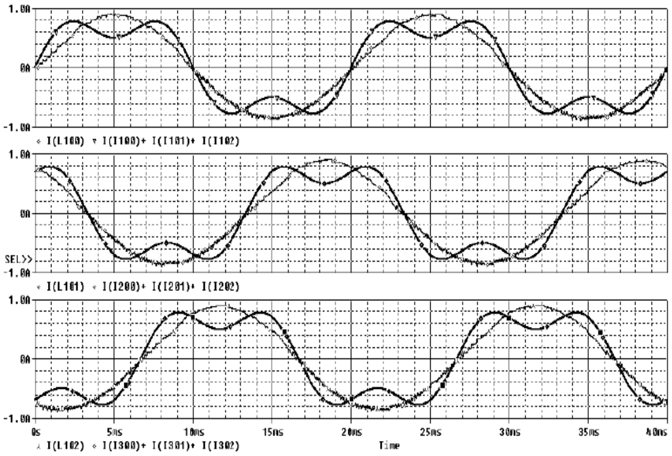

Fig. 6. Currents of the three-phase system obtained by computer simulation of a parallel active filter.

V. CONCLUSION

The equipment and applied technology described in this paper demonstrate new possibilities for addressing the correction of unwanted current harmonics in the power supply network with increased efficiency. The principle of operation of a parallel active power filter with a converter featuring a resonant intermediate circuit was presented in detail here. The presented simulation results confirm the correct choice of the circuit concept of the resonant circuit and its implementation within the filter structure, and thus also its practical feasibility.

the aforementioned filter as a whole. The simulated circuit structure was assembled as a simplified model, but even under this condition, it is absolutely necessary to use a high-performance computer for the simulation calculations. The presented concept offers general advantages of applying a resonant converter, which include both the reduction of energy losses and better compatible properties. The upcoming practical implementation will be based on the results of computer simulations that were presented here.

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