A method for controlling a resonant-mode power supply and a resonant-mode power supply with a controller

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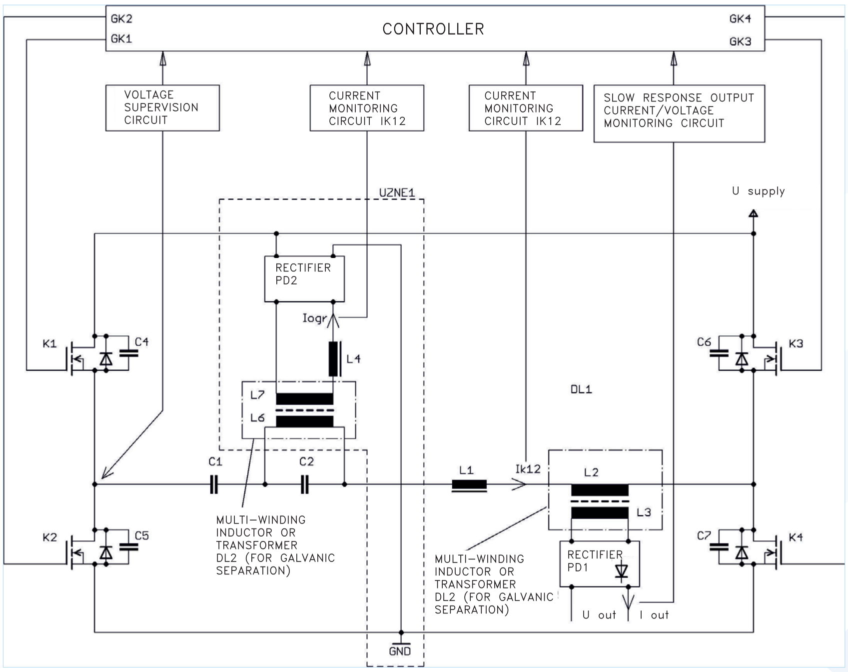

Fig.1 Example of a resonant-mode full-bridge power supply with a controller, incorporating the multi-winding inductor L1 and quality factor limiter DL2

The subject matter of the invention is the method for controlling a resonant-mode power supply and the resonant-mode power supply with a controller intended for the output voltage, current or power stabilization. An advantage of the invention is the possibility of achieving a very high energy efficiency as well as good stabilization of output parameters over the entire load range, i.e. from the open to shorted output, including transient states. This is achieved by maintaining the current continuity in the resonant circuit irrespectively from the load and ensuring that switches are switched at the quasi-optimal point. An additional advantage is the improved dynamic response to load changes which is particularly significant where fluctuating loads or loads with enhanced functional requirements are to be supplied. The proposed method is characterized by monitoring the current in the quality-factor limiter circuit and sequential cycle-stealing of the resonant circuit self-oscillation full cycles by way of shorting some of the switches and turning them on again at the instant when the current passing through these switches is negative or zero.

The technology

The new method for controlling a resonant-mode power supply based on the controller (S) is characterized, among other things, in that for the purpose of output voltage or current stabilization it utilizes frequency control comprising at least two loops: a slow-response loop with response time (τ_1), receiving control signals from the output voltage or current monitoring circuit (UMW), and a fast-response loop with response time (τ_2), receiving control signals from the fast-response monitoring circuit (UMP1) of the recirculation circuit (UZNE1) current (Iogr), while $\tau_1 >> \tau_2$. In the simplest case UMP1 is a comparator that responds to exceeding a threshold value by the quality-factor limiter current (Iogr), enables fast reaction to undesired transients and protects the power circuit components against overvoltages.

In a more complex version, e.g. for large-power systems operating under heavy loads, the output voltage or current are stabilized by means of the controller (S) by way of adjusting the switching frequency, whereas at light loads the output voltage or current are stabilized by means of sequential cycle-stealing of the resonant circuit self-oscillation full cycles by way of shorting a part of the switches (e.g. K2 and K4) and turning the remaining switches off (e.g. K1 and K3) and, after a certain time, turning the inverter and switches on again at the instant when the current passing through these switches is negative or zero. The path for the resonant circuit current is therefore closed and due to a high quality factor the resonant circuit maintains current circulation in its circuits over a relatively long time, oscillating with its natural resonance frequency. When the voltage across the output capacitor/filter drops, the inverter is started again in order to supply energy to the load.

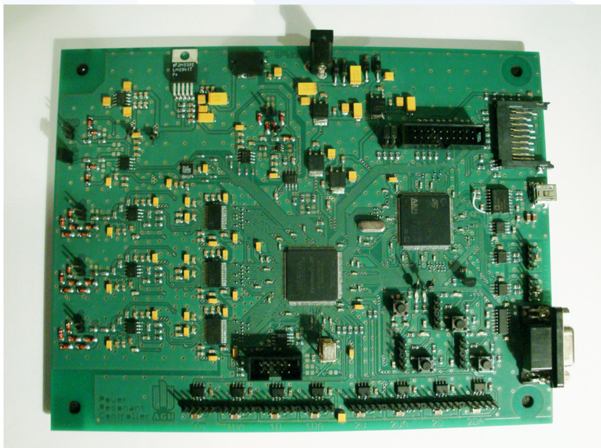

Fig.2 Exemplary prototype of a resonant-mode power supply controller.

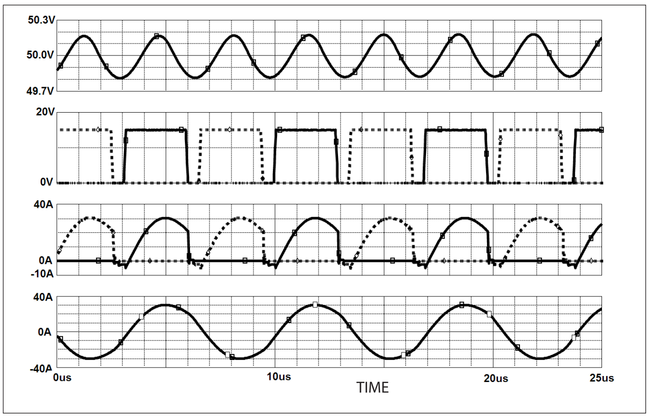

Fig.3 Current and voltage waveforms taken from an exemplary resonant-mode power supply (see Fig.1) for nominal load. The first plot from the tops shows the output voltage. The second plot represents the gate drive voltage of the high-side transistor K1 (solid line) and the gate drive voltage of the low-side transistor K2 (dashed line). The third plot shows the drain currents of K1 and K2 transistors respectively. The bottom plot shows the current in L1 inductor.

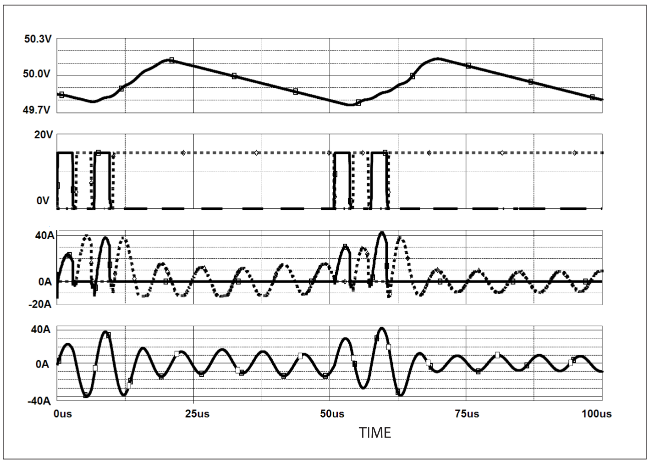

Fig.4 Current and voltage waveforms taken from an exemplary resonant-mode power supply (see Fig.1) for light load (c.a. 20%). The first plot from the tops shows the output voltage. The second plot represents the gate drive voltage of the high-side transistor K1 (solid line) and the gate drive voltage of the low-side transistor K2 (dashed line). The third plot shows the drain currents of K1 and K2 transistors respectively. The bottom plot shows the current in L1 inductor.

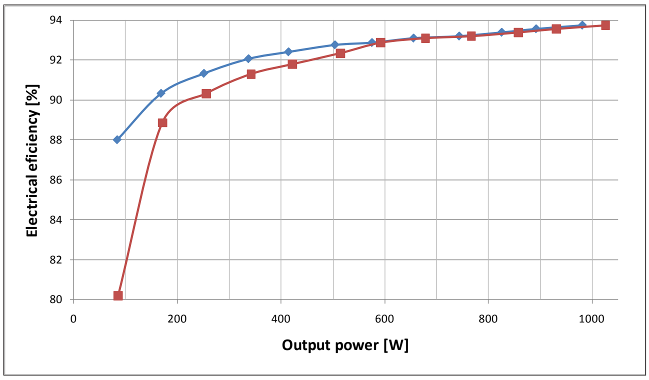

Fig.5 Typical plot of efficiency as a function of output power for resonant-mode power supply controlled through frequency modulation (red line). The proposed new control method increases the efficiency (blue line). As an example a 1kW LLC type resonant-mode power converter was selected.

Main benefit

The main benefit of the invention application is increasing the energy efficiency of resonant power-conversion systems, particularly at light loads, as shown in figures below.

This is achieved by ensuring that switches are switched at the quasi-optimal point, and there also are no dynamic losses associated with switching because when power demand is low transistor switches are turned on off or in an appropriate sequence.

Further advantageous features of the proposed solution are quality-factor limiter circuits that in transient states are feeding excess energy from the resonant circuit back to the supply source in an almost lossless manner while maintaining sinusoidal current in the power system. This provides a hardware protection of the resonant-mode power supply against overvoltages.

The fast-response monitoring circuit (UMP1) of the recirculation circuit (UZNE1) current (Iogr) enables detection of undesired operating areas and limiting the power circulating in the circuit: supply source ↔ resonant circuit. Thus quality-factor limiter circuits can be designed so that they transfer only a small fraction of the main resonant circuit power and therefore be relatively cheap.

Moreover, the solution enables operation with continuous current in the resonant circuit and quasi-sinusoidal waveforms irrespectively from the load. That results in low emission of both conducted and radiated disturbances, as well as improved dynamic response to sudden changes of load.

Proposal

A method for controlling a resonant-mode power supply and a resonant-mode power supply with a controller is protected by a patent. The University of Science and Technology, Krakow offers:

- Nonexclusive licence for the technology in selected areas of application;
- Services within the scope of the technology adaptation to the customer needs, in collaboration with the patent authors.

Interested persons are kindly requested to contact with:

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