Current Source LCC Resonant Converter for an EDM Power Supply

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In this paper, the design of a low size power supply prototype for Electrical Discharge Machining is presented. The system is a dc to dc LCC resonant converter whose switching frequency is tuned at the natural resonant frequency where the converter tends to act as a current source. In this way, two effects are achieved: 1) the necessary over-voltage, first to ionize the dielectric and then to establish the electric arc is generated and 2) a constant current is supplied during the erosion of the workpiece, providing the circuit with inherent protection under short circuit conditions. The output voltage is intended to be adjusted by an external system that controls the gap distance.

Electrical Discharge Machining (EDM) is an electrothermal process. EDM uses an electrode positioned at a fixed small distance (spark gap) above the workpiece, both submerged in a dielectric fluid. A pulsating dc power supply or EDM generator applies voltage pulses between the electrode and workpiece, generating sparks or current conduction through the gap. Each spark results in localized heating that melts a small area of the workpiece surface.

Traditional EDM power supplies convert the energy at low frequency, directly from the utility line and they are able to deal with a wide spectrum of output power. The EDM power supply must achieve high voltage to generate the spark and large current to maintain the ion column. To achieve this, large and heavy transformers and inductances are required.

Our proposal uses the characteristics of power mosfet devices and resonant converters to achieve a compact solution to be applied in field machining to provide maintenance and repair services to nuclear or traditional power plants or any industrial plant. EDM is an adequate technique to perform machining tasks in nuclear plants because it does not produce chips that could cause damage to reactor components. In EDM, micron size particles are immediately flushed away with the dielectric fluid. In addition, it is ideally suited for underwater applications.

The proposed solution for the EDM requirements is a full-bridge LCC resonant converter operating at a switching frequency of 200 kHz, used as a current source.

Resonant converters have well-known advantages for high frequency dc to dc power supplies because they result in small size, light weight and highly efficient systems since high frequency operation minimizes the size of the magnetic components.

LCC resonant converters are able to achieve the required voltage for the dielectric breakdown, and working above the resonant frequency, current lags voltage so this topology achieves zero voltage switching, that is, transistors turn on at zero voltage, resulting in minimum switching losses.

The full bridge configuration has been chosen because of its capability of converting high power.

As the continuous change in the gap distance may lead to load changes from open to short circuit conditions, the resonant inverter is designed as a current source to provide the system with inherent protection under short circuit conditions. The open circuit fault must be limited by an over-voltage protection.

The design sequence of the LCC resonant inverter is oriented to achieve the dielectric breakdown and current stabilization while limiting maximum stress on the components by design.

A control circuit has been developed to establish the switching frequency of the resonant inverter slightly above $\omega_0$ to fix the desired output current during the on-time. During the off-time, the power switches turn off. It should be noted that the behavior of the LCC inverter is highly dependent on the load except if, for current source operation, the switching frequency is $\omega_0$ and, at this frequency, the inverter is designed to supply the nominal output current.

The logic of the control circuit is implemented by means of a CPLD, which allows easy modification of the design. This control circuit, clocked by a 20 MHz crystal oscillator, provides the driving signals to the power mosfets at the desired frequency. If the over-voltage protection is activated during the on-time, the power mosfets are turned off until the next machining pulse. The control circuit operates in open loop because the practical tuning of $\omega_0$ is good enough, the control circuit is greatly simplified and the control signals are not perturbed by the power section.

Some prototypes have been designed based on the techniques presented in this paper. First, the performance of the inverter was verified, the results confirm stable behavior under the control criteria of the inverter working at high frequency at the constant current operating point. The latest prototypes include the transformer and the output rectifier. At present, preliminary results on the EDM system have been obtained. Results of the dc-dc converter and the results of the EDM system are presented.

The performance of a practical implementation of the converter has been verified by loading the circuit with: 1) the nominal resistance that models the arc, 2) a resistance that models an overload of 50% and 3) under short-circuit conditions. First experiments have been carried out on an EDM system and the prototype of the LCC converter has been proved to be well suited to fulfill the EDM requirements with the addition of further performances regarding efficiency and current stability under very irregular load conditions. Further work is in progress to characterize the resulting EDM process parameters such as metal removal rate, surface finish and electrode wear.