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Design and Development of Electromagnet Power Supply for Burst Mode Repetitive High Power Microwave Sources

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Abstract

Single frequency High-power microwave sources like Backward Wave Oscillator, Relativistic Magnetron etc., require a high magnetic field of about 1T to 4T for efficient operation. Single-shot HPM systems usually consist of pulsed magnetic systems. However, for repetitive HPM generation, a continuous magnetic field is required. To obtain a continuous high magnetic field in the required volume usually three solutions are worldwide preferred i.e., permanent magnet, DC electromagnet with cooling arrangements and superconductor-based magnetic coil. All these three systems are bulky, expensive and technologically demanding. In this paper, a novel power supply has been suggested that discharges a charged capacitor through a magnetic coil keeping the discharging current constant for a small period like hundreds of milliseconds to a second. An IGBT switch is used to discharge the capacitor[1]. The duty cycle of the IGBT switch is controlled using a current feedback signal from the hall sensor, thus keeping the current steady at a preset reference value. An experimental set-up has been developed using a 300mF capacitor. A constant current up to 500A is achieved for 200mS. This system is scalable. For a longer duration of operation, more capacitor modules need to be added. Details of design, development and experimental results are presented in this paper.

Keywords: Backward Wave Oscillator, High Current, High Magnetic Field

1. Introduction

High power microwave finds various applications for strategic and non-strategic purposes. Devices like magnetrons, vircators and backward wave oscillators are widely used for HPM generation. In magnetron and backward wave oscillators high magnetic field is required to guide the relativistic electron beam to traverse through a specified path so that the energy of the electron beam can be extracted efficiently in the form of a high-power microwave[5]. In this article, a novel approach is adopted to develop a high current, a few hundred milliseconds (up to 1000mS) duration power supply for a high flux magnetic coil (approx 0.7T). This high-current power supply is designed to deliver a maximum of 500A current for 200mS. Since, the operation of a backward wave oscillator requires a high voltage pulse of (500-700 kV) of 80-100nS duration and a magnetic field of 0.7-1T for ≤100nS for single-shot operation, this power supply can support the repetitive operation of backward wave oscillator.

2. Circuit Topology and Design

This power supply consists of a single-phase rectifier, capacitor bank (300mF, 450V), IGBT switch (1.2kV, 800A), microcontroller-based switching control unit and a current sensing device for feedback and diagnostic purposes. The capacitor bank is a parallel combination of 20 nos. of 15mF, 450V electrolytic capacitor which is charged initially through a resistor and after a certain time, this charging

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resistor is passed using a timer and contactor so that the bank can be charged at a faster rate. An Arduino board (UNO Atmega 328P) is programmed to generate switching signals for the IGBT switch. Output current is measured by a hall sensor (1000A/200mA sensitivity) and also provides feedback to the microcontroller. For the controlling, a simple ON/OFF technique is used by comparing the feedback to the set value. Since the 0-5V range signal can be fed to the controller as an analogue input, the output current 0-500A is scaled in the 0-5V range by using suitable resistors and fed to the controller. The most vulnerable part in this circuit is the IGBT switch and due to the high rate of hard switching at higher power the switching losses can be significant to affect the device performance or even damage in certain conditions may occur[2]. Hence an appropriate capacity heat sink is used to dissipate the excessive heat. Switching at a high current also causes re-striking reversal voltage across the IGBT, which is suppressed by applying a suitably designed RC snubber circuit across the collector-emitter terminal of the IGBT. A schematic of the electrical circuit of the power supply is given in Figure 1. The load is an electromagnetic solenoid coil of 10 mH with 130 mΩ internal resistance.

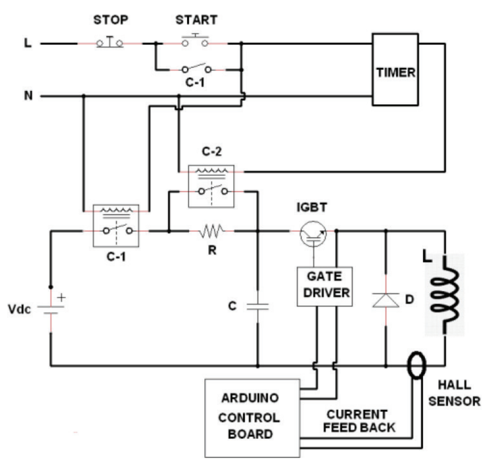


Figure 1. Electrical circuit.

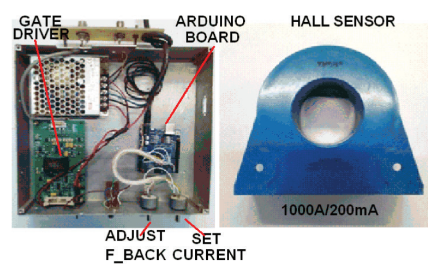
3. Experimental and Theoretical Details

The development of this power supply aims to pump a high value of constant current into an inductive load. However, the given load cannot be purely inductive and some internal resistance is always associated. This internal resistance of inductive load causes loss of electrical energy in the form of heat and decides the duration of a certain amplitude of current will sustain for how long time for the stored energy in the capacitor. Theoretically, the constant current duration is given by Equation (1).

$$\tfrac{1}{2}CV^2 = i^2 R_{coil}\, t_p + \text{switching losses} \qquad (1)$$

where, C is the total capacitance of the bank, V is voltage charged, i is current in the coil, R_{coil} is internal resistance of the coil and t_p is current flowing duration.

Since hard switching of IGBT is done at high current, switching losses can be significant but for a short duration (≤1000mS) it is manageable by proper heat dissipation. During the operation, due to switching, a high level of EMI noise is produced and this causes disturbance in the measurement of current as well as feedback signal. To overcome this a metallic container is used to house the capacitor bank and IGBT, while the control circuitry and gate driver are also kept inside another metallic box and sufficiently remote from the noisy environment. The measurement of current and feedback employs a non-contact method by using a hall sensor. A freewheeling diode is connected across the inductor to provide a conducting path to the reversal current from the inductor, resultantly a unidirectional current flows through it. Figure 2 presents the controls, gate driver for IGBT and hall sensor for current measurement. The developed power supply is given in Figure 3 with capacitor bank-1. In Figure 3 an additional capacitor bank-2 of 420mF is given. Since the system is under development, this bank will be connected in parallel with the existing and experiments will be performed in future.



(a) (b)

Figure 2. (**a**) Microcontroller board and IGBT gate driver. (**b**) Hall sensor.

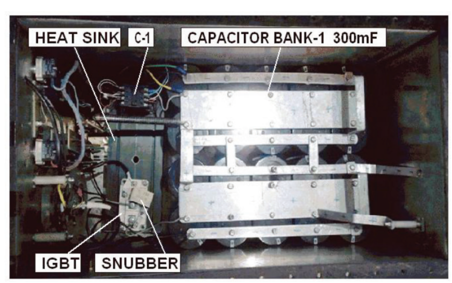


Figure 3. Experimental setup of power supply.

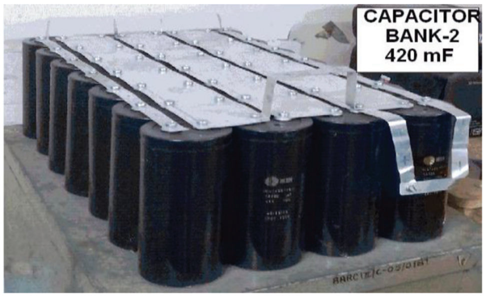


Figure 4. Additional capacitor bank of 420 mF.

4. Experimental and Simulation Results

The circuit is simulated for the given parameters and the result is compared with the experimental. The simulation result is given in Figure 5 and the experimental result is in Figure 6. The capacitor bank is charged up to 200 V and discharged through the inductor of 130 mΩ resistance and the current is measured. It is found that the duration of current in simulation is 50 mS greater than observed in the experimental with the same circuit conditions. This difference is due to the switching and other losses in the practical circuit which are not present in the simulation components. In both results, the drawn current is approximately 500 A.

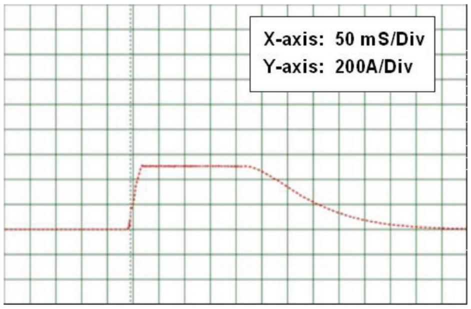


Figure 5. Simulation output current, 500A, 250mS.

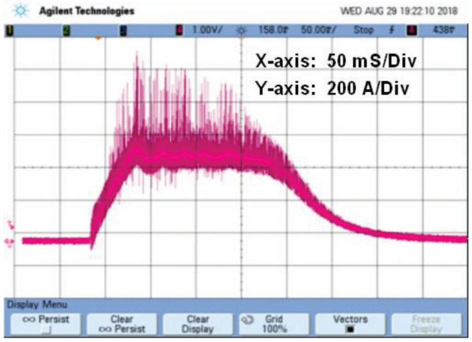


Figure 6. Experimental output current, 500A, 200mS.

5. Conclusion

The topological circuit of the power supply is simulated and compared with the experimental result. Experimental observations give a good closeness to the theoretical and simulation outcomes. Hence it is concluded that the topology and approach adopted have a reasonable practical validation and by increasing the input stored energy and circuit components rating a larger amount of current can be drawn for an extended time duration. Resultantly, this power supply can be applied to feed high current to the electromagnetic coil for high-power microwave applications in repetitive mode.

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7. References

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