DESIGN AND DEVELOPMENT OF BIPOLAR 4-QUADRANT SWITCH-MODE POWER CONVERTER FOR SUPERCONDUCTING MAGNETS

Yashwant Kumar, S. K. Thakur, M. K. Ghosh, T. P. Tiwari, Anirban De, S. Kumari, S. Saha
Variable Energy Cyclotron Centre, Kolkata-700064, India.

Abstract

A uniform zero crossing magnetic field in a magnet can be achieved by using bipolar power converter with four quadrant operation. A high current bipolar switch-mode power converter (rated ±27 $V_{max,}$ ±7V flat top, ±300A, 100ppm) has been designed and developed indigenously at VECC Kolkata. Four quadrants operation is accomplished by using power IGBTs in an H-bridge configuration with switching frequency around 20 kHz. The switch-mode power converter is used because of high dynamic response, low output ripple, high efficiency and low input current harmonics. In this paper, circuit topology, function of system components and key system specifications of high current bipolar switch mode power converter is discussed.

INTRODUCTION

For the correction magnets, bipolar power supplies (BPSs) are required to produce either polarity of magnetic fields. This power supply is equipped with a passive high frequency filter to reduce the ripple components of output current. Danfysik make DCCT (model-866S) senses the output current and provides a feedback signal to IGBT via PWM controller for the regulation. The current transducer which has high precision and low drift (1ppm) is used.

CIRCUIT DISCRIPTION AND OPERATION PRINCIPLE

Figure 1 shows the schematic diagram of power supply. The H Bridge is constructed of four IGBT switches S_1, S_2, S_3 and S_4. DC voltage of around 40V is derived from three phase transformer followed by full bridge rectifier and LC filters. A set of IGBTs working as switches in H-bridge configuration is employed for regulation. S_1 and S_2, is used for one direction of load current (say positive current), and other set of switches, S_3 and S_4, for the negative portion of the load current. L_m and R_m represent the inductance and resistance of magnet (load). In a typical voltage source converter, the operation principle is same as dc/dc buck converter. For a positive magnet current, switches S_1 and S_2 are closed to deliver power to load for a period of Ton. After the period of $T_{on,}$ the upper switch S_1 is open for a period of T_{off}, while the lower switch S_2 remains closed. When S_1 is opened for T_{off}, the magnet current freewheels through switch S_2 and diode D_3. For negative magnet current switches S_3 and S_4 and diode D_2 are operated in a symmetrically opposite manner.

This is to point out that for ac operation there is an additional mode of operation. For positive di/dt, it is operated in same manner as dc operation explained above. In order to increase the magnet current, the ON time of upper switch S_1 and S_4 is longer than the OFF time (i.e. $T_{on}>T_{off}$). For negative di/dt (in order to decrease magnet current), the OFF time of the upper switch is more than ON time (i.e. $T_{off}>T_{on}$). It is point out that even with 100% off time (i.e. S_1 completely OFF with S_2 ON), the magnet current does not decay fast enough to follow the reference signal due to large time constant of the magnet. Therefore, it is necessary to introduce another mode of operation by opening switch S_2 (S_3). The stored energy of the magnet return the source via diode D_4 and D_3, resulting the faster decay of magnet current.

Note that in this ac operation only upper switch S_1 (S_4) is controlled according to the PWM signal until the magnet current no longer keeps tracking the reference signal while lower switch S_2(S_3) remains ON, and only lower switch S_2(S_3) is controlled while upper switch S_1(S_4) remains OFF. Hence, only one switch is controlled at the time of ac operation.

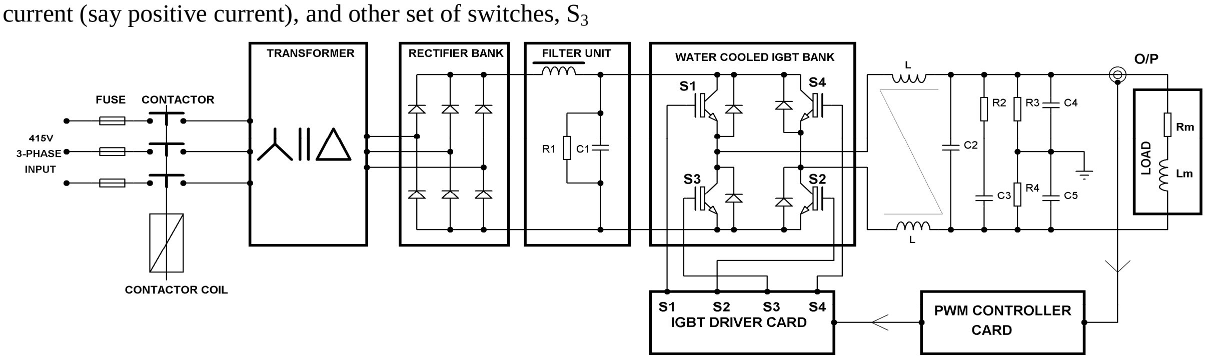

Figure 1: Schematic of Bipolar Magnet Power Supply.

PWM REGULATION SCHEME

The simplified regulator circuit used to generate PWM signals is shows in fig.2. In order to regulate the magnet current, the ramp comparison method and PI controller are used. The magnet current information is fed back to an error amplifier input via a current measuring device (DCCT) as a feed-back signal (I_{fb}). Analogue reference signal, V_{ref}, is set from -10V to +10V corresponding to magnet current -300A to +300A linearly with smooth zero crossing. A polarity signal, which determines a set of switches to be controlled, is derived from error signal by using a comparator. This PWM signal combined with the polarity signal using an AND gate to determine which switch, S_1 or S_4, is to be controlled. A logic low signal, which selects switches S_1 and S_2, is obtained for a positive value. Similarly, a logic high signal, which selects switches S_3 and S_4, is obtained for negative value. The regulation is achieved by pulse-width modulation (PWM) method. Two dual packages Insulated Gate Bipolar Transistors (IGBTs) are used as switching devices due to their ruggedness and simple drive requirement.

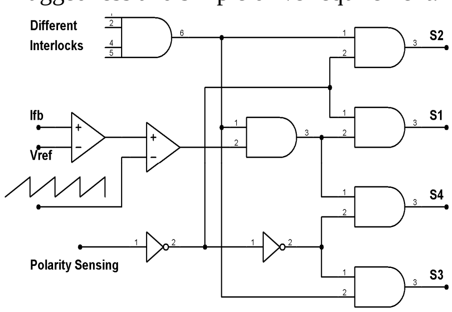

Figure 2: PWM Regulation Scheme.

TEST RESULTS

Figure 3 shows measured wave form of power supply which consists of three wave forms. Channel- 1 shows gate pulse of IGBT, channel- 3 shows V_{CE} pulse of switched IGBTs and channel-4 output ripple ~1V peek to peek.

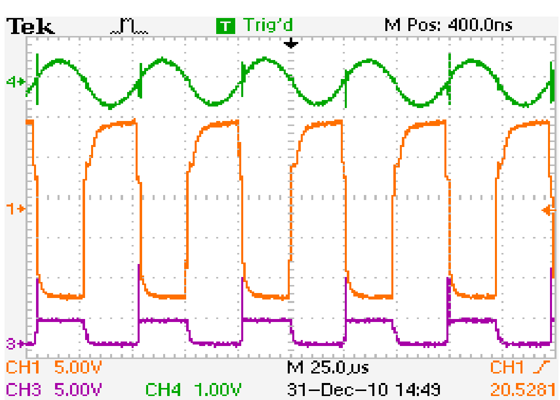

Figure 3: Measured wave form of power supply.

Figure 4 shows stability of power supply for ~ 4-hours with a sudden power dip in between.

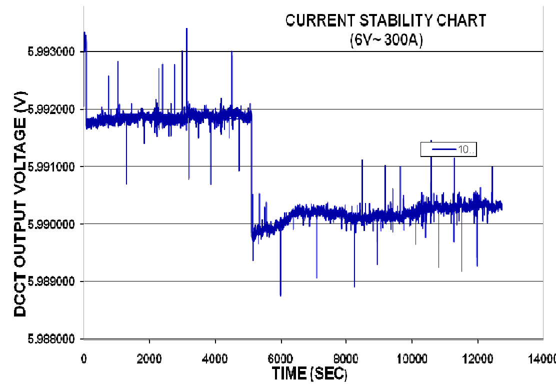

Figure 4: Current Stability Chart.

CONCLUSION

In this paper a current controlled PWM bipolar power supply for a magnet load has been presented. At present analogue PWM controller is designed and power supply operation could be tested at rated current with resistive load. It is planned to replace analogue PWM converter with DSP based PWM converter and power supply will be with actual magnet load shortly.

ACKNOLEDGEMENT

The authors would like to thank each and every Technical staffs of HVPS Section, VECC for their sincere effort for the development and testing of power supplies successfully.

REFERENCES

1) Y.G, Kang "A current-controlled PWM bipolar power supply for a magnet load", Industry Application Society Annual Meeting, 1994, Vol.2p.805.
2) S.H. Jeong, "Design and Implementation of bipolar power supply for correction magnet", Proceeding of FEL 2009, Liverpool, UK.
3) S. Dewan (DPS),"1400A, ±900V Peak pulse switch mode power supplies for SNS Injection kickers", Proceeding of the 2003 Particle Accelerator Conference.
4) Si Fang, "Four quadrant 250 KW switch mode power supply for Fermi lab main Injector", Proceeding of the 1999 Particle Accelerator Conference, New York, 1999.
5) Chen-Yao Liu, "Design and Implementation a switched mode bipolar power stage of the Correction power supply", Proceeding of EPAC 2004, Lucerne, Switzerland.