

1400A, +/- 900V PEAK PULSE SWITCH MODE POWER SUPPLIES FOR SNS INJECTION KICKERS

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Abstract

This paper describes simulation and experimental results for a 1400A, $\pm 900V$ peak rated, switch mode power supply for SNS Injection Kicker Magnets. For each magnet (13 m Ω , 160 μ H), the power supply must supply controlled pulses at 60 Hz repetition rate. The pulse current must rise from zero to maximum in less than 1 millisecond in a controlled manner, flat top for up to 2 millisecond, and should fall in a controlled manner to less than 4A within 500 μ s. The low current performance during fall time is the biggest challenge in this power supply. The simulation results show that to meet the controlled fall of the current and the current ripple requirements, voltage loop bandwidth of at least 10 kHz and switching frequency of at least 100 kHz are required. To achieve high power high frequency switching with IGBT switches, a series connected topology with three phase shifted (0°, 60° & 120°) converters each with 40 kHz switching frequency (IGBT at 20kHz), has been achieved. In this paper, the circuit topology, relevant system specifications and experimental results that meet the requirements of the power supply are described in detail. A unique six pulse SCR rectifier circuit with capacitor storage has been implemented to achieve minimum pulse width to meet required performance during current fall time below 50A due to the very narrow pulse width and non-linearity from IGBT turn-on/off times.

INTRODUCTION

This paper deals with the description, experimental and simulation results of the 1,400A, $\pm 900V$ switch mode converter with six pulse SCR rectifier circuit and storage capacitors. In section 2, the basic converter topology including system parameters is described. The relevant specifications are outlined in section 3. The simulation results are outlined in section 4. In section 5, the experimental results show good agreement between experimental and simulation results both at low and high current values. Section 6 discusses the major conclusions of this research.

BASIC CONVERTER SYSTEM

Figure 1 shows the essential elements of the two-quadrant switch mode converter system. For the function of components with lighter lines, refer to reference 1 for details.

All the essential circuit parameters on Fig.1 are the same as reference 1. Additional components added to

improve low current performance are shown in thicker lines in Fig.1. The function and parameter values of these additional components are as follows;

- DC storage capacitor Cs to provide essentially a DC source of approximately 60V with low ripple to keep minimum pulse width in the IGBT switching modules. The value of Cs is 1.64F.
- DC filter choke La (30 μ H) to reduce the 360 Hz ripple in the six pulse rectifier
- Six pulse SCR rectifier (SCRs, Q1 to Q6) that operates in the inverting region at delay angle $\alpha=135^\circ$.
- An isolating transformer LRT (460:58V) to isolate the load from the 3 phase input

SYSTEM SPECIFICATIONS

This section identifies the significant performance requirements/results for input and output of the pulse converter.

Input

Voltage RMS	460V, +10%, -5%
Current RMS	50A

Output

DC Voltage	0 to 900V, 0 to -900V
DC Current	0 to 1,400A max. Pulsed (400Arms equivalent)
Pulse Repetition Frequency	60Hz
Switching Frequency	108kHz
Large Signal Current Response	> 2kHz at 45° Shift at 1.4kA
Load Current Tracking	See Figure 2
Tracking Error	0.1%
Load Current Fall time	< 0.5msec. from 1.4kA to 4A
Current Stability	
In Flat Top	< 0.1% (1.4A)
Magnet Load	L= 160 μ H, R=0.013 Ω

Note:

1. The linear rise plus the flat top of the current reference waveform varies from 2 to 3 ms and since fall varies from 280 μ s to 1 ms, the worst case pulse width is 4 ms.
2. The fall time for the reference is 280 μ s and the load current falls to less than 4A in less than 500 μ s. Any overshoot on the current waveform shall settle in less than 300 μ s.

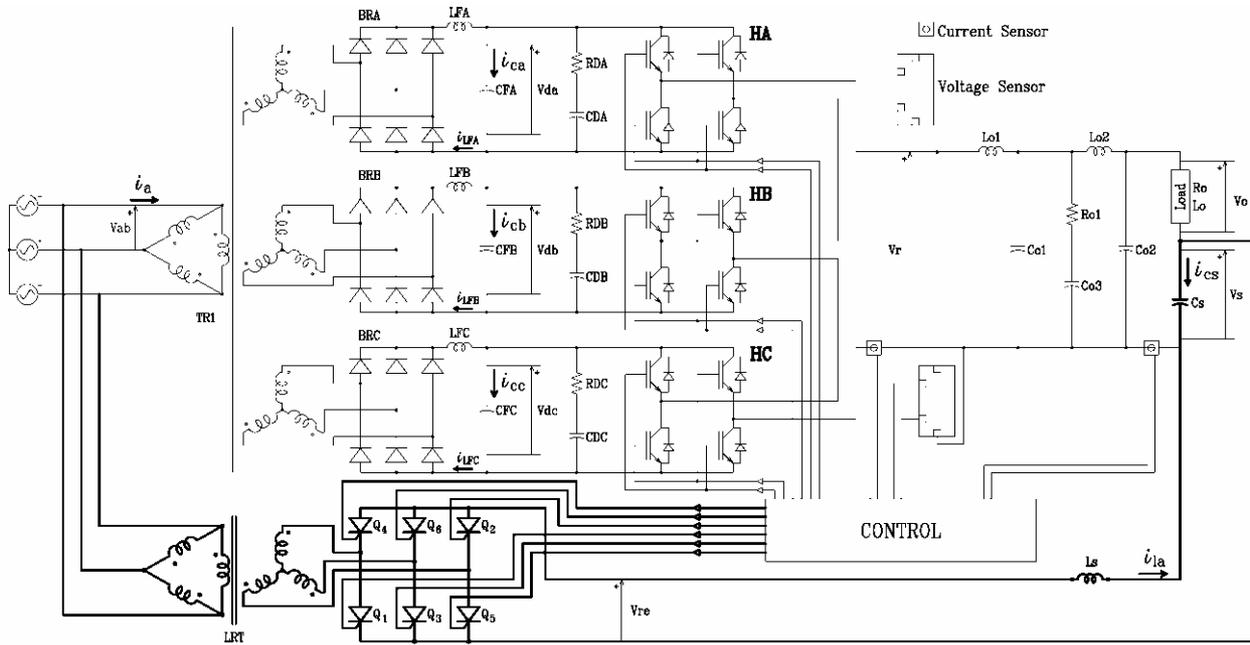


Figure 1 Basic 1,400A, ±900V Converter System with Energy Storage Capacitor CS and Six Pulse SCR Rectifier

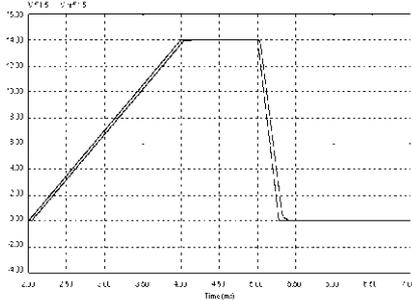


Fig.2 Output current (100A/V) and required output current feedback (100A/V), according to system specifications

angle $\alpha=135^\circ$. The steady state DC storage capacitor voltage (V_s) is 65V with 0.5V peak to peak ripple at pulsing frequency of 60 Hz.

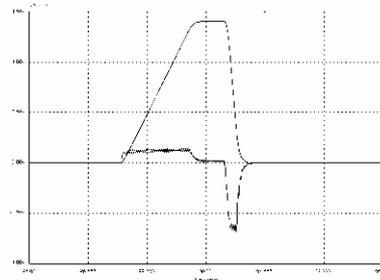


Figure 3 output current i_o (500A/div), and output voltage v_o (500V/div) for rated value of i_o

SIMULATION RESULTS

This section provides the following simulation results (in addition to the simulation results in reference 1):

- i. Figure 3 shows output current i_o , and output voltage (v_o) for rated value of i_o
- ii. Figure 4 shows energy storage capacitor current (i_{cs}) and output current i_o for rated value of i_o
- iii. Figure 5 shows filter inductor (L_a) current (i_{la}) and six pulse rectifier voltage (v_{ro}) for rated value of i_o
- iv. Figure 6 shows output current i_o , and output voltage (v_o) for i_o near zero for rated value of i_o

These results meet the required critical specification close to zero output current. These results show how a minimum DC voltage is introduced in the circuit that absorbs and acts as a DC battery source. A storage capacitor CS only absorbs AC current, DC current (i_{ra}) returns the active DC power to the ac source due to inverter region operation of the six pulse bridge (delay

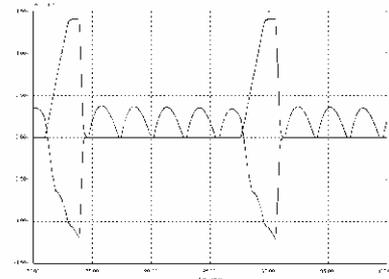


Figure 4 Energy storage capacitor current i_{cs} (500A/div) and output current i_o (500A/div) for rated value of i_o

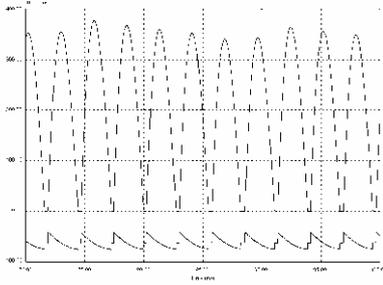


Figure 5 Filter inductor i_{la} (100A/div) and six pulse rectifier voltage v_{re} (100V/div) for rated value of i_o

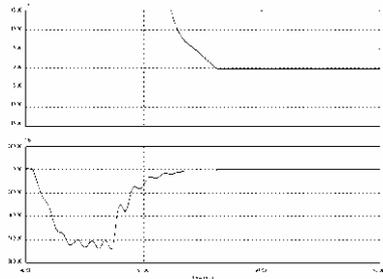


Figure 6 Output current i_o (5A/div), and output voltage v_o (200V/div) for i_o near zero for rated value of i_o

EXPERIMENTAL RESULTS

Experimental results shown in figures 7 to 10 are in close agreement with simulated results in figures 3 to 6.

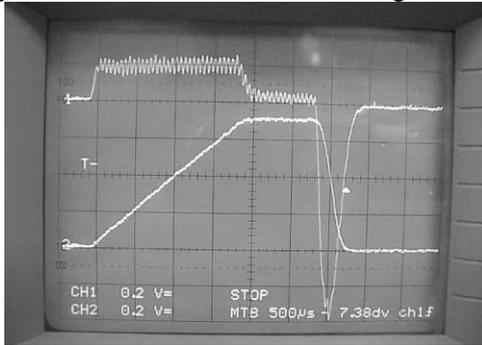


Figure 7 Output voltage v_o (100V/div) and output current i_o (400A/div)



Figure 8 Capacitor current i_{cs} (240A/div) and output current i_o (140A/div)

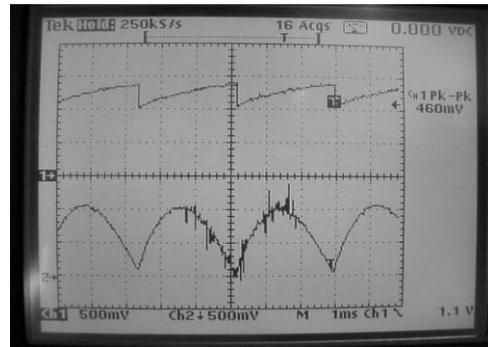


Figure 9 Output voltage of SCR rectifier v_{re} (25V/div) and filter inductor current i_{la} (250A/div)

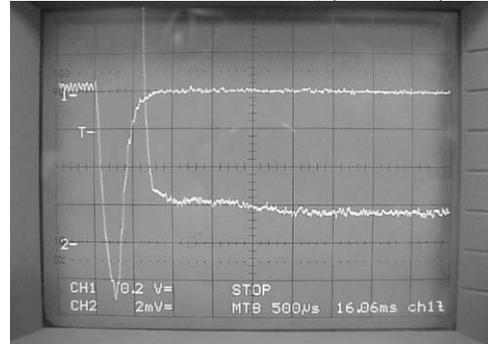


Figure 10 Output current i_o (4A/div), and output voltage v_o (100V/div) for i_o near zero for rated value of i_o

CONCLUSIONS

This paper has discussed the features and results of a high power amplifier. The desired rise, flat top and fall time current results were achieved for pulse magnet current from 1,400A to 4A. The main problems are:

- 1). The peak to peak ripple current at flat top is about 4A (required is 1.4A)
- 2). The current tracking between two similar units should be better than 0.5%. A great deal of simulation work is needed to establish the most sensitive parameters that affect current tracking. Also means must be identified to correct for practical variations in load parameters.

Further modification to the converter circuit and controls to achieve desired ripple and tracking current performance will be presented in a subsequent paper. For any question, please contact

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REFERENCES

- [1] S. Dewan, et.al “ 1.12 MVA Peak Two Quadrant Pulse Switch Mode Power Supply for SNS Injection Bump Magnet,” EPAC’02, Paris, June 2002, pp.2460-2462.