Design of High Load Current Power Supply for Seabed Logging Application

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***Abstract*—Low frequency signal with high load current study is very important for Seabed Logging (SBL) application. SBL is currently an emerging method to find hydrocarbon layer inside the ocean floor. In SBL, a high current with low frequency power supply is needed to assist the transmission process that uses Horizontal Electric Dipole (HED). HED emits electromagnetic signal throughout the seabed layer containing hydrocarbon. This power supply with such capabilities is essential for the transmitter to transmit the signal required to the targeted area and its surrounding, and for the receivers to receive back the signal containing accurate data. In this paper, the processes to design and stimulate a power supply with the required output for SBL application is explained in details.**

***Keywords*— Horizontal Electric Dipole; Seabed Logging; Power Supply; High Current; Low Frequency**

I. Introduction

In seabed logging (SBL) application, the frequently used waveform in transmission process is square wave where the electric dipole transmitter produces maximum current at one polarity for half a period, and switches the polarity for the second half of the period, producing a square wave current waveform. As the square wave source current is at its peak value, it can transfer maximum energy to the subsurface. Another characteristic of the square wave current source is that the frequency domain current amplitudes are proportional to the inverse of the frequency. Therefore, the current amplitudes increase when the frequency decreases [1].

The horizontal electric dipole (HED) used in SBL application is required to emit continuous high current with low voltage waveform at a low fundamental frequency. High current is needed to penetrate deep down to the ocean floor, whilst low frequencies are used to provide sufficient signal penetration to the targets. This is due the electromagnetic 'skin-depth' effect which causes current density to decrease with increasing ocean's depth [2]. Therefore, a power supply that can produce high current with a low frequency output is essential to overcome these obstacles in gaining an accurate data required for SBL application.

A high current load with low frequency power supply for SBL application has to be designed and simulated. The output should be positive DC current for half cycle and negative DC in the next cycle with ± 1000 A amplitude and 5 Hz frequency.

II. Literature Review

A. High Current Low Voltage Converter

The purpose of the circuit designed in Fig. 1 is to have an output voltage varies between 0 and 15 V and currents between 0 and 1000 A of the converter to excite the superconducting corrector magnets in particle accelerators. To achieve the output required with high efficiency, a full bridge IGBT topology featuring zero voltage transition (ZVT) converter with isolation in high frequency is used. As this power source is based on a ZVT converter, it produces high efficiency, small output ripple, outstanding regulation of line, and fulfill the electromagnetic compatibility (EMC) normative.

Based on Fig. 1, a three-phase line acts as the source of energy to the converter. The non-controlled rectifier with input inductors is designed to produce low frequency harmonic regulations. These inductors, together with the output capacitors of the rectifier form a DC filter with 42 Hz cut-off frequency to acquire less than 40 mV ripple audio susceptibility.

The ZVT converter, high current transformer, rectifier and filter form a high frequency inverter section. Phase shifting is carried out in the ZVT converter to achieve power regulation with operating frequency of 35 kHz to balance between the losses and a practical size for the transformer.

As in Fig. 1, the leakage inductance, L_{lk}, which mainly consists on the leakage inductance of the ZVT transformer and an added inductance, is set to 17 mH. This is designed to obtain an optimum relationship between the losses to conduction, the range of ZVT operation, and the electromagnetic interference (EMI) generation.

After the rectifying stages, four transformers with the primaries connected in series with bus-bar of very small resistance, and the secondary is connected in parallel, also with bus-bar of very small resistance are implemented to provide galvanic isolation. For each set of transformer-rectifier stage, the secondary with centre-tapped configuration used high current (400 A) and high voltage (100 V) Schottky diodes with the aim to decrease the losses.

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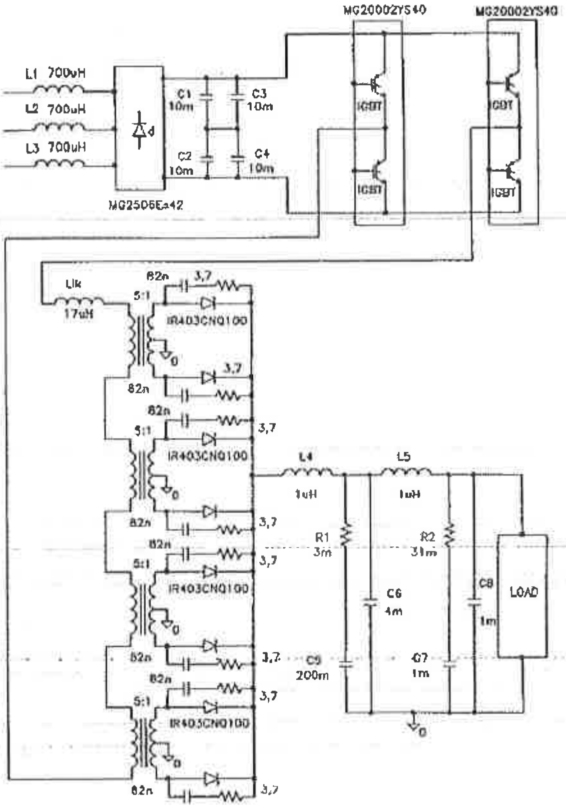

Figure 1. Converter of a High Current Power Supply [3]

In order to damp the parasitic oscillations between the leakage inductance and the capacitance of the diodes, a simple low power RC network is used. Air core inductors and a fourth order filter with cut-off frequencies of 320 Hz and 20 kHz are implemented to retain the switching ripple and the desired levels of electromagnetic interference (EMI).

B. High Current Low Voltage AC-DC/DC-DC Converter

The design in Fig. 2 has the following specifications; three-phase 380 V 50 Hz input voltage, 0-12 V output voltage, 0-1000 A output current, more than 90 % efficiency, and less than 1 % output ripple at full load. In addition, the output current could reach 80000 A, with the efficiency above 90 % by paralleling several modules.

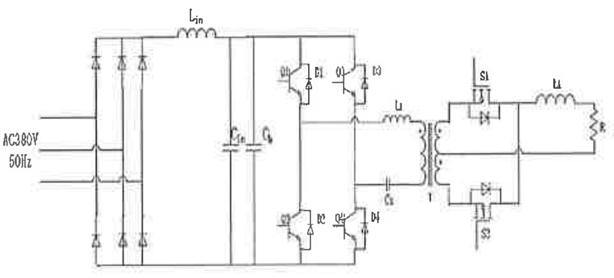

Figure 2. Power Stage of an AC-DC/DC-DC Converter [4]

The AC-DC network of this circuit comprises of a three-phase uncontrolled rectifier and a LC filter, which provides passive power factor correction. In this filter, large capacitor is helpful to reduce the input DC voltage ripple, but it would cause high harmonic component in the ac line current. Therefore, to counter this situation, an inductor is needed.

The DC-DC network is made up of a ZVS phase-shift full bridge with synchronous rectification. An IGBT module with the switching frequency of 20 kHz is used in the high frequency inverter. A nanocrystalline transformer is applied in this design. Synchronous rectification is used instead of the Schottky diode rectification in the secondary side of transformer. No capacitor is connected to the output, as this design is in fact a current source. Moreover, the system is modularized with the aim of producing ultra-high output current along with flexibility for maintenance.

III. METHODOLOGY

In order to achieve the objective of this paper, a procedure summarized in the following block diagram is carried out.

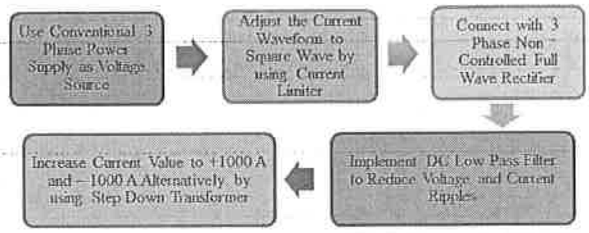

Figure 3. Methodology Flow Diagram

For the fourth method, three phase input supply is connected. The supply voltage and current waveforms are adjusted to square wave by using current limiter. Current limiter also limits the current to the required value. Then, the supply will go through a rectifier to convert the signal to alternating DC signal. After that, a low pass filter is implemented to have minimum voltage and current ripple. The output frequency required is also adjusted here. Last but not least, a step down transformer is used to increase the current value while decreasing the voltage.

A. Transformer Configuration

The basic design for high current low voltage power supply circuit is shown in Fig. 4. First, a three phase power supply with standard ratings, which are 230 V at 50 Hz is used. Then, this supply is stepped down using linear transformers TX1, TX2 and TX3 with 6:1 turn ratio to increase the current.

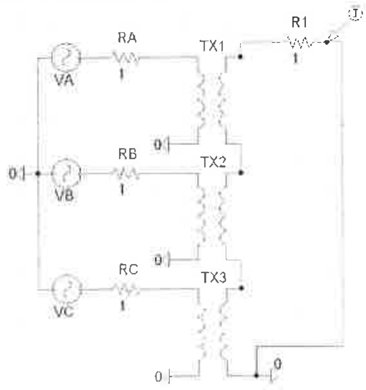

Figure 4. Transformer Configuration

Linear transformer is chosen as it does not change the waveform of the input at the output. This turn ratio is determined and adjusted with the maximum allowable turn ratio in the circuit simulation that will give maximum output current. RA, RB and RC resistors are placed at the supply to avoid short circuit current. The output current waveform of the transformer is observed as in Fig. 5. The step to increase the current by reducing the voltage is completed.

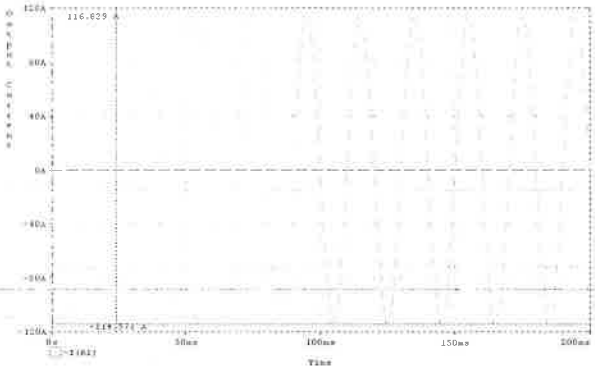

Figure 5. Output Current Waveform from Fig. 10 Circuit

B. Full Wave Rectifier with Low Pass Filter

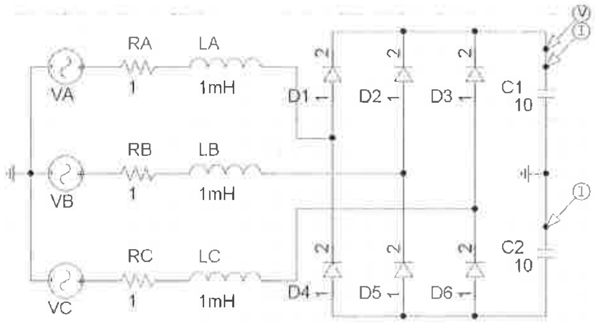

Figure 6. Full Wave Rectifier with Low Pass Filter Circuit

A full wave rectifier is used as it is suitable for very high current, very low ripple outputs with high input voltage applications. From Fig. 6, 120NQ045 Schottky diode rectifier is chosen for this rectifier as it allows up to 120 A current to flow through it, and the output current is rectangular. The rectifier functions as a converter which converts the AC input into DC output. The low pass filter is adjusted to obtain a 5 Hz output current waveforms as shown in Fig. 7 and Fig. 8 respectively.

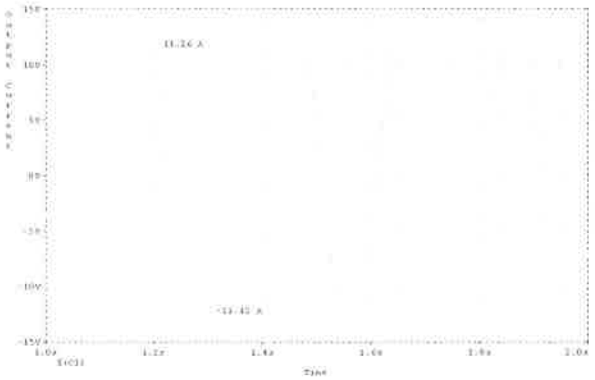

Figure 7. Output Current Waveforms from Fig. 6 Circuit

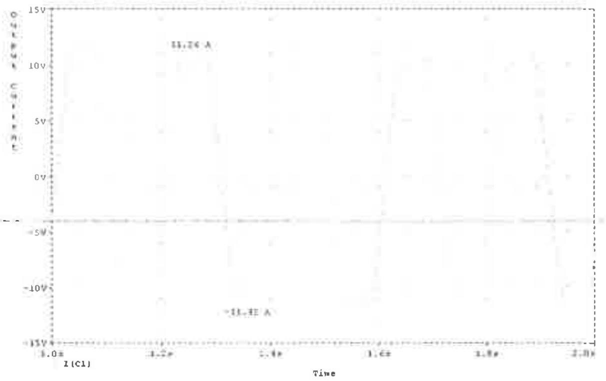

Figure 8. Output Current Waveforms from Fig. 6 Circuit

IV. RESULT AND DISCUSSION

The expected waveform of the output current is shown in Fig. 9. This waveform is used as a target in order to achieve the required output correctly.

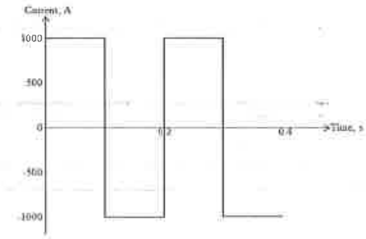

Figure 9. Expected Current Output Waveform

By having correct transformer and full wave rectifier configurations, a power supply with the required alternately positive and negative of 1000 A square waved output is generated. The resulting circuit design is shown in Fig. 10. The transformer is using 6:1 turn ratio and resistors are connected to each supply to avoid short circuit current. Current limiters are placed to limit the current to positive and negative 1000 A, employing a very high gain to produce a near rectangular current waveform. The resulting output current waveforms are shown in Fig. 11 and Fig. 12 respectively.

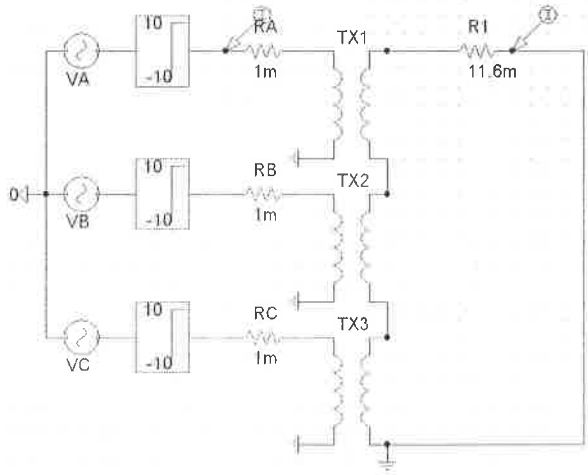

Figure 10. Power Supply with 1000 A Output Current

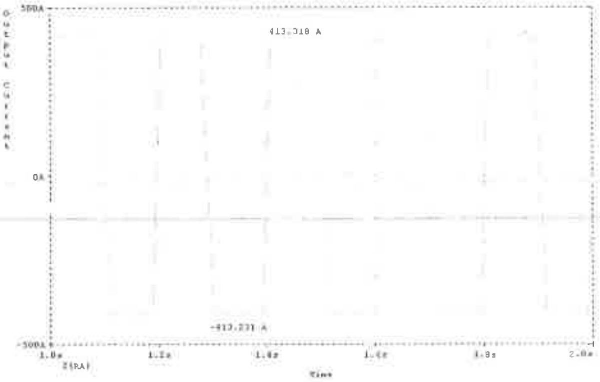

Figure 11. Output Current Waveforms for Fig. 10 Circuit (RA)

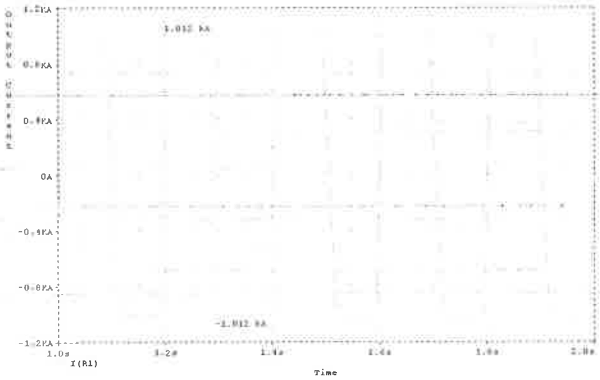

Figure 12. Output Current Waveforms for Fig. 10 Circuit (R1)

The output current has approximately achieved its targeted values which are 1.012 kA and -1.012 kA for R1 output, exceeding by 12 A at positive cycle and -12 A at negative cycle of the targeted values 1000 A and -1000 A alternating output current. The output waveform is also in almost perfect alternating square wave shape, with 0.2 s period for each cycle which equivalent to 5 Hz frequency. In this design, the frequency of the supply is directly changed to 5 Hz due to time constraint. In practice, a square wave inverter is needed in the design. In order to do this, a three phase AC power supply is required. The power supply is rectified using a rectifier to convert the AC voltage to DC voltage.

Then, a three phase controlled inverter made up of transistors and diodes are used to control the frequency of the output voltage and current. After that, the current limiter is used to limit the current to certain appropriate range, and also to have a perfect square waved signal by controlling the current limiter gain. Subsequently, step down transformers will be used to increase the output current until it reaches ± 1000 A.

V. CONCLUSION

The paper has been successfully presented a proof of concept that they design of high current power supply is possible and feasible for the SBL application. The next step of action will be to verify with other design requirements and hence validate using experimental work.

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