STUDY OF HIGH LOAD CURRENT POWER SUPPLY DESIGN FOR LOW FREQUENCY SEABED LOGGING APPLICATION

By

NUR AIMAN BINTI MOHAMMAD SUHAIMI

FINAL YEAR PROJECT II
PROGRESS REPORT

Submitted to the Department of Electrical & Electronic Engineering
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(Electrical & Electronic Engineering)

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

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Dr. Nor Zaihar Bin Yahaya,
Project Supervisor

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TRONOH, PERAK

January 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Nur Aiman Binti Mohammad Suhaimi.

ABSTRACT

Low frequency, high load current study is very important for Seabed Logging (SBL) application. SBL is currently an emerging method to find hydrocarbon layer beneath the ocean floor. In SBL, a high current low frequency power supply is needed to assist the transmission process that uses Horizontal Electric Dipole (HED). HED emits electromagnetic signal throughout the sea in the expected area containing hydrocarbon layer. This power supply with the ability to produce high current low frequency output 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 required. In this project, the processes to design and simulate a power supply with the required output for SBL application is explained in details. At the end of this project, a power supply which has high current and low frequency output is completely designed.

ACKNOWLEDGEMENTS

The completion of this Final Year Project (FYP) 1 and 2 was made possible thanks to the valuable supports I received from many individuals. First and foremost, I would like to express my greatest gratitude to my supervisors, Dr. Nor Zaihar Bin Yahaya and Mrs. Zazilah Binti May for their continuous guidance, patience, and support throughout completing this project. Zillions of appreciation I bid to both of my supervisors, as this project will not be completed without the supervision from them. Special thanks for their endless efforts to assist me in the course of this program and for the golden time spent on me for further improvement and guidance on this project.

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In a nutshell, I would like to express oceans of gratitude to anyone that provide helps directly or indirectly towards completing this project. It is to them that I owe my deepest appreciation in making this Final Year Project a success.

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NUR AIMAN BINTI MOHAMMAD SUHAIMI

Electrical & Electronics Engineering Department

Universiti Teknologi PETRONAS

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LIST OF ABBREVIATIONS

AC	: Alternating Current
A	: Ampere
A/V	: Audio-Visual
BJT	: Bipolar Junction Transistor
CSEM	: Controlled Source Electromagnetic
DC	: Direct Current
EMC	: Electromagnetic Compatibility
EMI	: Electromagnetic Interference
ET	: Electronic Transformer
HED	: Horizontal Electric Dipole
Hz	: Hertz
MOSFET	: Metal Oxide Semiconductor Field Effect Transistor
Op-amp	: Operational Amplifier
SBL	: Seabed Logging
SMPS	: Switched Mode Power Supply
V	: Volt
W	: Watt
ZVS	: Zero Voltage Switching
ZVT	: Zero Voltage Transition

CHAPTER 1
PROJECT BACKGROUND

In order to fully understand the context of this project, as well as to underline its objectives, studies have been done in related areas. In this chapter, this project background, problem statement, objectives and scope of study are written in details to give a brief idea on the subject matter.

1.1 Background Study

Power supply is a device that provides electric power for the use of one or more loads. Power supply mainly functions as a converter that changes one form of electrical energy to another. Nevertheless, it also converts another form of energy to electrical energy [1]. Power supplies are categorized as either AC power supplies or DC power supplies according to the type of output voltage. For both AC and DC power supplies, they are further divided into three categories, which are switch mode power supplies, resonant power supplies and bidirectional power supplies. These three types of power supplies are differentiated by their conversion techniques and the direction of power control.

On the other hand, seabed logging (SBL) is an engineering method to discover the position of a hydrocarbon layer beneath a seabed. Currently, there are several techniques for SBL, for instance by seismic sounding [2], well-borehole logging [3], and controlled source electromagnetic (CSEM) [4] method. For CSEM method, an electric dipole antenna, while being submerged and deep-towed by a ship, is releasing electromagnetic signals throughout the sea and its surrounding in several directions. Simultaneously, an array of electromagnetic receivers that record the electric and magnetic fields which are directed, refracted or reflected from all parts of air, seawater, sediments, and hydrocarbon layer are located at the ocean floor as shown in Fig. 1 [5,6].

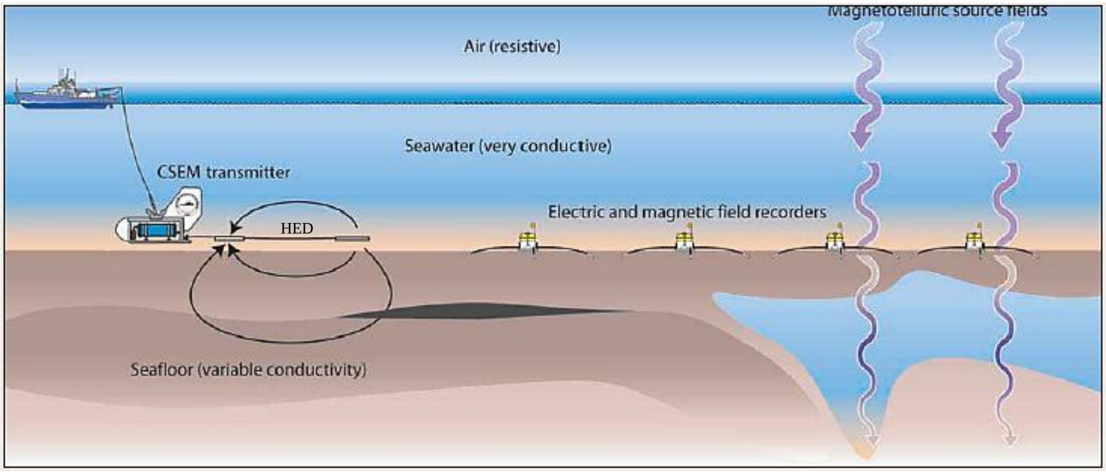


Figure 1 Conceptual Diagram of the Marine CSEM Method [6].

In SBL application, the electric dipole antenna used for CSEM transmitter is Horizontal Electric Dipole (HED). HED antenna acts as the source that emits an alternating current typically in the range of 0.1 to 10 Hz [7].

1.2 Problem Statement

The concept of the project is to design and simulate a power supply that can produce high current with low frequency output. High load current is required to assist the transmission of signal detection for SBL application. In addition, by using a small frequency range, the detection process can be done effectively. For this project, a new power supply that is capable to produce a high current at the load is designed and simulated.

As stated above, SBL is a new and emerging method for remote and direct identification of hydrocarbon filled layers in deep water areas. In fact, researches have been done to apply this method in shallow water areas [8]. Therefore, in order to compete with the fast growing technologies, it is significant to carry out the project.

1.3 Objectives and Scope of Study

The first objective of this project is to understand high power application of power supply module. After this objective is accomplished, the second objective, which is to design specific high load current and maintain stability of the output is pursued. Then, power supply knowledge will be used to design power supply for seabed logging application. Afterward, when all these three objectives are successfully achieved, the drawbacks in the design of high load current will be determined.

As discussed above, many applications have been developed for seabed logging transmission. This project will focus on the electronic side of the methodology. For that purpose, high load current for low frequency power supply for SBL method has to be designed. 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. This will be designed and simulated using MATLAB and PSpice software.

This project is feasible and relevant to be conducted within two semesters, as it mostly involves simulation using software. In the end of the project, a power supply with the required output stated above will be simulated. The project will be conducted according to the planning in methodology chapter.

CHAPTER 2
LITERATURE REVIEW

In this chapter, research papers, journals, technical papers and other references related to achieving the objectives of this project are compiled for future references. The literature reviews are organized according to the stated objectives in previous chapter, respectively.

2.1 Categorization of Power Supply

In order to operate a power supply, the energy needed to supply its load to carry its task must be acquired from an energy source. This energy might be supplied from electrical energy transmission systems, or from energy storage devices, depending on the power supply design. According to [9], in designing power supplies, some or all specifications as listed below must be achieved:

a. The source and the load are isolated.
b. High-power density to reduce its size and weight.
c. Power flow direction control.
d. High conversion efficiency.
e. Low total harmonic distortion input and output waveforms for small filters.
f. (For AC voltage source) Controlled power factor.

Nowadays, power supplies are needed in most electrical and electronic applications. Different applications might need different types of outputs from the power supply. The type of output or outputs required must be considered in the design process. The outputs can be specified into three categories [10]:

a. Regulated output: Constant output voltage within a specified range in the input voltage and the output loading.
b. Isolation: The output and input might be required to be electrically isolated.

c. Multiple outputs: Positive and negative outputs that might have different voltage and current ratings. These outputs might need to be isolated from each other. In this project, this type of output may be used.

The following Table 1 and Table 2 are some available power supply modules for low power and high power applications from two well-known companies.

2.1.1 Low Power Modules

Table 1 Low Power Modules in the Industry [11 ,12, 13]

Module	Details	Ratings	Applications
Applied KiloVolts MP Series 	• Output voltage controlled by a high frequency pulse width modulated switching techniques and ferrite step-up transformer • High Stability, Low Ripple, Low Drift • Short Circuit & Flashover proof • PCB Mounting • 24 hour burn in • Positive & Negative versions • 0 V-10 V Control Input	Output Power = 2 W Output Voltage (V) | Output Current (A) 50 to 1 k | 2 m -50 to -1 k | 2 m 100 to 2.5 k | 1 m -100 to -2.5 k | 1 m 125 to 3 k | 700 µ -125 to -3 k | 700 µ	• Photo-multipliers • Mass Spectrometers • Lens and Bias Supplies • Surface Science and Analysis • Test Equipment
Applied KiloVolts 3590 Series 	• Compact DC to DC converter designed for small spaces • Provide accurate controlled high voltage output • Use high stability components within the feedback system to ensure a low temperature coefficient and good long and short term drift • Ideal for use in many low power and portable applications • External control voltage of 0 to +5 V • Monitoring of output voltage and current are provided • Positive and negative polarity options • Remote voltage programming or potentiometer setting • Voltage monitor and current monitor included • Encapsulated in screened metal case for reduced EMI • Flashover and short circuit protected • UL approved and CE marked	Output Power = 5 W Input Voltage = 12 V or 24 V Output Voltage (V) | Output Current (A) 2.5 k | 2 m 5 k | 1 m 7.5 k | 0.65 m 10 k | 0.5 m	• Mass spectrometer • Nuclear instrumentation • Ion pump • CRT • Image intensifier

<table>
<tr>
<td>AEG CM 01 to 04 SI Series
</td>
<td>• Small size, high reliability DC to DC converters
• Designed to meet or exceed the electrical and thermal performance of other modules, allowing customers to take advantage of the full rated output power.
• 1500 Vdc isolation voltage
• Meets basic insulation spacing requirements
• Reverse polarity protection
• Over voltage protection
• Output voltage adjustment
• Operating temperature: - 40 °C to + 85 °C
• Current limitation
• Remote on/off (positive control logic)
• External output voltage adjustment (trim)</td>
<td>Input Voltage = 19 to 36 VDC or 36 to 75 VDC
<table>
<tr><td>V_{out} (V)</td><td>I_{out} (A)</td><td>P_{out} (W)</td></tr>
<tr><td>12</td><td>1.25</td><td>15</td></tr>
<tr><td>5</td><td>3</td><td>15</td></tr>
<tr><td>3.3</td><td>3.5</td><td>12</td></tr>
</table></td>
<td>• Tele-communication</td>
</tr>
</table>

2.1.2 *High Power Modules*

Table 2 High Power Modules in the Industry [14, 15, 16]

<table>
<tr><th>Module</th><th>Details</th><th>Ratings</th><th>Applications</th></tr>
<tr>
<td>Applied KiloVolts HX Series
</td>
<td>• High Frequency switch mode
• Internal control or externally programmable
• Flashover proof
• 24 hour burn in
• Control of the output voltage by internal potentiometer, external potentiometer or by external 10 V analogue control voltage
• Control connections are by a 16 Way Ribbon
• All units are short circuit proof
• High frequency pulse width modulated switching techniques used with a ferrite step-up transformer to control the output voltage</td>
<td>Output Power = 200W
Input Voltage = 24V
<table>
<tr><td>Output Voltage (V)</td><td>Output Current (A)</td></tr>
<tr><td>50 to 1 k</td><td>200 m</td></tr>
<tr><td>2 k to 40 k</td><td>5 m</td></tr>
<tr><td>5 k to 50 k</td><td>4 m</td></tr>
</table></td>
<td>• Lasers
• Capacitor Charging
• Ion Pumps
• X-Ray
• Ion Implantation
• Magnetrons</td>
</tr>
<tr>
<td>Applied KiloVolts HW Series
</td>
<td>• High Frequency switch mode
• Internal control or externally programmable
• Flashover proof
• 24 hour burn in
• Control of the output voltage by internal potentiometer or by external potentiometer or by an external 10 V analogue control voltage
• All units are short circuit proof and include an over-current trip.</td>
<td>Output Power =100 W
Input Voltage = 24 V
<table>
<tr><td>Output Voltage (V)</td><td>Output Current (A)</td></tr>
<tr><td>50 to 1 k</td><td>100 m</td></tr>
<tr><td>100 to 2.5 k</td><td>40 m</td></tr>
<tr><td>250 to 5 k</td><td>20 m</td></tr>
<tr><td>500 to 10 k</td><td>10 m</td></tr>
<tr><td>750 to 15 k</td><td>6.66 m</td></tr>
<tr><td>1 k to 20 k</td><td>5 m</td></tr>
<tr><td>1.5 k to 30 k</td><td>3 m</td></tr>
<tr><td>2 k to 40 k</td><td>2.5 m</td></tr>
<tr><td>50 k</td><td>2 m</td></tr>
</table></td>
<td>• Lasers
• Capacitor Charging
• Ion Pumps
• X-Ray
• Ion Implantation
• Magnetrons</td>
</tr>
</table>

<table>
<tr>
<td>AEG CMF 21-25 DC/DC Converter
</td>
<td>Fully isolated full brick package DC to DC converter
Enhanced to be mounted on the enclosure of an outdoor unit with a single PCB solution directly in contact with its baseplate
The output schematic using synchronous rectification and filtered by ceramic capacitors is adapted to load transients required by power amplifiers</td>
<td>Output Voltage = 28 V
<table>
<tr><td>V_{in} (V)</td><td>I_{out} (A)</td><td>P_{out} (W)</td></tr>
<tr><td>36 to 75</td><td>215</td><td>600</td></tr>
<tr><td>36 to 75</td><td>25</td><td>700</td></tr>
<tr><td>18 to 36</td><td>215</td><td>600</td></tr>
</table></td>
<td>Wireless Application</td>
</tr>
</table>

2.1.3 Techniques in Designing Power Supplies

In power supply industry, there are two major techniques for the design. One is called linear power, and the other one is switching power supplies. The following subtopics will discuss these techniques in further details.

2.1.3.1 Linear Power Supply

Linear topology is the elementary design for a power supply. It comprises of a control element, a rectifier and load device connected in series. Fig. 2 shows an example of a series regulated supply, where the phase controlled pre-regulator represented as a power switch, whilst the series element represented as a variable resistor. The phase controlled pre-regulator purpose is to reduce the power dissipated at the series element by keeping a small and unchanged voltage drop value at the series element. Feedback control circuits observe the output and alter the series resistance to keep a constant output voltage. The variable resistance series element of the supply shown in Fig. 2 is actually produced by one or more power transistor operating in the linear mode, thus giving its name linear power supply. Power supplies with single range can have maximum power output only at full scale voltages and current. A linear power supply as in Fig. 2 produces almost maximum two ranges output power at full scale, permitting more voltage at a lower current or more current at a lower voltage [17].

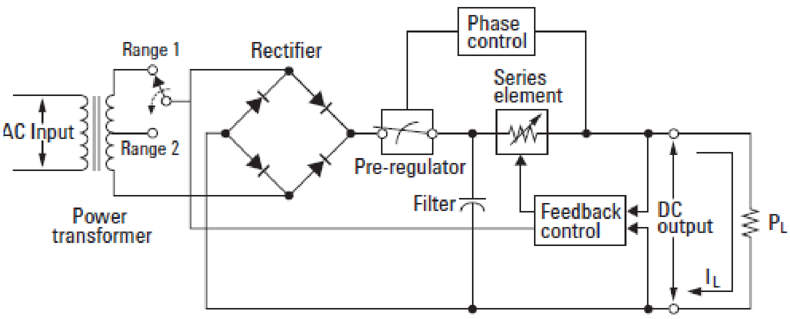


Figure 2 Simple Linear Power Supply [17]

Linear power supplies have several advantages. They are known as the simplest, most effective bench power supplies as they offer sufficient power with stable regulation and very little noise. In addition, a linear power supply has very precise regulating properties and fast responds to variable lines and loads. Consequently, this gives superiority to its line and load regulation and transient recovery time when compared to supplies with other regulation techniques. Moreover, linear power supply exhibits low ripple, can adjust to variable ambient temperature, and is greatly reliable due to the simplicity of its circuit.

2.1.3.2 Switching Power Supplies

A switched mode power supply (SMPS) is an electronic typed that integrates switching regulator in order to effectively convert electrical power. By switching ideal storage elements, such as inductors and capacitors, into and out of various electrical configurations, SMPS regulates output voltage or current. The transistor of a SMPS repetitively switches between low dissipation, full on and full off states, and uses very little time in the high dissipation transitions, thus minimizes wasted energy. By changing the duty cycle, the voltage regulation is achieved.

As SMPS uses smaller transformer size and weight and switching transistor dissipates very small amount of power, it is used instead of linear when higher efficiency, smaller size or lighter weights are essential for the power supply. Moreover, due to its higher efficiency, it has a lower heat generation.

Nonetheless, SMPS is more complex, as its switching currents can result in electrical noise problems if not prudently blocked. Furthermore, a low pass filter must be used to block the generation of high amplitude, high frequency energy to prevent electromagnetic interference (EMI). A simple and very low cost SMPS might have a poor power factor, which can lead to harmonic distortion, as well as interference with A/V equipment connected to the same phase caused by electrical switching noise flowing back onto the mains power line [18].

There are a number of topologies available for SMPS. They are divided into isolated and non-isolated topologies. They will be further discussed in the following subtopics.

2.1.3.2.1 Non-Isolated Topologies

Non-isolated and isolated are the two frequent terms used to categorize DC to DC converters. 'Isolation' denotes the presence of an electrical barrier between the input and output of a DC to DC converter. Therefore, non-isolated topology is when there is no electrical separation between the input and the output. Non-isolated converters have lower cost and simpler circuit compared to isolated converters. However, electrical connection between input and output can sometimes bring harms to the circuit.

There are numerous types of non-isolated topologies for switching power supply. However, the most commonly used are buck, boost and buck-boost topologies.

A Buck Converter

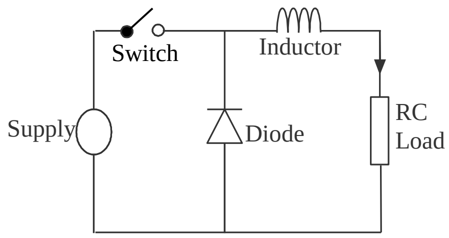


Figure 3 Basic Buck Converter Configuration

Fig. 3 shows a basic configuration of buck converter. A buck converter is also called step down DC to DC converter since the output voltage is less than the input voltage. For some applications, regulating the DC component of a pulsed output of the type in basic DC to DC switching converter might be enough. However, a buck converter frequent objective is to produce an output that is purely DC. One of the ways to obtain a DC output is by including a low pass filter after the switch in the circuit.

From Fig. 3, the diode provides pathway for the inductor current when the switch is opened and is reverse biased when the switch is closed. Buck converter configuration is mainly used in the regulated DC power supplies and the DC motor speed control. Normally, to operate buck converter, an inductor and two switches (usually a transistor and a diode) which control the inductor, are used. The switch connects the inductor to supply voltage to store energy in the inductor and discharge the inductor into the load alternately. For an ideal converter, the switch and the diode have zero voltage drop when on, and zero current flow when off, as well as zero series resistance at the inductor. Additionally, for infinitely large output capacitance, input and output voltages are assumed to be unchange over the course of a cycle [19].

B Boost Converter

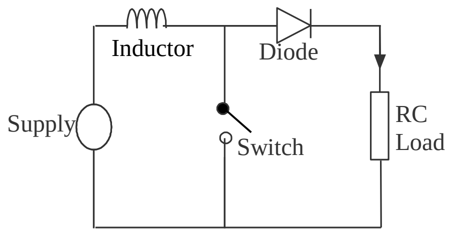


Figure 4 Basic Boost Converter Configuration

A boost converter, also called step up converter is a DC to DC converter with an output voltage greater than its input voltage. As the power is conserved, increased output voltage causes the output current to be lower than the source current. Boost converter mainly consists of at least two semiconductor switches (usually a diode and a transistor) and at least one energy storage element, a capacitor or an inductor, or both combined. Capacitors alone or in combination with inductors are commonly added to the output of the converter as filters used to reduce output voltage ripple.

By referring to Fig. 4, the diode reverse biased when the switch is closed, hence the output is isolated. When the switch is opened, the current cannot change instantly. Therefore the diode is forward biased to provide a path for the inductor current. The output stage receives energy from the inductor plus from the input during forward bias [20].

C Buck-Boost Converter

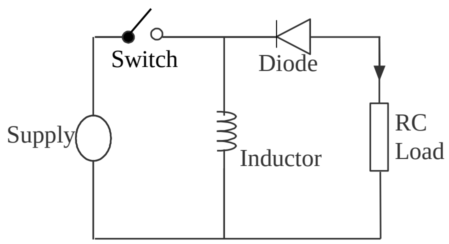


Figure 5 Basic Buck-Boost Configuration

Buck-Boost converter is one type of DC to DC converter which can have smaller (Buck) or larger (Boost) output voltage compared to the input voltage depending on the duty ratio of the switch. From Fig. 5, when the switch is closed, the diode reverse biased, hence isolating the input source from the output stage. The energy is first stored in the inductor; meanwhile the capacitor which is charged up earlier provides energy to the output load. When the switch is opened, the diode is forward biased and the output stage obtains energy from the inductor. The energy stored in the inductance charge up the capacitor and transferred to the load simultaneously. The output voltage has a negative polarity pertaining to the common terminal of the input voltage [21].

2.1.3.2.2 Isolated Topologies

For isolated topologies, the input part is electrically separated from the output part. A high frequency transformer is included in an isolated DC to DC converter to provide that isolation or barrier. This barrier can tolerate from a few hundred volts up to several thousand volts. Moreover, the output of an isolated converter can be designed to be either positive or negative.

A Flyback Converter

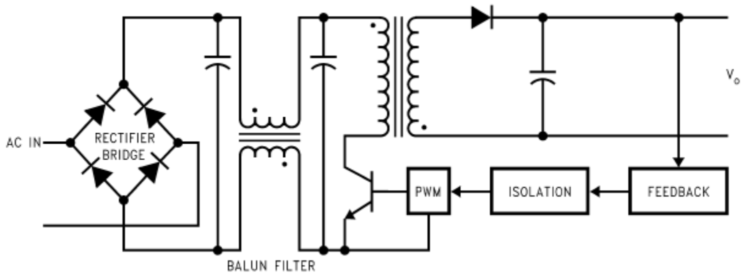


Figure 6 Flyback Converter Configuration [22]

A flyback converter is used in both AC to DC and DC to DC conversion. Its design is similar to a buck-boost converter, except the part where the inductor is split to form a transformer, so as to multiply the voltage ratios with an additional advantage of isolation. Consequently, the operating principle of both converters is alike.

When the diodes are in forward mode, the input voltage source is directly connected to the transformer's primary part. Accordingly, energy is stored in the transformer as the primary current and magnetic flux in the transformer increases. As the induced voltage in the secondary winding is negative, the diode reverse biased. The output load energy is supplied by the output capacitor. When the switch is opened, the primary current and the magnetic flux decreases. The secondary voltage becomes positive, the diode forward biased, and passes flow of current from the transformer. The output capacitor is then recharged, and therefore, the load is supplied by the energy from the transformer core.

The method of storing energy in the transformer before supplying it to the output part of the converter gives simplicity to this topology as multiple outputs are easily generated with very few additional circuitry. However, the output voltages have to match each other through the turn ratio. In addition, a controlling rail is needed and has to be loaded before load is applied to the uncontrolled rails, in order to allow the PWM to open up and supply enough energy to the transformer.

As flyback converter is an isolated converter, isolation of the control circuit is required. There are two main control schemes available, which are voltage mode control and current mode control. Frequently, current mode control is used for stability during operation. Both control schemes need a signal related to the output voltage. For that reason, two methods are developed to generate this voltage. One is by using an opto-coupler on the secondary circuitry to send a signal to the controller. The other one is to prepare a separate winding on the coil and rely on the cross regulation of the design [22].

B Forward Converter

Forward converter is a DC/DC converter that uses transformers instead of inductors to alter the output voltage subject to the transformer turn ratio, as well as isolating the input from the load. Fig. 7 shows forward converter basic topology. For this configuration, both higher and lower voltage outputs can be supplied by using multiple output windings. In addition, the forward converter is commonly used to provide intermediate power supplies of 100 to 500 W ranges [23].

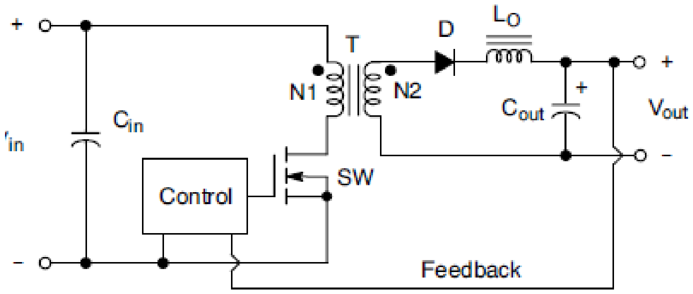


Figure 7 Forward Converter Configuration [24]

Its operation is somewhat similar to the flyback converter, but with more efficient energy usage. However, compared to flyback converter, the forward converter does not store energy during the switch conduction time. This is because unlike inductors, transformer cannot store large amount of energy. Therefore, during the switch conduction phase, this energy is delivered directly to the output by transformer action [24].

2.2 Related Devices to Design a Power Supply

The following few subtopics are about several circuit designs from previous researches and journals which can be used in achieving the second objective of this project.

2.2.1 Basic Switching Supply

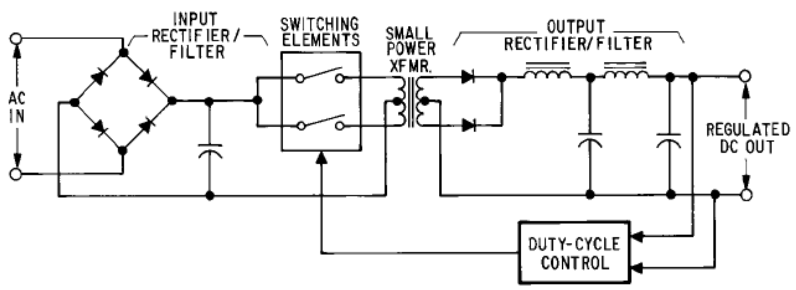
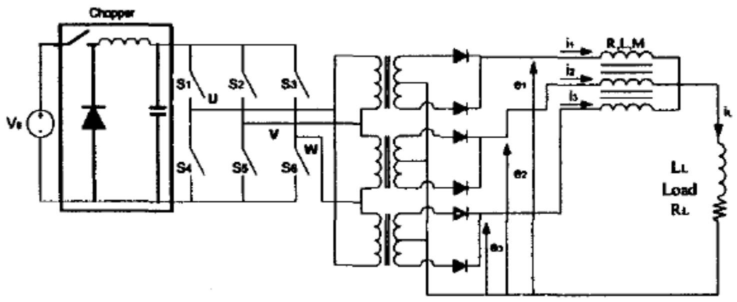


Figure 8 Basic Switching Supply [25]

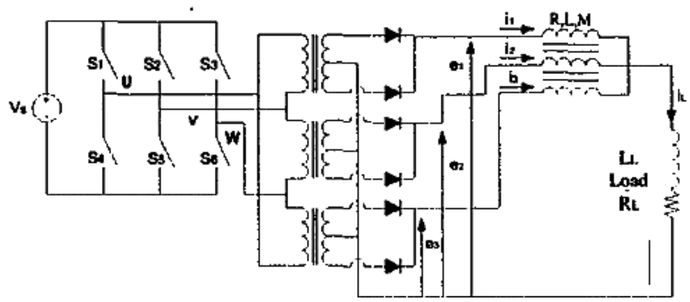
In a basic switching supply as in Fig. 8, the regulating elements are comprised of transistors connected in series that act as switches that open and close swiftly. Firstly, the input AC is converted to unregulated DC which is chopped by the switching element operating at a very fast rate, normally at 20 kHz. This resultant 20 kHz pulse train is then transformer-coupled to an output rectifier/filter network which acts to smoothen the final rectification of the DC output. Regulation is produced by changing the on-off periods which is the duty cycle of the switching elements at the controlled circuits, in case the output voltage starts to change.

In order to produce low voltage high current output, the input AC is step down by the series regulated supply. The energy storage is ensured to be in a filter capacitor with low voltage through it. On the other hand, from Fig. 8, the input AC is directly rectified and the filter capacitor is able to charge to a high voltage, up to the peaks value of the AC line in a switching supply.

2.2.2 DC to DC Converter Topologies



(a) DC-DC Converter Topology 1



(b) DC-DC Converter Topology 2

Figure 9 DC-DC Converter Topologies [26]

Fig. 9 shows the circuit diagram of the high current low voltage DC power supplies. In Fig. 9 (a), a DC chopper is used to convert an unregulated DC voltage source into a controllable DC voltage. After that, by using a high frequency inverter, this DC output voltage from the chopper is converted into a high frequency AC voltage. Then, by using a specific rectifier topology for high current low voltage applications, the output of the inverter is reduced and rectified. According to the researches done on this design, it is proven that this method will produce minimum output current ripple. Even so, because of chopper losses, this design efficiency might be lower than in Fig. 9 (b).

In Fig. 9 (b), the DC chopper is removed, and consequently also the chopper losses. To control the DC output current, the output voltage of the inverter is controlled using a specific pulse width modulation technique. This results in higher inverter switching frequency compared to the first scheme. To conclude, the efficiencies of both designs are relatively the same.

2.3 Existing Designs of High Current Power Supplies and Converters

The following few subtopics are several circuit designs from previous researches and journals which can be used in achieving the third objective of this project.

2.3.1 Self-Commutated AC to DC Converter

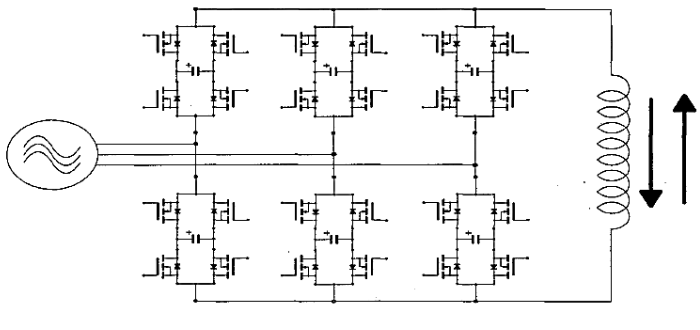


Figure 10 Self-Commutated AC/DC Converter with Bi-Directional Switching Unit [27]

In the design as shown in Fig. 10, the switching units have bi-directional switching characteristics with self-commutating performance element in order to make the DC current of the converter output in both positive and negative direction. The energy stored in snubber capacitor is discharged to the load efficiently so that the snubber circuit loss is reduced. In addition, the snubber capacitor is recharged through the power MOSFET element in the off-state of switching unit. To reduce the operational loss of the converter, the on-state resistance is minimized. The output ratings of this DC power supply are 10 V, 20 MA and 20 s operation time [27].

2.3.2 High Current Low Voltage Converter

The purpose of the circuit designed in Fig. 11 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 fulfil the electromagnetic compatibility (EMC) normative.

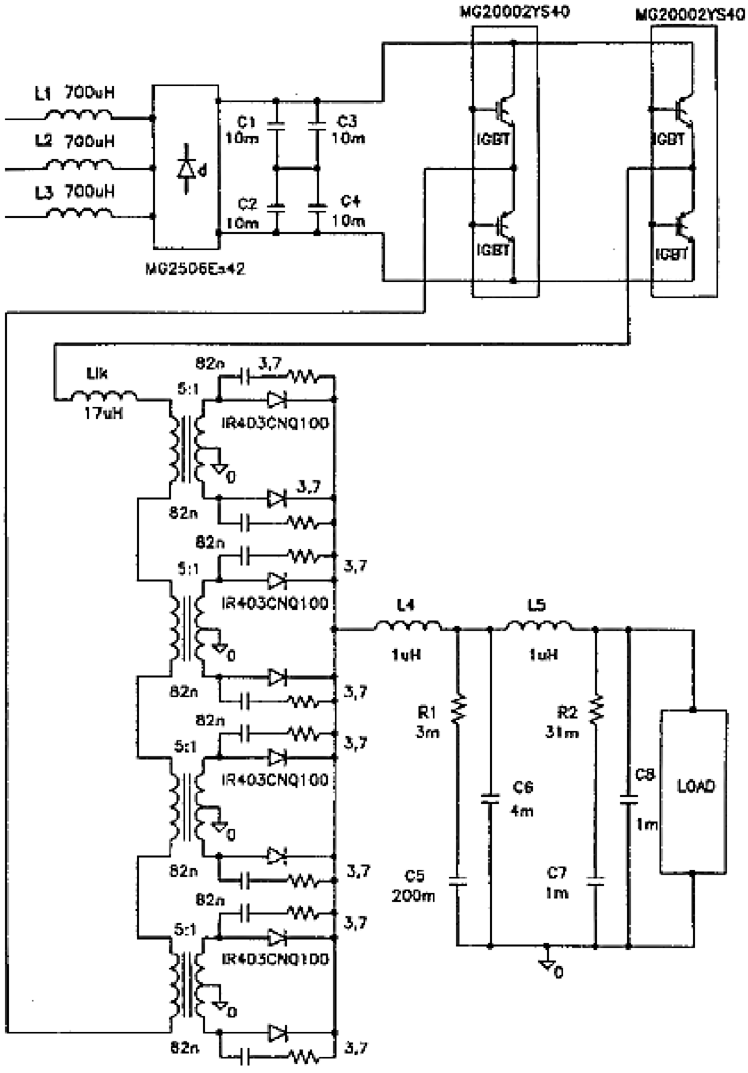


Figure 11 Converter of a High Current Power Supply [28]

According to Fig. 11, a three phase line acts as the source of energy to the converter. The non-controlled rectifier with input inductors in the input section 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. 11, the leakage inductance, Llk, which mainly consists on the leakage inductance of the ZVT transformer and an added inductance, is set to 17 mH to have optimum relation 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 secondaries 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 secondaries with centre-tapped configuration use high current (400 A) and high voltage (100 V) Schottky diodes with the aim of decreasing the losses.

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 EMC.

2.3.3 High Current Low Voltage AC-DC/DC-DC Converter

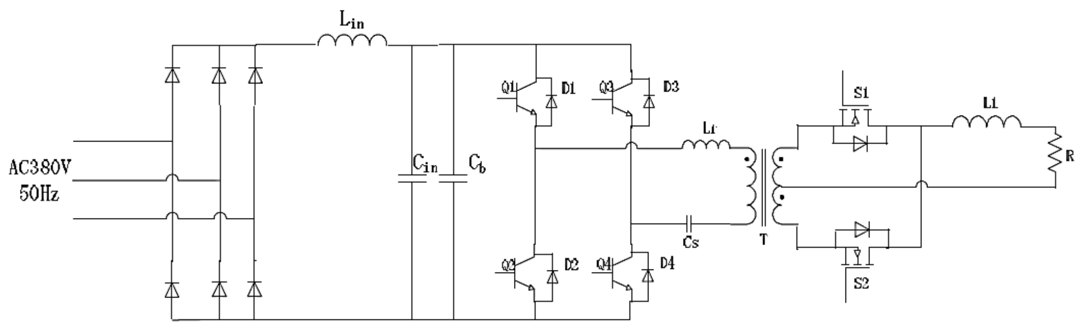


Figure 12 Power Stage of an AC-DC/DC-DC Converter [29]

The design in Fig. 12 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.

The AC-DC network of this design 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.

2.3.4 Compact High Voltage Low Frequency Power Supply

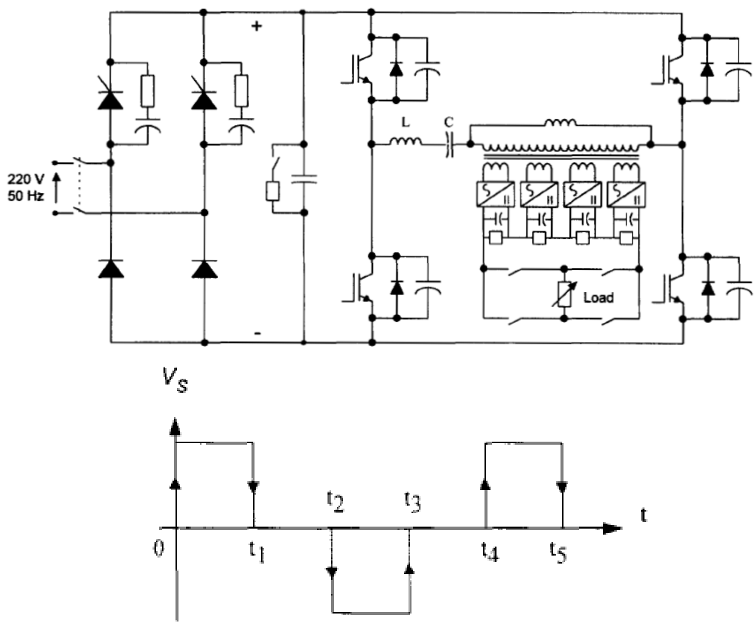


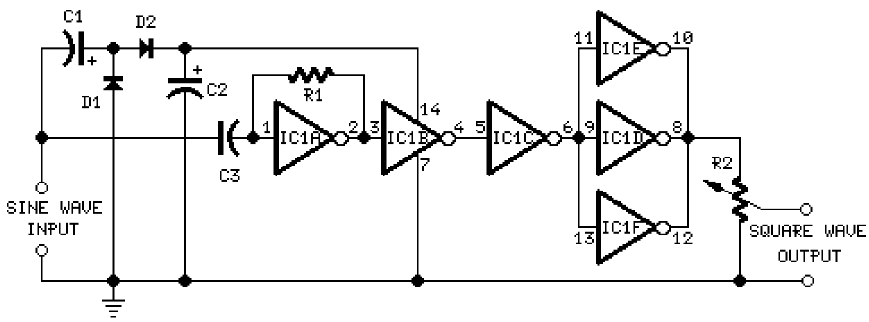
Figure 13 High Voltage Low Frequency Power Supply and the Output Voltage Waveform [30].

The compact high voltage low frequency power supply circuit is designed to meet the following specifications:

a. Variable output frequency from 0.1 to 2 Hz.
b. Variable output power from 0 to 3 kW, with two output voltage levels; 750 V, 4 A, or 3000 V, 1 A.
c. Standard input voltage of 220 V and 50/60 Hz.
d. Galvanic isolation between input and output.
e. Output voltage waveform as in Fig. 13.
f. Low cost and weight for portability.

2.3.5 Sine Wave to Square Wave Converter

Operational amplifier (op-amp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and typically a single-ended output. An op-amp produces a higher output voltage, normally hundreds of thousand times larger than the voltage difference between its input terminals. One of op-amp configurations is positive feedback, which takes a fraction of the output signal back to the non-inverting input. Positive feedback op-amp can be used as a sine wave to square wave converter, probably for below 100 Hz [31].



R1 = 1 M ¼ W Resistor
R2 = 100 kΩ Linear Potentiometer
C1, C2 = 100 µF 25 V Electrolytic Capacitors
C3 = 10 nF 63 V Polyester Capacitor
D1, D2 = 1N4148 75 V 150 mA Diodes
IC1 = 4069 Hex Inverter IC

Figure 14 Self-powered Sine to Square wave Converter [32].

Fig. 14 shows a circuit consists of several op-amps that act as a sine wave to square wave converter. This converter can be a good aid in designing the power supply needed in this project. The main operation of this circuit is to convert a sine wave input source from a generator to a square waves output. For this converter, no power-source is required. Hence, the input and the circuit can directly be connected. From Fig. 14, the input sine wave flows into a voltage doubler formed by C1, C2, D1 and D2, which powers the IC. IC1A amplifies the input sine wave, while other IC1 inverters squaring the signal and delivering an output square wave of equal mark to space ratio through a 20 Hz-20 kHz frequency range.

Why we need a square wave output? In SBL, the frequently used waveform in transmission process is square wave, because square wave is easy to generate. During transmission process, the electric dipole transmitter produces maximum current at one polarity for half a period, and switched the polarity for the second half of the period, producing a square wave current waveform. As the square wave source current is running at its peak value all of the times except for possible switching intervals, 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. The periodic waveform for the transmitter current is represented by the following Eq. (1) until Eq. (6) [33].

$$J_n = J_{max} \frac{2}{n\pi} \sum_{m=1}^{M} (-1)^{m-1} e^{i\omega_n \tau_m} \sin[\omega_n(\Delta t_m - t_\sigma)] \tag{1}$$

$$\omega_n = n\omega_0 \tag{2}$$

$$\omega_0 = 2\pi f_0 = 2\pi \frac{1}{T_0} \tag{3}$$

$$\tau_m = \frac{1}{2}(t_m + t_{m-1}) \tag{4}$$

$$\Delta t_m = \frac{1}{2}(t_m - t_{m-1}) \tag{5}$$

$$t_\sigma = \frac{1}{2} t_s \tag{6}$$

Where J_n is the Fourier coefficient of transmitter current, J_{max} is the peak amplitude of transmitter current, ω_0 is the angular frequency, M is an integer, and t_s is switching interval.

2.3.6 Transformer

A transformer is a device that alters the voltage level of an AC electric power through magnetic field. Transformer basically consists of two sets of windings which are attached to a core. These windings are connected through the magnetic flux present within the core, not directly connected. One of the transformer windings, the primary winding is connected to the source of AC electric power, whereas the second transformer winding supplies electric power to the loads (secondary winding) [34]. Fig. 15 shows the construction of a step down transformer.

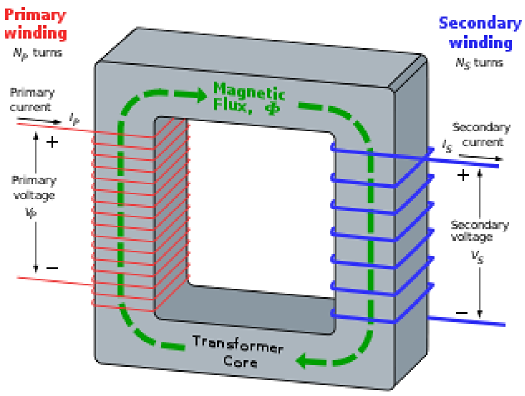


Figure 15 Construction of a Step Down Transformer [35].

In this project, a transformer is needed to reduce the output voltage of the power supply in order to get a high current output. This can be done as the output power of the transformer is equal to the input power, as long as all the incoming energy is transformed from the primary windings to the magnetic field, and into the secondary windings, as in Fig. 15. This relation is shown as in the Eq. (7):

$$P_{in} = V_pI_p = V_sI_s = P_{out} \tag{7}$$

In electronic circuits, electronic transformer is used to change the voltage level. An example of electronic transformer (ET) is shown in Fig. 16. This ET is divided into three parts. The first part is a filter comprises of an inductance and a capacitor. The second part is conventional bridge rectifier made of diodes. The last part is class-D zero voltage switching (ZVS) inverter which corresponds to transformer TI and the load.

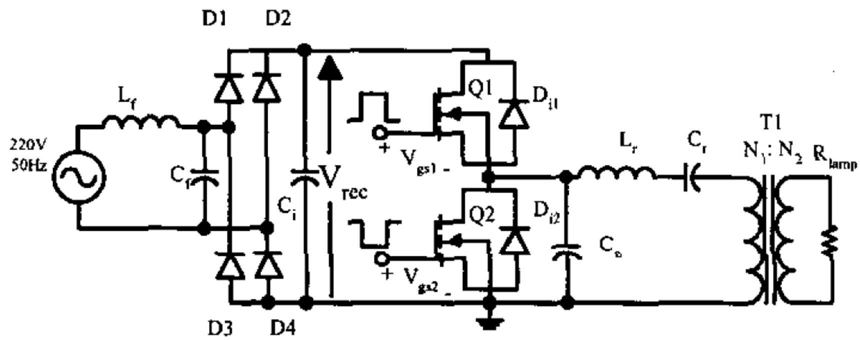


Figure 16 Electronic Transformer [36].

2.3.7 Low Pass Filter

A low pass filter attenuates high frequencies signals which are more than the cutoff frequency and passes low frequencies signals. A cutoff frequency, symbolized by f_c is the borderline in a system's frequency response where energy that flows through the system starts to reduce (attenuate or reflect) instead of passing through. The cutoff frequency is determined by the time constant, τ, while the time constant is the product of resistor and capacitor value [37]. The equation to calculate the cutoff frequency in hertz (Hz) is:

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC} \tag{8}$$

The equation needed to calculate the cutoff frequency in radians per second (rad/sec) is:

$$\omega_c = \frac{1}{\tau} = \frac{1}{RC} \tag{9}$$

A basic low pass filter contains a resistor and capacitor as configured in Fig. 17. The value of the resistor and capacitor will directly affect the cutoff frequency of the low pass filter, as shown in the Eq. (8) and Eq. (9).

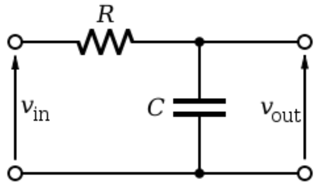


Figure 17 Simple Low Pass RC Filter [37].

According to [38], a low pass filter that can withstand a very high current is configured as in Fig. 19. This filter is for 150 V, 1500 A magnet power supplies, and was designed to attenuate 60 Hz by 10 dB and to cease ringing after 80 ms, as in Fig. 18. An inductor is needed in this circuit because inductive low pass filter is more suitable for high current circuit design as additional resistance is undesirable.

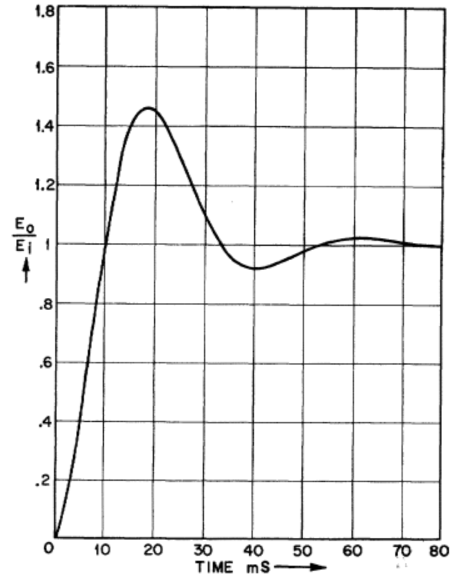
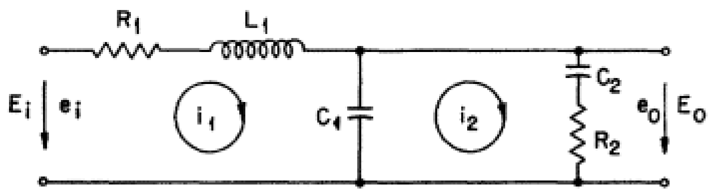


Figure 18 Time response to Unit Step of the Filter [38].



$R_1 = 2$ mΩ

$L_1 = 0.7$ mH

$C_1 = 37$ mF

$R_2 = 180$ mΩ

$C_2 = 90$ mF

Figure 19 Low Pass Filter for 150 V, 1500 A Power Supply [38].

From Fig. 19, this filter response to a unit step input is as follows:

$$E_o(s) = \frac{E_i(s)}{s} \frac{sT_2 + 1}{s^3 T_2 L_1 C_1 + s^2(T_1 T_2 + L_1 C_1 + L_1 C_2) + s(T_1 + T_2 + T_3) + 1} \quad (10)$$

$$I_1(s) = E_i(s) \frac{sC_1 T_2 + C_2 + C_1}{s^3 T_2 L_1 C_1 + s^2(T_1 T_2 + L_1 C_1 + L_1 C_2) + s(T_1 + T_2 + T_3) + 1} \quad (11)$$

$$I_2(s) = E_i(s) \frac{C_2}{s^3 T_2 L_1 C_1 + s^2(T_1 T_2 + L_1 C_1 + L_1 C_2) + s(T_1 + T_2 + T_3) + 1} \quad (12)$$

2.3.8 Three Phase Uncontrolled Full Wave Rectifier with Source Inductance

Rectification is the process of converting alternating voltages and currents to direct currents. The device that carries rectification process is called rectifier. Diodes are used in rectifier circuits, as they conduct current in one direction. Uncontrolled rectifiers indicate that there is no external control on the diodes. For uncontrolled rectifiers, there are two available types; half wave and full wave. Full wave rectifiers or also called bridge rectifiers have better performance than half wave rectifiers, and usually used for high power applications. This is because three phase full wave rectifiers have the highest possible transformer utilization system. In some cases, source inductances are placed in the circuit to change the shape of the output voltage, and decrease the DC component of the output voltage. Fig. 20 shows an example of three phase uncontrolled full wave rectifier.

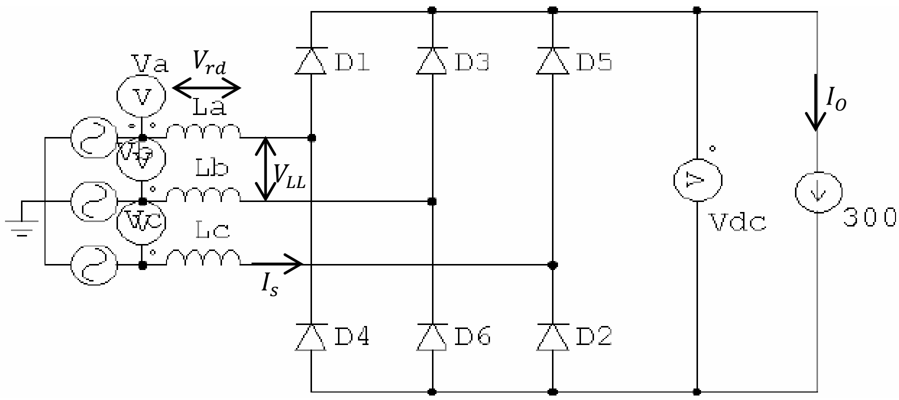


Figure 20 Three Phase Full Wave Rectifier with Source Inductance [39]

By referring to Fig. 20, diodes D1, D3, D5 are the upper half of the bridge, whilst diodes D2, D4 and D6 are the lower half. At least one diode must conduct in each half of the bridge for the load current to flow. When the current flows, proper line to line supply point voltage is applied across the load. Full wave has peak load voltage three times more than half wave rectifier.

Based on Fig. 20, Eq. (13) until Eq. (18) show some parameters in three phase full wave rectifier, where L_S (L_a, L_b and L_c) is the source inductance, I_O is the output current, $V_{LL}$is the line to line voltage, f is the supply frequency, u is the commutation angle, V_{rd} is the DC voltage reduction due to source inductance, $V_{dc|actual}$ is the DC voltage without source inductance, I_S is the RMS value of supply current, and I_{S1} is the RMS value of fundamental of supply current [39].

$$u = \cos^{-1}\left[1 - \frac{\sqrt{2}\omega L_S I_O}{V_{LL}}\right] \tag{13}$$

$$\omega = 2\pi f \tag{14}$$

$$V_{rd} = \frac{6\omega L I_O}{2\pi} = 6 f L_S I_O \tag{15}$$

$$V_{dc|actual} = 1.35 V_{LL} - V_{rd} \tag{16}$$

$$I_S = \sqrt{\frac{2I_O^2}{\pi}\left[\frac{\pi}{3} - \frac{u}{6}\right]} \tag{17}$$

$$I_{S1} = \frac{2\sqrt{6}I_O}{\pi u}\sin\left(\frac{u}{2}\right) \tag{18}$$

2.4 Drawbacks in the Design of High Load Current

Nowadays, the emerging technology produces many applications that need high current devices to operate. The improvement in the developments of high load current devices help power supplies industries to expand further in order to increase revenue. However, high current power supplies have disadvantages such as potentially dangerous, limited number of electronic devices for very high current applications, and also enormous device size and cost. These following subtopics will explain the drawbacks in the design of high load current in details.

2.4.1 High Current Protection

The escalating demand on high current power supply has created the need for circuit protection for specific current and voltage ratings. Numerous reasons for high current protections can be outlined, such as to detect and isolate faulty equipment, maintain system stability, minimize damage and fire risk, and most importantly to minimize risk to personnel. There are several types of high current protection, for instance protective relay, circuit breaker and fuse. The type of protection chosen is depending on which device to be protected, and what the device should be protected from. For high current applications, the related devices are usually protected from overvoltage and overcurrent.

2.4.1.1 Protective Relay

For protective relay, there are three categories. The first one is electromechanical relay, which uses current and voltage to produce magnetic flux in order to generate torques on movable disks and relays. The second type is solid state relay, which uses detected currents and voltages to produce low voltage analogue. Solid state relay uses discrete electronics and basic logic circuits, and might use basic microprocessor for logic and calculation purposes. The third category is numeric relay. It is a multifunction, programmable logic relay, which digitizes detected current and voltage to calculate RMS or phasor equivalent value by using a high-end microprocessor. For high current protection, normally electromechanical protection relay is used. Current and voltage transformers are frequently used with protective relays to step down the high voltages or currents to a level suitable for the relays [40].

2.4.1.2 Circuit Breaker

A circuit breaker is a mechanical switching device which makes, carries and breaks currents under normal circuit conditions, or for a specified time, as well as breaks currents under specified abnormal circuit conditions, for example during short circuit. A circuit breaker is designed to open and close a circuit by non-automatically or automatically on a predefined overcurrent range without any damage caused when accurately applied within the circuit breaker rating.

Circuit breaker mainly functions to protect circuit's components by providing overcurrent protection and isolation from energized and un-energized circuit components. The circuit breaker operates by sensing and measuring the current flow in the circuit. Then, the measured current value is compared with the preset trip point. If the current exceeds the trip point, the circuit breaker reacts within time period set beforehand by opening the circuit as fast as possible to minimize the amount of current which is allowed to flow [41].

2.4.1.3 Fuse

Fuse is a device which provides overcurrent protection for the load or source circuit in a wiring system or electrical equipment. Main component of a fuse is a metal wire or strip that melts when too much current flows through it, caused by short circuit, overloading, mismatched loads or device failure in order to disrupt the circuit connection. The circuit needs to be disconnected to avoid further damages by overheating or fire caused by the excessive current flow.

Fuses are available in wide range of current and voltage ratings, and these ratings are selected accordingly to tolerate certain normal current range and to allow excessive current only for very short periods. Contrasting with a circuit breaker which can be reset to resume normal operation, a fuse must be replaced after use. However, self-resetting fuse, which automatically restores the circuit operation after the fault has been cleared are used in aerospace or nuclear applications, as fuse replacement is impossible in these applications.

A specific type of fuse, which is called current limiting fuses are used for very high current transformer protection, capacitor protection and sectionalizing. This current limiting fuse has non-gas element which allows maximum energy limitation and minimum peak arc voltages without corrosive aftereffect. Consequently, the electrical and mechanical stresses on the equipment and the whole system supplying the fault can be significantly restricted [42].

2.4.2 Limited High Current Components

Components used in very high current applications need to have several important features, especially very low resistance in order to minimize losses at the components. However, the components must be resilient enough to allow very high current flows. Currently, not many components are manufactured specifically for very high current applications with minimum losses and at the same time protect the circuit from possible damages.

2.4.3 Enormous Device Size and Cost

Generally, circuit complexity increases with the required output values. This is because higher current or voltage outputs need more components in the circuitry design. Furthermore, for the generation of very high output current, isolated power supply topologies are mandatory and these topologies requires complex power stage and the isolation in the control circuitry. Complex circuitry with numerous components will result in very huge size device with high production cost. Moreover, high current protections are needed in each design, thus increasing the size and cost of the device.

2.5 Power Supply in Seabed Logging (SBL) Application

Horizontal Electric Dipole (HED) used in SBL application emits continuous high current and low voltage waveforms at a low fundamental frequency. High current is needed to penetrate deep down to the ocean floor, whilst low frequencies are needed to provide sufficient signal penetration deep to the targets, due the electromagnetic ‘skin-depth’ effect which causes current density to decrease with increasing ocean’s depth [43]. Therefore, a power supply that can produce high current with low frequency output is essential to overcome these obstacles and gain an accurate data required for SBL application. In this project, a power supply with high current and low frequency output is needed. Therefore, with the aid from these numbers of circuits, a design for the stated power supply that gives the required output will be produced.

2.5.1 Seismic Sounding

A seismic profile records specifically to study the lower crust, the Mohorovicic discontinuity and the mantle of the Earth, typically using refraction methods. Most standard seismic reflection profiles record only a small fraction (typically, on the order of 10 km) of the Earth's crust, which is 5 to 75 km thick.

Seismic sounding uses EM energy transmitted by an HED source to detect contrasts in subsurface resistivity. Resistivity variations in rocks are generally controlled by the interplay between highly resistive minerals (1011-1014 Ωm) and pore fluids including low resistive saline water (0.04-0.19 Ωm) and/or infinitely resistive hydrocarbons. Tight crystalline rocks such as oceanic crust typically show high resistivities (100-1000 Ωm) with variations mainly controlled by saline fluids in fracture networks. Sedimentary rocks can exhibit a wide range of resistivities (0.2-1000 Ωm) mainly controlled by variations in porosity, permeability and pore connectivity geometries in addition to pore fluid properties and temperature [44].

2.5.2 Well-Borehole Logging

Well logging, also known as borehole logging is the practice of making a detailed record (a well log) of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (geological logs) or on physical measurements made by instruments lowered into the hole (geophysical logs). Well logging can be done during any phase of a well's history; drilling, completing, producing and abandoning. Well logging is done in boreholes drilled for the oil and gas, groundwater, minerals, geothermal, and for environmental and geotechnical studies.

The oil and gas industry records rock and fluid properties to find hydrocarbon zones in the geological formations intersected by a borehole. The logging procedure consists of lowering a 'logging tool' at the end of a wireline into an oil well (or hole) to measure the rock and fluid properties of the formation. An interpretation of these measurements is then made to locate and quantify potential depth zones containing oil and gas (hydrocarbons). Logging tools developed over the years measure the electrical, acoustic, radioactive, electromagnetic, nuclear magnetic resonance, and other properties of the rocks and their contained fluids. Logging is usually performed as the logging tools are pulled out of the hole. This data is recorded either at surface (real-time mode), or downhole (memory mode) to electronic data format and then either a printed record or electronic presentation called a "well log" provided to the client. Well logging is performed at various intervals during the drilling of the well and when the total depth is drilled, which could range in depths from 150 m to 10668 m (500 ft. to 35,000 ft.) or more [45].

Electric line is the common term for the armored, insulated cable used to conduct current to downhole tools used for well logging. Electric line can be subdivided into open hole operations and cased hole operations. Open hole operations, or reservoir evaluation, involves the deployment of tools into a freshly drilled well. As the toolstring traverses the wellbore, the individual tools gather information about the surrounding formations. A typical open hole log will have information about the density, porosity, permeability, lithology, presence of hydrocarbons, and oil and water saturation.

Cased hole operations, or production optimization, focus on optimizing the completed oil well through mechanical services and logging technologies. At this point in the well's life, the well is encased in steel pipe, cemented into the well bore and may or may not be producing. A typical cased hole log may show cement quality, production information, and formation data. Mechanical services use jet perforating guns, setting tools, and dump bailors to optimize the flow of hydrocarbons [46].

2.5.3 Controlled Source Electromagnetic (CSEM)

The Controlled Source Electromagnetic (CSEM) method is an offshore geophysical technique, employing electromagnetic remote-sensing technology to indicate the presence and extent of hydrocarbon accumulations below the seabed.

In CSEM, electric and magnetic field recorders are deployed on the seafloor, weighed down by environmentally benign anchors made from standard or degradable concrete. Electromagnetic fields are broadcasted from a horizontal electrical dipole (HED) antenna, 50 to 300 m long and emitting as much as a thousand amps of current into the seawater. The transmitter and antenna are towed close to the seafloor commonly at a height of 25 to 100 m to maximize coupling with seafloor rocks and sediments and to minimize coupling with the air. Transmission currents are typically binary waveforms with 0.1 to 0.25 Hz fundamental and higher harmonics. Square waves, with geometrically decreasing odd harmonics, were used initially, although the present trend is to shape the waveform to have more desirable frequency content [47, 48].

CHAPTER 3
METHODOLOGY

In this chapter, the steps that must be taken to successfully achieve the objectives of this project are outlined and explained in details. As presented in the previous chapter, this chapter is also organized in the order of the objectives.

3.1 Understanding High Power Applications

In order to understand the high power applications, the procedure as shown in the Fig. 21 is carried out.

Figure 21 Process to Understand High Power Applications

The first step is to study the categorization of power supply, either in low power or high power ratings. A number of available modules in the industry are selected to be studied. Then, the following current and voltage ratings for each power rating of the modules are determined. The suitable applications for each module are discovered.

The next step is to learn the different techniques available in designing power supply with different specifications. The dissimilarities, advantages and disadvantages of each technique and topology are studied. The results of the study will be used to help in designing the required power supply.

3.2 Design of 1000 A 5 Hz Output Power Supply

Before designing the circuit of the required power supply, several block diagrams on the methods to get the required output are drawn. This is to ensure that the method chosen will have the best performance and the most accurate output as desired.

3.2.1 Method 1

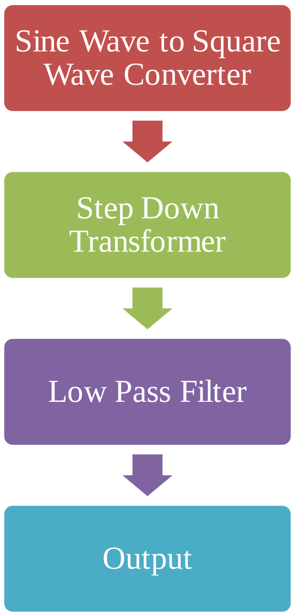


Figure 22 Method 1 Flow Diagram

In this method, a single phase input supply is connected. After that, the output of the supply will go through a sine wave to square wave converter that is made from a number of operational amplifiers. Then, the square wave will be stepped down by a transformer to reduce the voltage and increase the current value. Finally, the output from the transformer will be filtered by a low pass filter to allow only certain low frequencies range to pass as the final output.

3.2.2 Method 2

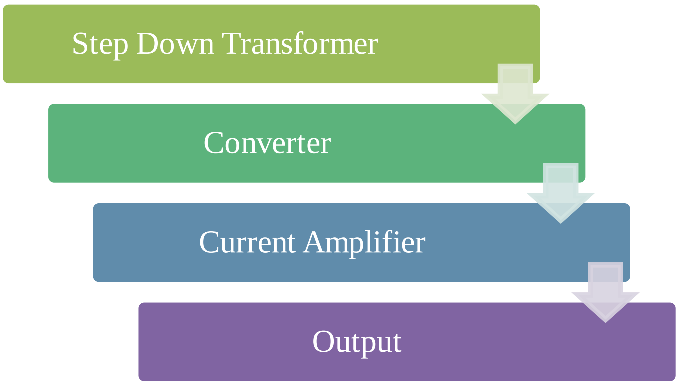


Figure 23 Method 2 Flow Diagram

For the second method, a single phase input supply is connected. Then, the supply will go through a step down transformer to increase the current value while decreasing the voltage. After that, the duty cycle of the supply will be adjusted until 5 Hz frequency is gained. Finally, the current will be further amplified by using current amplifier to get the desired value.

3.2.3 Method 3

Figure 24 Method 3 Flow Diagram

In the third method, single phase supply is also used. Firstly, the supply will be stepped down by using a step down transformer to get a higher current value. A center tap transformer will be used to have only positive output waveform. Then, capacitors will be used to regulate the current waveform. After that, an astable multivibrator is used to have both positive and negative values at the output. Last but not least, a timer is used to have the positive and negative waveform alternating at 5 Hz frequency.

3.2.4 Method 4

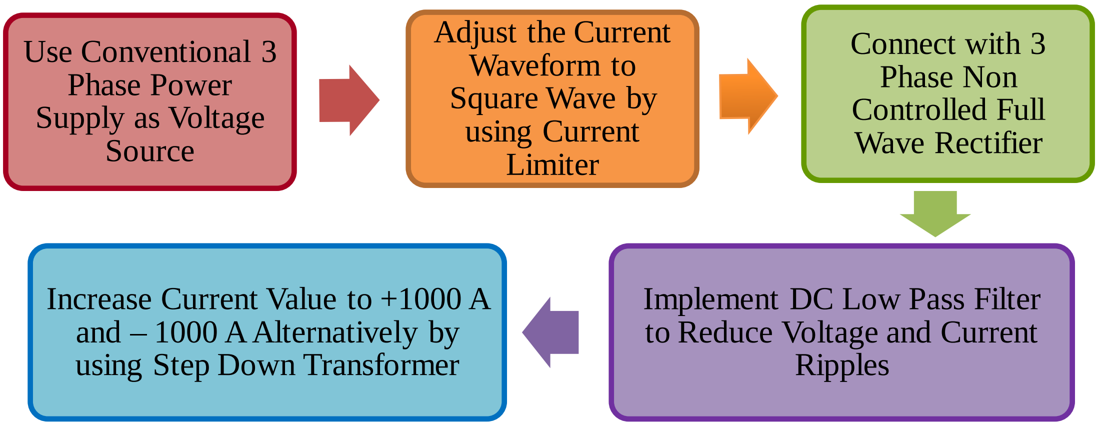


Figure 25 Method 4 Flow Diagram

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.

3.3 Power Supply Design for Seabed Logging Application

To accomplish the objectives of this project, the fourth method shown in Fig. 25 is chosen as it gives the best output waveforms when compared to the other methods. The expected waveform of the output current is shown in Fig. 26. The following subtopics show the components and configurations used to accomplish the third objective of this project.

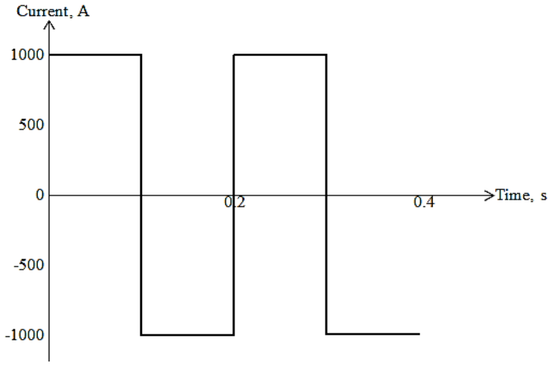


Figure 26 Expected Output Waveform

3.3.1 555 Timer Configuration

By referring to the literature review chapter, the ideas and designs are applied in this project. The first step is to convert the straight line output to square wave output by using a 555 timer. The circuit is as in Fig. 27. R1 is set at 1 kΩ, and R2 is set so that 50 % duty cycle can be acquired. Eq. 19 shows how to calculate duty cycle, and the following Eq. 20 shows how to get C1 values. The output waveform of this 555 timer configuration is as in Fig. 28.

$$\text{Duty Cycle (\%)} = \frac{R1 + R2}{R1 + 2R2} \qquad (19)$$

$$f\ (\text{Hz}) = \frac{1.44}{(R1 + 2R2)\ C1} \qquad (20)$$

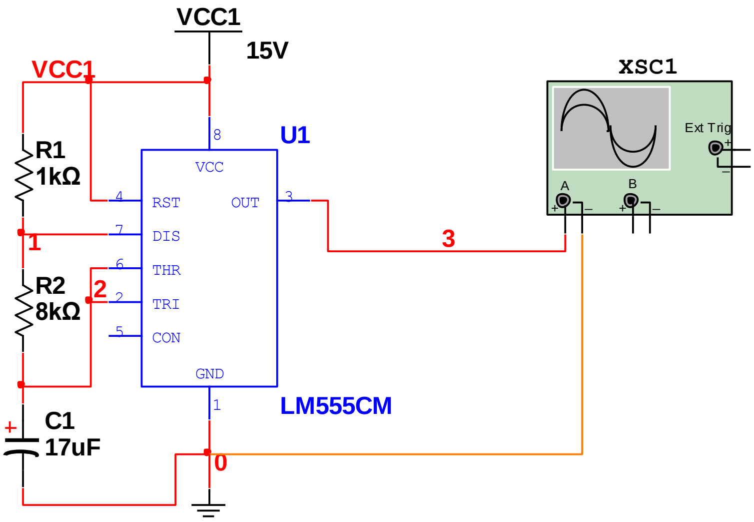
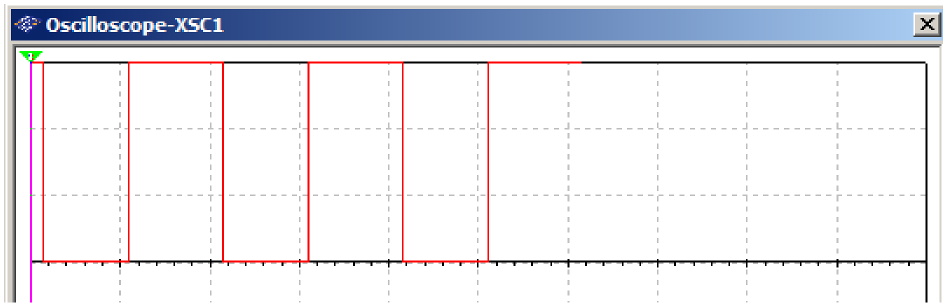


Figure 27 555 Timer Configuration

V_{max}, V



Time, s

Figure 28 Output Waveform after the 555 Timer

The output waveform is square wave as needed, but the output voltage and current are small as the result of 555 timer limitations. This is because 555 timer is only able to deliver maximum 15 mA output current at 15 V supply. Therefore, a transformer is needed to get high current output.

3.3.2 Transformer Configuration

The basic part of the design for high current low voltage power supply circuit is shown in Fig. 29. 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.

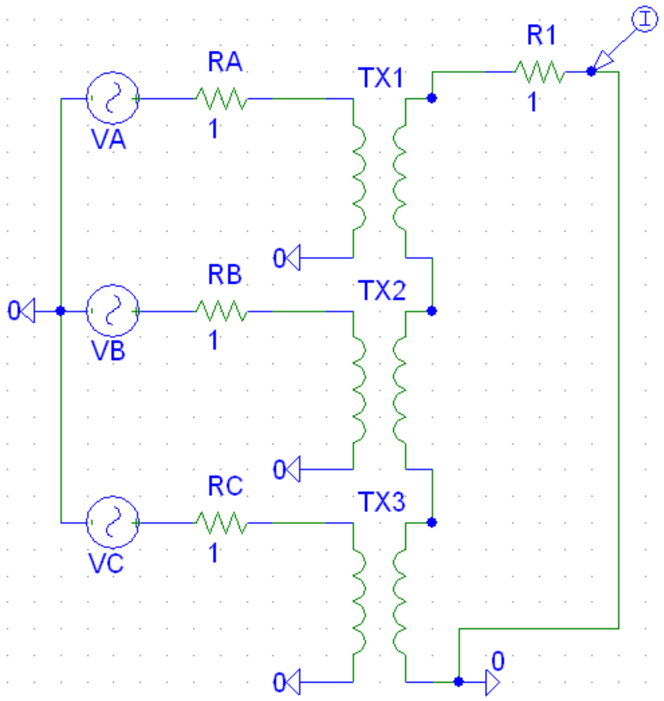


Figure 29 Transformer Configuration Circuit

Linear transformer is chosen as it does not change the waveform of the input at the output. This turn ratio is determined by using Eq. (7), 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. 30. The first step to increase the current by reducing the voltage is completed.

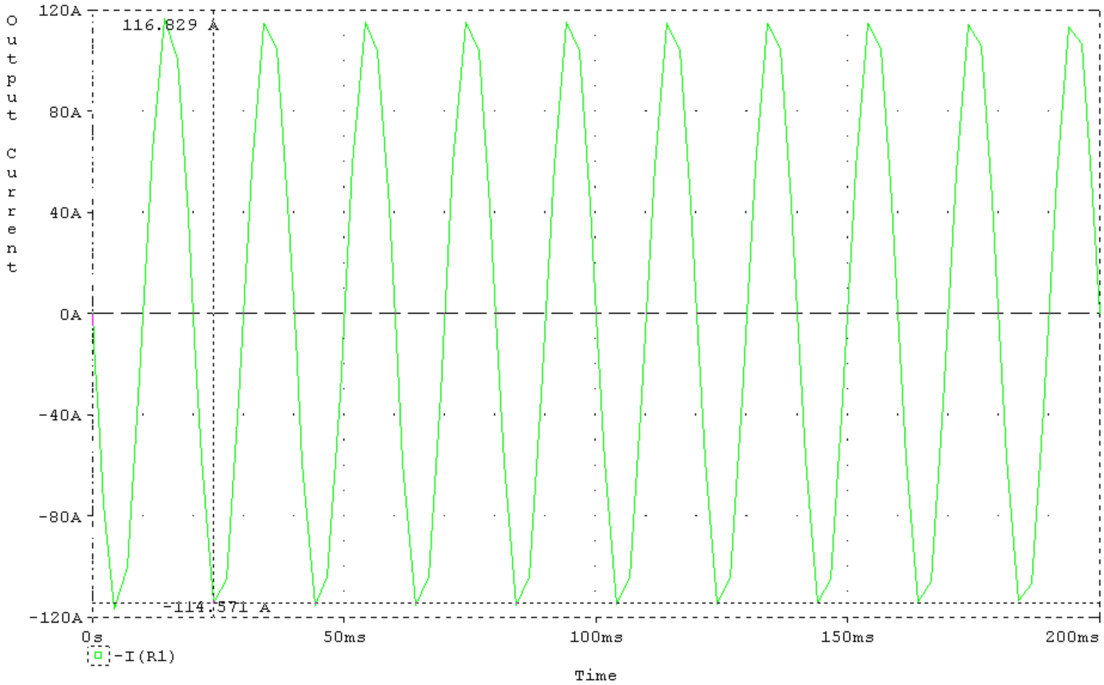


Figure 30 Output Current Waveform from Fig. 29 Circuit

3.3.3 Full Wave Rectifier with Low Pass Filter

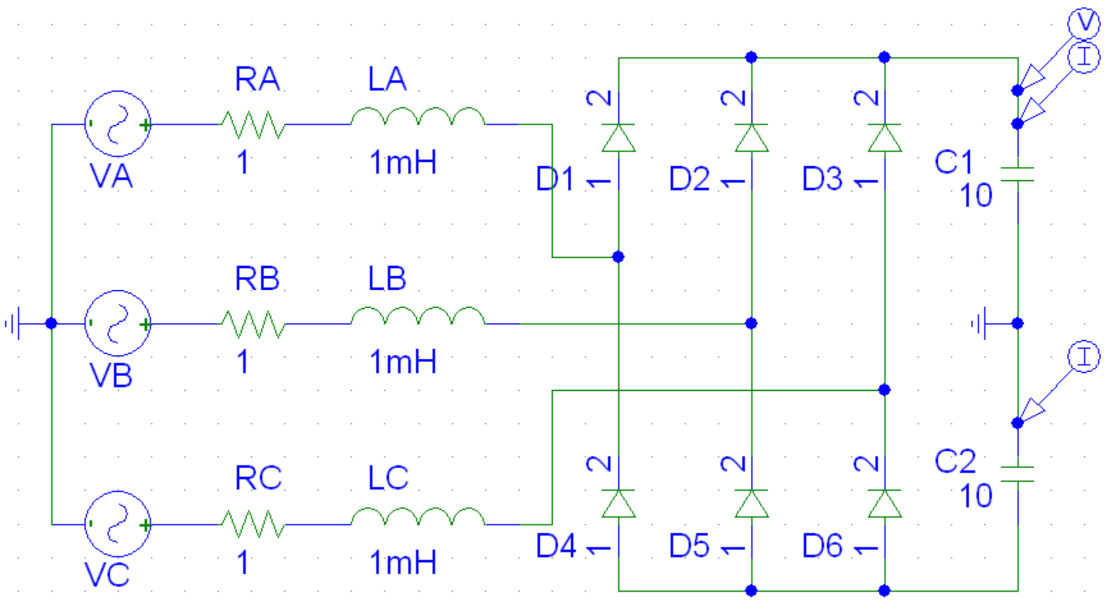


Figure 31 Full Wave Rectifier with Low Pass Filter

A full wave rectifier is used as it is suitable for very high current, very low ripple outputs with high input voltage applications. 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 according to Eq. (8) to obtain a 5 Hz output current waveform as in Fig. 33 and Fig. 34.

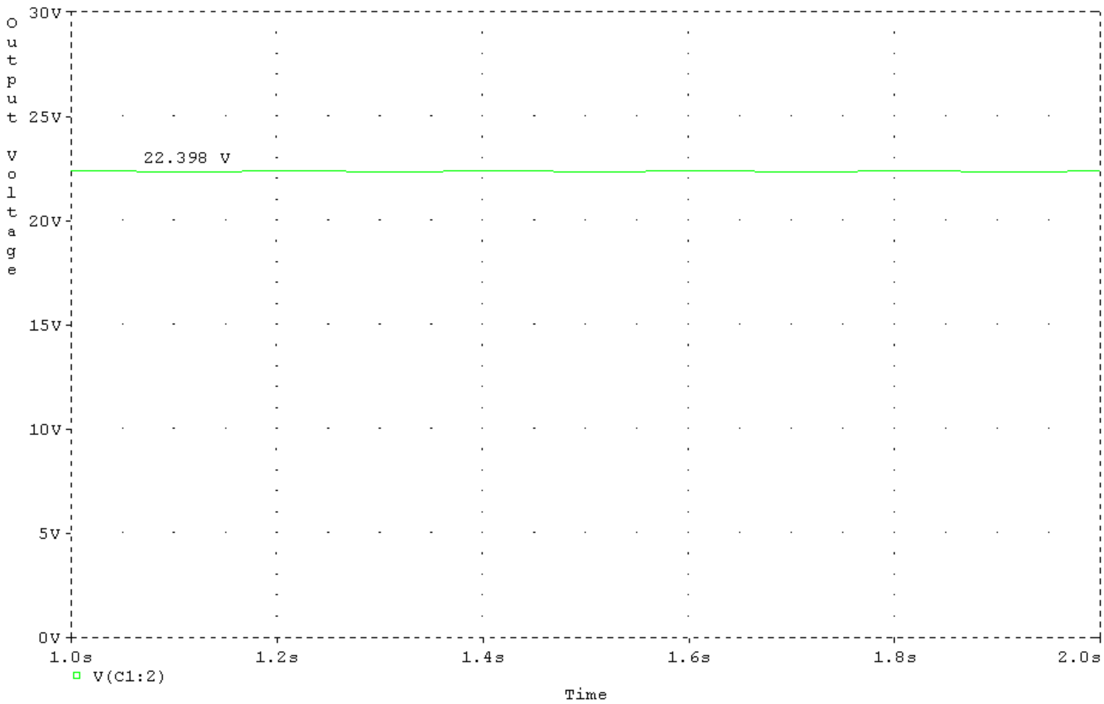


Figure 32 Output Voltage Waveform of Fig. 31 Circuit

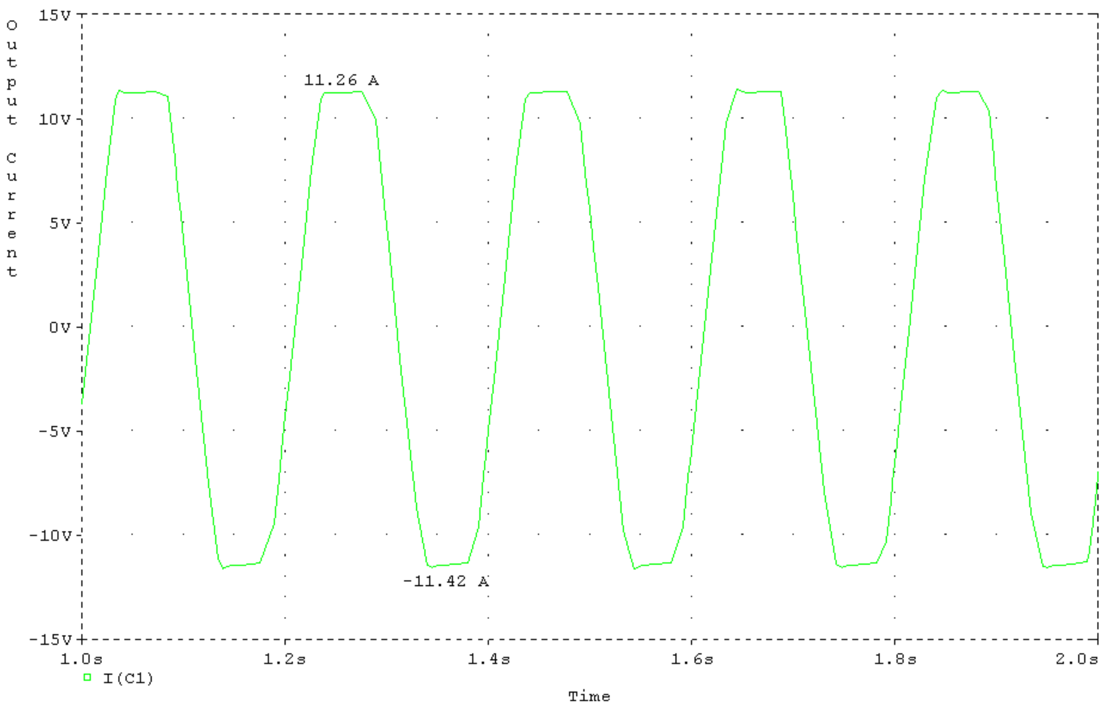


Figure 33 Output Current Waveform of Fig. 31 Circuit (C1)

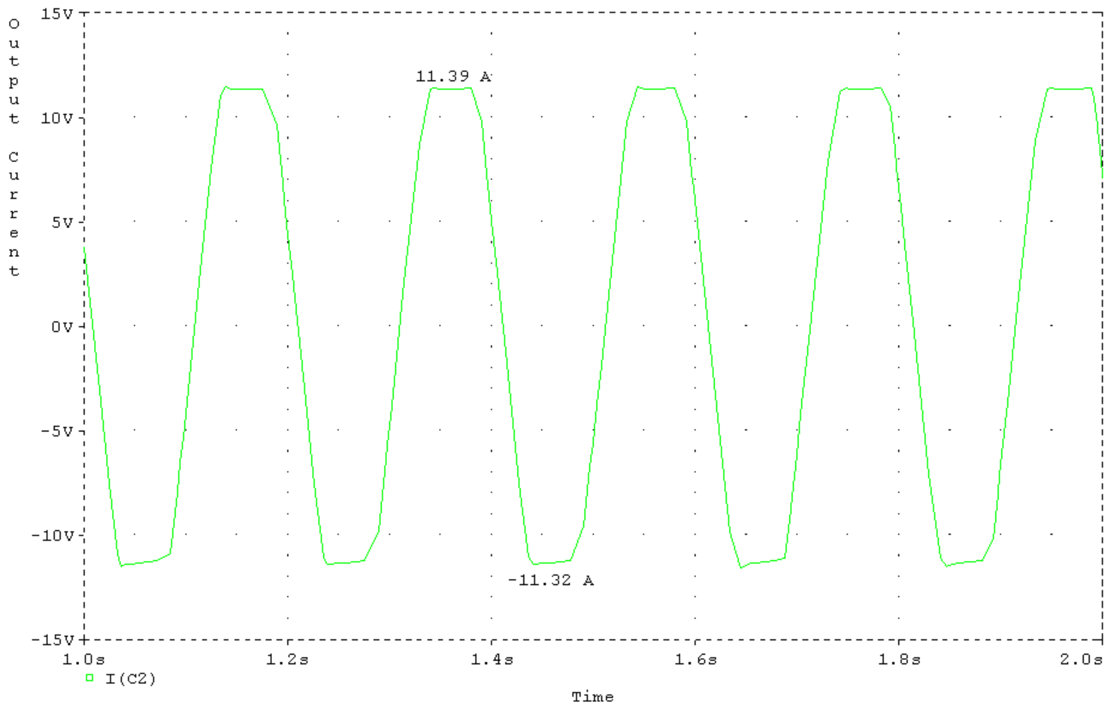


Figure 34 Output Current Waveforms of Fig. 31 Circuit (C2)

3.4 Drawbacks in the Design of High Load Current

In order to achieve the final objective of this project, a procedure has been prepared. The procedure is summarized in a block diagram as in Fig. 35.

Figure 35 Process to Determine the Drawbacks of High Power Applications

With the aim to determine the drawbacks in the design of high load current, research is done on the existing designs of power supplies and the respective applications. Flaws and disadvantages of each design are listed. After that, possible solutions for each flaw and disadvantage are discovered. Subsequently, a suitable technique to overcome the drawbacks in the design of high load current is applied in the design planned in previous subtopic in order to improve the design of 1000 A 5 Hz output power supply.

3.5 Research Methodology

Fig. 36 shows the overview of research methodology for both FYP 1 and FYP 2.

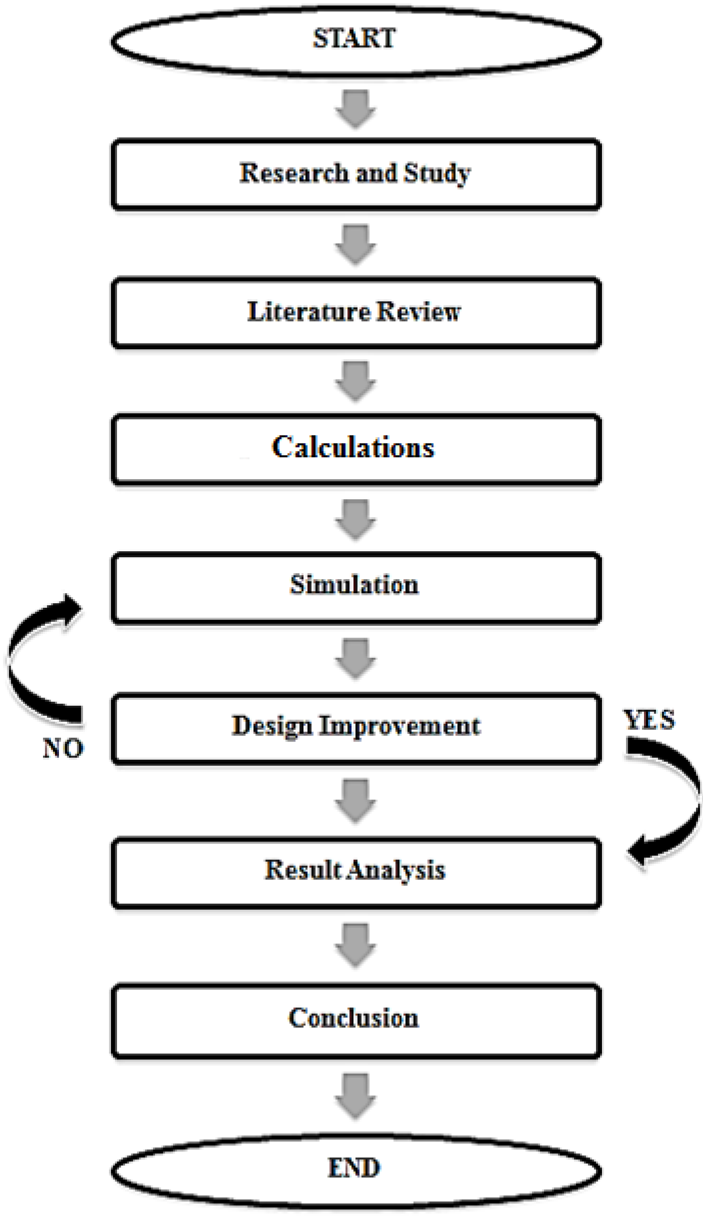


Figure 36 Research Methodology Flow Chart.

In the beginning of this project, proposal writing is carried out to outline problem statement and objectives. The scope of study is narrowed down to make this project relevance and feasible. A realistic plan is prepared to achieve the objectives within the given timeframe.

The next step is research on seabed logging (SBL) methods and applications. Then, detailed study on electrical and electronic part of SBL is carried out. All related terms are studied and understood. Journals, thesis, conference papers, and technical reports are referred during this process. Literature reviews are written to summarize and keep track on the references used throughout the project.

For the simulation work, required data and information are gathered through studies and calculations. Electronic network of the power supply is designed, and the requisite parameters for simulation are obtained. Afterward, simulation of the electronic network is done using PSpice. Results and output waveforms gain are analyzed.

If the results are not satisfactory, improvement in the network will be carried out. Changes in calculation and parameters value will be needed. When the required result is obtained, result analysis will be carried out. The end result should be a 1000 A current supply with 5 Hz frequency output. Analysis on how to have a better outcome is carried out subsequently. Recommendation is made for further improvement in the future design.

3.6 Key Milestone

The following Fig. 37 explained the key milestone for FYP 2 based on the submission dates.

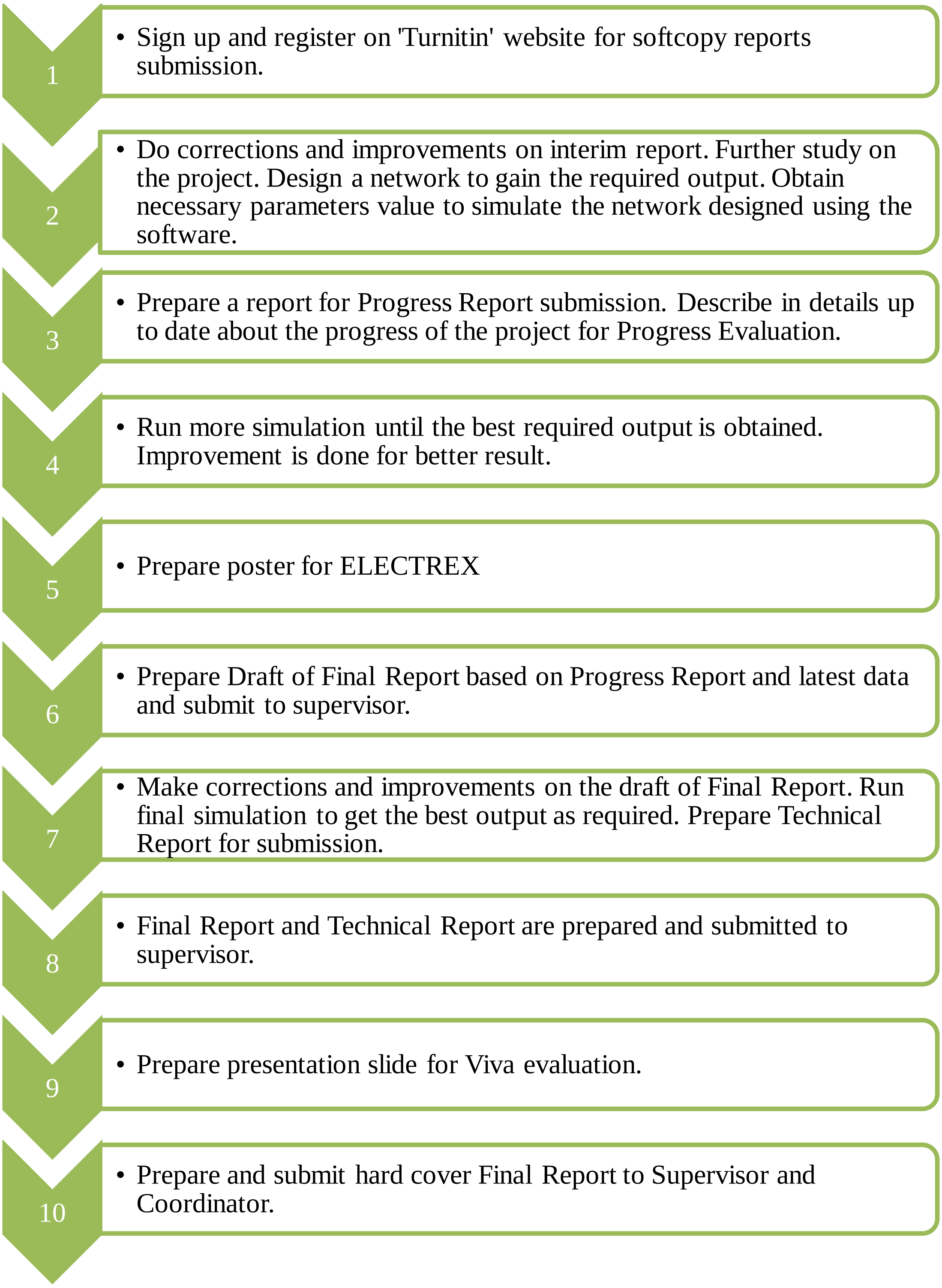


Figure 37 FYP 2 Key Milestone.

3.7 Gantt Chart

As shown in Table 3, the Gantt chart for FYP 2 is prepared pertaining to the submission dates.

Table 3 FYP1 Gantt Chart

Details	Week																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Preparation of Progress Report	■	■	■	■	■	■	■	■									
2. Submission of Progress Report								■									
3. Preparation for ELECTREX								■	■	■	■						
4. ELECTREX											■						
5. Preparation of Draft Report											■	■					
6. Submission of Draft Report												■					
7. Preparation of Final Report, Technical Report, Viva												■	■				
8. Final Report, Technical Report Submission, Viva														■			
9. Preparation of Hard Cover Final Report														■	■	■	
10. Submission of Hard Cover Final Report																	■

3.8 Software Required

To carry out the simulation of the power supply network, the software needed are as in Fig. 38:

Figure 38 Software Required to Design the Project

First, the parameters required in the design are determined. Then, the suitable values of each parameter are calculated using MATLAB software. The values are then substituted in the circuit designed in Multisim beforehand. The output waveform is analyzed to decide for better parameters' values. The values are then recalculated using MATLAB. This process is repeated until the best circuit design and parameters are acquired. The final circuit is drawn in PSPICE to get more accurate result analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 High Power Applications

In order to understand the classification of power supplies and their applications, studied had been done on several available power supply modules. It has been found that there are no specific numbers to outline the range of power which fall into the low power or high power categories. In the industry, from below 1 W up to two digits values can be considered as low power, and hundreds and more watt power are considered as high power. However, this might change according to some particular applications.

There are two main techniques in designing power supplies, which are linear and switch mode power supply. Table 4 shows the differences between linear power supply and switch mode power supply.

Table 4 Differences Between Linear and Switch Mode Power Supply

Linear Power Supply	Switch Mode Power Supply
• Variable resistance produced by power transistors operating in linear mode. • Comprises of control element, rectifiers and load connected in series. • Phase controlled pre-regulator as power switch, reduce power dissipated at series element. • Series element as variable resistor. • Feedback control observes the output and alters the series resistance for a constant output voltage.	• Integrate switching regulator to convert electrical power. • Use ideal storage elements such as inductors and capacitors. • Transistor repetitively switches between low dissipation, full on and full off state. • Use smaller transformer size and weight. • Less power dissipations, increase efficiency.

• Two output ranges: high voltage at low current or high current at low voltage.	• More complex. • Non-isolated and isolated topologies.

For switch mode power supply, it is further divided into two categories, namely isolated and non-isolated topologies. It is called isolated topology as the output part is isolated from the input part. For isolated topologies, the basic configurations are flyback and forward configuration. Each topology has specific voltage and current requirements for the power transistors (MOSFET or BJT) used in the design. Specific equations and calculations are used to determine the requirements of the transistors. Table 5 shows the comparison between forward and flyback converter.

Table 5 Forward and Flyback Converter

Forward Converter	**Flyback Converter**
• DC to DC converter. • Design similar to buck-boost with additional transformer. • Transformer alters the output of voltage and provides isolation from input. • Intermediate power supplies of 100 to 500 W ranges. • Power is delivered during the on time of the transistors. • Rectifiers work as average rectifiers.	• Both AC to DC and DC to DC conversion. • Design similar to buck-boost with additional transformer. • Transformer alters the output of voltage and provides isolation from input. • Energy stored in the transformer before supplying it to the output. • Delivers power to the load during the off time of the transistor. • Rectifiers work as peak rectifiers.

On the other hands, buck, boost and buck-boost converters are the basic configurations for non-isolated topologies. Each of the configurations has its own characteristics and advantages which will determine which configuration is the best to be used in specific output and application. Table 6 shows summarized details on non-isolated topologies configuration.

Table 6 Non-Isolated Topologies Power Supply

Buck Converter	• Step down DC to DC converter: output voltage is less than input voltage • Produce pure DC output using low pass filter. • Diode provide forward bias when switch opened, reverse bias when switch closed.
Boost Converter	• Step up DC to DC converter: output voltage greater than input voltage. • Output current lower than source current. • Usually consist of switches (diode and transistor), and storage element (capacitor and inductor) as filter. • Diode provide forward bias when switch opened, reverse bias when switch closed.
Buck-Boost Converter	• Can have smaller (buck) or larger (boost) output voltage compare to input voltage. • Diode provide forward bias when switch opened, reverse bias when switch closed. • Negative polarity output voltage.

4.2 Power Supply with 1000 A, 5 Hz Output for SBL Application

By referring to the transformer configuration and full wave rectifier setting in Methodology chapter, a power supply with the required alternately positive and negative of 1000 A square waved output is designed. The resulting circuit design is as in Fig. 39. The transformer is using 6:1 turn ratio with the reason stated in the previous chapter. Resistors are connected to each supply to avoid short circuit current. Current limiters are placed after all sources to limit the current to positive and negative 1000 A, with very high gain to produce a near rectangular current waveform. The resulting output current waveforms are shown in Fig. 40 and Fig.41.

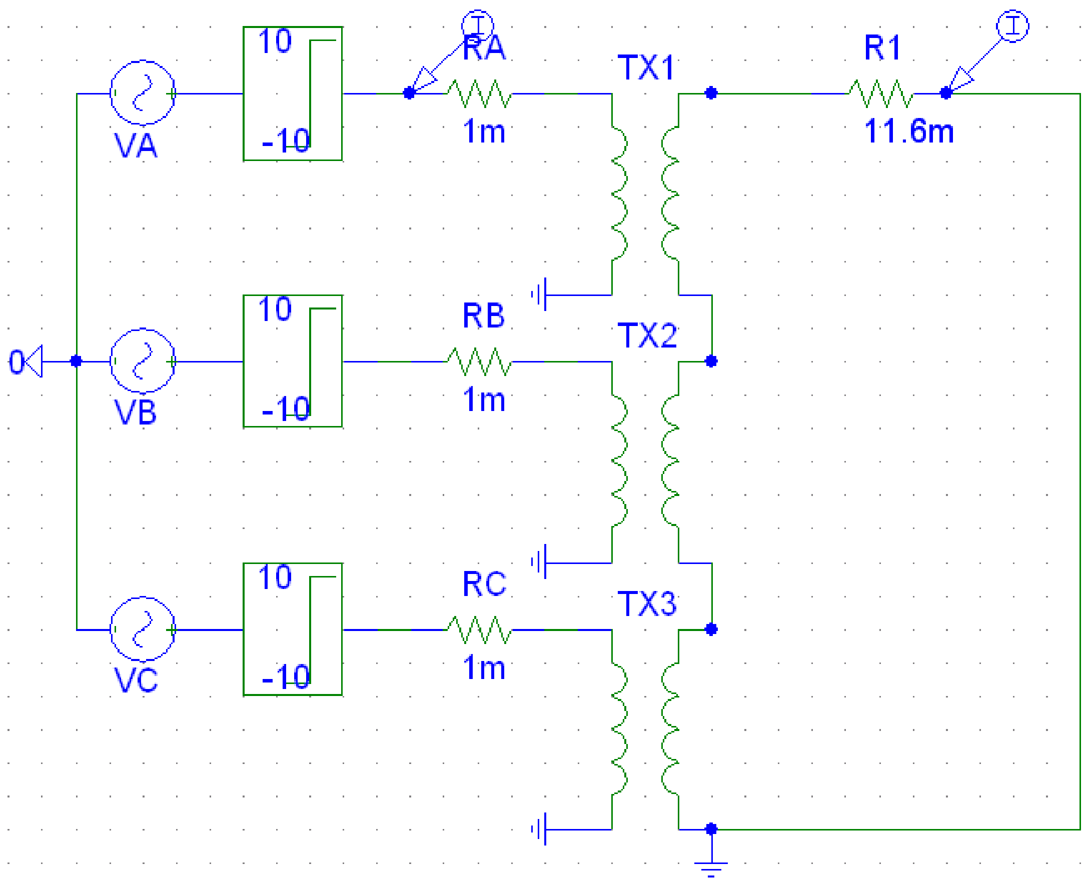


Figure 39 Power Supply with 1000 A Output Current

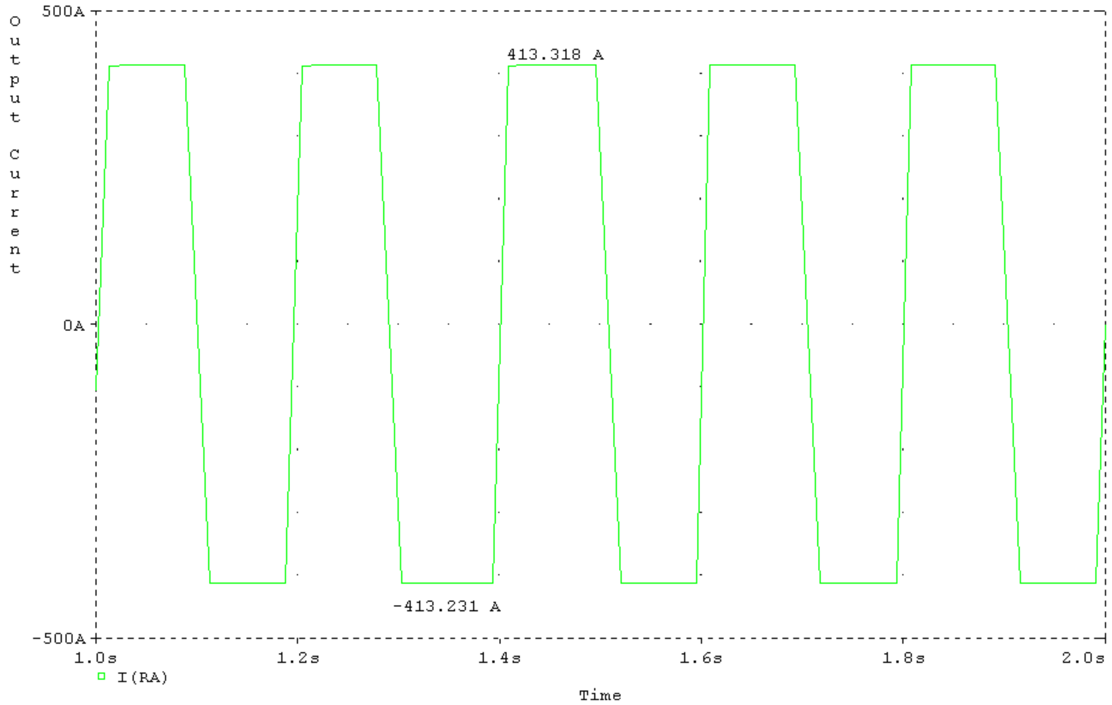


Figure 40   Output Current Waveforms for Fig. 36 Circuit (RA)

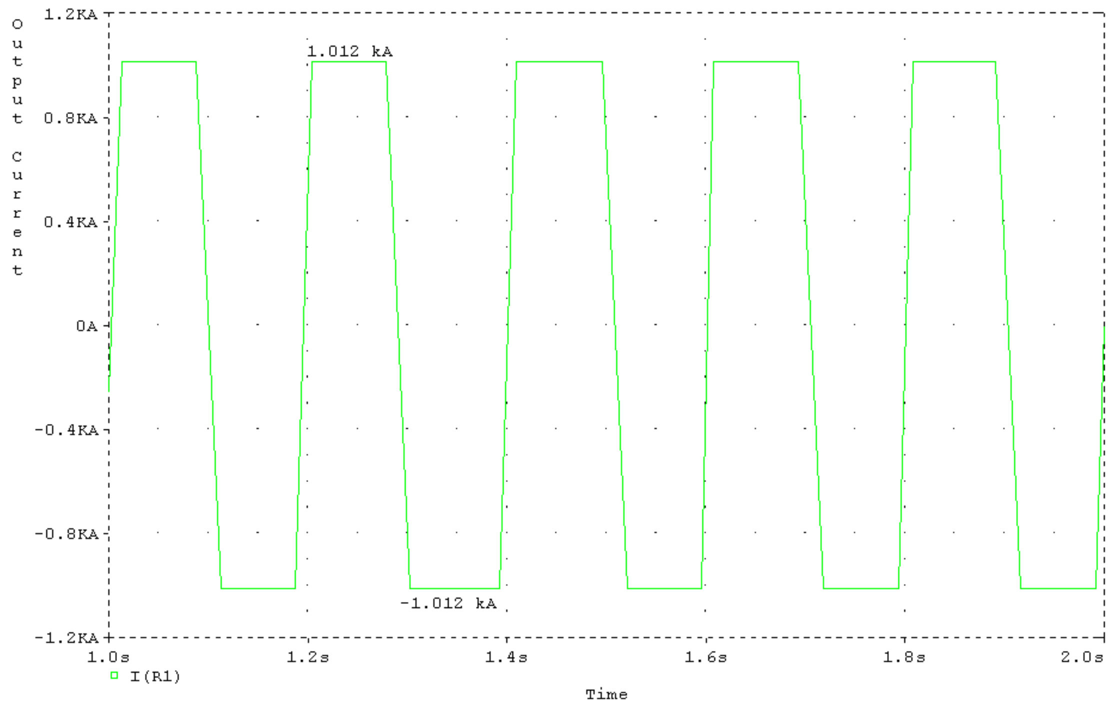


Figure 41   Output Current Waveforms for Fig. 36 Circuit (R1)

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.

However, 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.

4.3 Drawback of High Load Current Design

Presently, high load current devices are widely used in electrical and electronic industries, especially in power supplies industry for numerous applications. However, several disadvantages have been defined in the design of high load current applications. These include potential danger to circuit, environment and personnel in case of faults, limited choices of electronic devices for very high current applications, and also massive device size and cost. Therefore, the operation of high load current devices needs to be accompanied by appropriate protection device such as protection relay, circuit breaker and fuse to avoid any harm to the circuit and also to human. Table 7 shows the comparison between these circuit protection components.

Table 7 Circuit Protections

Protection	Description
Protective Relay	• Electromagnetic: uses current and voltage to produce magnetic flux in order to generate torques on movable disks and relays. • Solid state: uses detected currents and voltages to produce low voltage analogue. • Numeric relay: multifunction, programmable logic relay, digitizes detected current and voltage to calculate RMS or phasor equivalent value by using a high-end microprocessor.
Circuit Breaker	• Mechanical switching device which makes, carries and breaks currents under normal circuit conditions, or for a specified time. • Protect circuit's components by providing overcurrent protection and isolation from energized and un-energized circuit components.
Fuse	• Disconnected circuit to avoid further damages by overheating or fire caused by the excessive current flow. • Metal wire or strip that melts when too much current flows through it.

In order to overcome limited choices of electronic devices for very high current applications, further researches and studies are needed to design space reduction and cost reduction with protection enhancement components in high load current design with higher current and voltage rating. As high current application is often associated with high power losses which lead to reduction of efficiency, the circuit design must consider the power loss in each component. High power losses will lead to high heat dissipations, moreover heat sink will be necessary in circuit design. As high current supply often requires complex design with a lot of additional components, the power supply usually is larger in size and has higher cost compared to lower current supply.

CONCLUSION

Controlled Source Electromagnetic (CSEM) method in seabed logging (SBL) application has a rapid development due to the increasing need of a more effective and efficient method in finding hydrocarbon layers inside the seabed. Consequently, designing a power supply which provides a high current and low frequency output required for Horizontal Electric Dipole (HED) used in CSEM is highly necessary. In order to design a power supply with the stated output, a three phase input supply is connected. Afterward, the output of the power supply will go through a current limiter to have a square wave alternating positive and negative DC output. Next, the square wave will be stepped down by a transformer to get a higher current value. Lastly, the output from the transformer will be filtered by a low pass circuit to attenuate the high frequencies values. The design and simulation of this power supply is done by using two software, and necessary improvement will be taken to gain the best result from the design. At the end of this project, the objectives are successfully achieved by designing a power supply with alternating positive and negative 1000 A output at 5 Hz frequency for SBL application.

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APPENDIX A

120NQ045

International
IOR Rectifier

PD-2.224 rev. B 12/97

120NQ... SERIES

SCHOTTKY RECTIFIER

120 Amp

Major Ratings and Characteristics

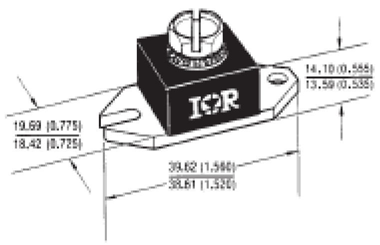
Characteristics	120NQ...	Units
$I_{F(AV)}$ Rectangular waveform	120	A
V_{RRM} range	35 to 45	V
I_{FSM} @ tp = 5 μs sine	29,000	A
V_F @120Apk, T_J=125°C	0.52	V
T_J range	-55 to 150	°C

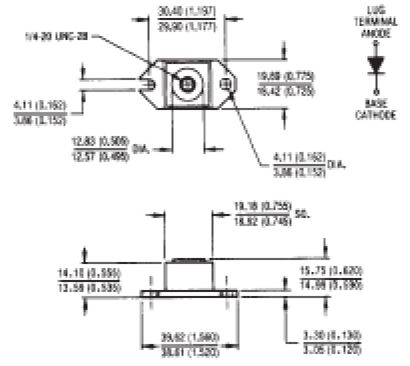
Description/Features

The 120NQ high current Schottky rectifier module series has been optimized for very low forward voltage drop, with moderate leakage. The proprietary barrier technology allows for reliable operation up to 150° C junction temperature. Typical applications are in switching power supplies, converters, free-wheeling diodes, and reverse battery protection.

- 150° C T_J operation
- Unique high power, Half-Pak module
- Replaces two parallel DO-5's
- Easier to mount and lower profile than DO-5's
- High purity, high temperature epoxy encapsulation for enhanced mechanical strength and moisture resistance
- Very low forward voltage drop
- High frequency operation
- Guard ring for enhanced ruggedness and long term reliability

CASE STYLE AND DIMENSIONS





Outline HALF PAK Module

Dimensions in millimeters and inches