DC-DC Hi-Voltage Converter in application of multi-stage coil gun power charger

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Abstract. The multi-stage coil gun is a coilgun with many coils as launchers. Coilgun requires a lot of power to work. High voltage and large currents are needed. Sources of energy to support the coilgun are limited. Alternatives that are often used by using high voltage capacitors bank. To store energy in a capacitor bank from a battery, a charging device is needed. High voltage DC to DC converter is required. In this article, a high voltage capacitor bank charging device is discussed to support a multi-stage coilgun. The device has been successfully implemented to support six coilgun levels with the ability to increase the voltage from 12 V to 1.1 kV DC.

1. Introduction

Many researchers have studied coilgun, starting from system modeling simulations, calculating each force and energy on a single level coilgun[1], construction and simulation of coilgun parts with capacitors as energy storage[2], coilgun current injection systems using genetics algorithmic methods to get pulse parameters to activate multi-stagecoilgun[3][4]. Comparison of simulations and experiments on the three-level coilgun has also been done[5]. The weakness of the coilgun is its relatively lower power compared to a conventional firearm. Multi coils used to increase the throwing power on the coilgun[6][7][8][9][10].

Most of the research is about simulation and modeling. The problem with real applications from coilgun is more complex. Coilgun requires a lot of energy to work. Taking energy directly from the battery is almost impossible because it requires very high current and voltage. Capacitor Bank is used to store energy. Capacitors with large capacity will be charged to the required limit. The required voltage can reach of kilovolts (kV). This capacitor charging system is very rarely resolved. This is a very vital system. Therefore, in this article about the application of DC-DC Hi-Voltage Converter for the application of capacitor bank charging on multi-stagecoilgun. The results of this study are that the coilgun energy charging system model can be used on real devices on multilevel coilgun as an alternative weapon to replace conventional firearms.

2. Research Method

To realize a multistage coilgun requires several parts including power supply, DC-DC Hi-Voltage Converter, Charging Controller, Bank Capacitor, Coils, Switching Circuit, and Control Unit. The complete system of the multistage coilgun is shown in Figure 1. In this study, 12V batteries are used as a power supply. The charger is a High-Voltage DC / DC converter consisting of a DC / AC converter,
voltage multiplier, set point and voltage monitor and charging control circuit consisting of an autocut circuit with hysteresis.

In designing devices that will be realized several important parameters have been established. Some of them are battery capacity, DC / AC converter capability, number of multipliers, switching capabilities and charging controllers. The parameters in the realization of the device are shown in Table 1.

Table 1. Parameters of the device

| No | Parameters                        | Value                      |
|----|-----------------------------------|----------------------------|
| 1  | Battery                           | 12 V 5000mAH               |
| 2  | DC/AC Converter                   | 12 V to 380V / 50Hz/ 500 Watt |
| 3  | Voltage Multiplier                | 10 Stage                   |
| 4  | Switching Circuit                 | IGBT 1500 V/ 300 A Max     |
| 5  | Charging Control Circuit          | Comparator w/ hysteresis   |

The capacitor bank specifications used are shown in table 2. In this study, the capacitors bank can supply 6 stages of coilgun with the energy of each stage displayed in the table. The energy displayed is the maximum energy that capacitors can store. Energy (Joule) can be calculated from the maximum capacitance and voltage values with equation 1.

\[ W = \frac{1}{2} CV^2 \]  

(1)

Table 2. Specification of Capacitor Bank

| Stage | 1   | 2   | 3   | 4   | 5   | 6   |
|-------|-----|-----|-----|-----|-----|-----|
| Voltage Max (V) | 100 | 100 | 300 | 600 | 900 | 1500 |
| Capacity (uF)    | 1000| 1000| 333.33| 166.66| 111.11| 66.66 |
| Energy Max (J)   | 5   | 5   | 15  | 30  | 45  | 75  |
| Total Energy Storage Max (J) | 175 |

3. Result and Analysis
To design and realize the device can be divided into several parts. In the discussion, the design and results of each part will be reviewed as a representation of the whole system. The characteristics of the charging for each stage will also be displayed here.

### 3.1.1. DC/AC Converter
The DC / AC converter circuit is built from a pulse generator mechanism, switching devices from MOSFETs and step-up transformers. Part of this system is shown in Figure 2. The output of the DC / AC is at the transformer output. The circuit afterward is only for monitoring the peak voltage of the system and the selection device ON / OFF. In testing, the system can provide 380 V output with a frequency of 50 Hz.

![Figure 2. Part of DC/AC Converter.](image)

### 3.1.2. Voltage Multiplier
The voltage multiplier design can be adjusted as needed. In this study using 10 levels of voltage multiplier for all stages. This is done by taking into account the maximum voltage needed from all stages. At lower levels, the voltage multiplier here will not have a significant effect. By making all the stages the same it will make it easier in the process of implementing the tool. Design 10 voltage multiplier levels shown in Figure 3.

![Figure 3. 10 Levels Voltage Multiplier.](image)
3.1.3. Capacitor Bank
The capacitors bank used are in accordance with the specifications in the previous section. The capacitor bank is composed of 1000µF / 100V electrolytic capacitors. To get the desired voltage, capacitors are arranged in series. In Figure 4 a series of 10 capacitors is displayed. Each capacitor is coupled with resistors in parallel. This is done as a voltage divider so that the capacitor is balanced. The imbalance of charging capacitors is dangerous because there is a risk that capacitors are overcharged.

3.1.4. Charging Control Circuit
Charging control circuit consists of a comparator with hysteresis and relay circuit. This circuit is used as a voltage monitor on the capacitor bank. When the voltage on the capacitor bank exceeds the setpoint voltage, the relay will turn off the charger circuit. The comparator uses hysteresis in order to avoid oscillation in the relay circuit due to the rise and fall of the voltage of the capacitor bank. The comparator provides a lower tolerance than the upper tolerance. The comparator has a stable reference voltage from the voltage regulator. The setpoint voltage can be adjusted by changing the existing variable resistor. This circuit is shown in Figure 5.

3.1.5. Switching Circuit
The switching section is the part that regulates the discharge time from the capacitor bank to the coil. With a large capacity capacitor bank, the current that can be passed is also very large. The choice of electronic components for high voltage and large currents is very limited. One of the main choices is IGBT (Insulated Gate Bipolar Transistor). IGBT provides maximum specifications of relatively large voltages and currents. In this study used specifications IGBT 1300V and 60 Ampere. To get a maximum current of 300 Ampere, IGBT can be arranged in parallel. To connect the control unit to the IGBT circuit is isolated using an optocoupler. This is done so that there is no voltage or reverse flow from the high voltage section to the low voltage section. The circuit used in this study is shown in Figure 6.

3.1.6. Charging Characteristic

Charging characteristics are observed by monitoring the voltage of the capacitor bank. With the six stages available, the capacitor banks used vary. The set-points used are in accordance with the table in the previous section. The charging time needed to fill the capacitor is shown in Figure 7. Based on the experiment, the charging time varies according to the value of the capacitor used. The greater the value of the capacitor, the charging time will be longer. The consecutive times needed for stage one to stage six are shown in Table 3. The stage one takes 25 seconds while six stages require a longer time which is greater than 400 seconds.

Table 3. Charging Time each Stage Capacitors Bank
| Stage | 1  | 2  | 3  | 4  | 5   | 6    |
|-------|----|----|----|----|-----|------|
| Voltage set-point (V) | 100 | 100 | 300 | 600 | 900  | 1500 |
| Time (s)   | 25  | 25  | 45  | 100 | 300  | >400 |

All the circuits discussed have been implemented. The implementation documentation of the DC / AC converter system and the charging control circuit is shown in Figure 8. Implementation of the system from bank capacitors and switching circuits is shown in Figure 9. All circuits are packaged in a metal box 50 x 50 x 12 cm.

4. Conclusion
Hi-Voltage Converter in Application DC-DC Multi-Stage Coil Gun Power Charger has been implemented. Based on the experiments carried out each part of the system functions properly. The charging time of the capacitor bank varies according to its capacitance. The greater the capacitance, the charging time will be longer. The higher the set-point voltage also requires more time. With a limited capacitor, the higher the capacitor voltage, the lower the capacitance value. Capacitor charging time for the first stage reaches 25 seconds while the last stage reaches > 400 seconds. So that the time of the six-stagecoilgun to be used requires the longest time, which is > 400 seconds with the energy charging ability
reaching 175 Joules. The charging time produced until now is still too long, so it is still less effective. Further research can be made of a mechanism for charging capacitor banks faster. Another alternative is to use other alternative sources that are more efficient.

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