High voltage capacitor charging system in application of multi-stage coil gun

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Abstract. High voltage capacitor charging system applied for multi-stage coil consisting of a coil arrangement as a launcher and requires much energy to work. However, large currents and the high voltage required are very limited. High voltage capacitor banks are used as an alternative for energy storage. This capacitor bank is supplied by batteries and requires a charging device. The process of charging a high voltage charging capacitor requires a DC-DC Converter device. In this article, to supply energy to the coilgun, a High Voltage Capacitor Bank is used. 10 capacitors are connected in parallel charging the capacitors with a voltage divider system to avoid swelling at the capacitor charge. This device has been successfully implemented in Multistage Coil Gun. The results achieved indicate an increase in voltage capability up to 1.8 kV DC.

1. Introduction

The application of the high voltage capacitor charging system circuit to flow current to the coilgun can be used to move the projectile. Coil gun is divided into 2 types namely single-stage and multi-stage. Coil gun has been widely studied from simulation to implementation. The 3-stage coil gun construction has been carried out using the genetic algorithm method that produces PWM pulse variations for current and voltage regulation [1-4]. The current settings are used to activate the coil gun. Weaknesses found are low power compared to conventional firearms [5-6]. The addition of the number of stage coil is used as a solution to increase the power of the coil gun to launch a projectile [7-10].

Most of the research deals with simulations and modelling [11]. While the implementation of the prototype has more complex problems [11]. To activate the coil gun requires large energy. The energy is very impossible to obtain if you take it directly from the battery because the coil gun requires a large voltage and current. As a solution, bank capacitors with certain specifications are needed to store energy. The voltage charged to the capacitor bank reaches kilovolts (KV). Capacitor charging system takes a short time so it is difficult to solve [12-15]. In a coil gun system, charging the capacitor is a very important process. In this article discusses the high voltage capacitor charging using a DC-DC converter. The result of this research is a model of energy coil gun charging system applied to multi-stage coil gun as an alternative weapon.

2. Methodology

2.1. Block diagram coil gun
The coil gun system consists of a series of the coil also Control Unit, switching Circuit, DC-DC Converter, power supply, Capacitor Bank and charge controller is shown in Figure 1.
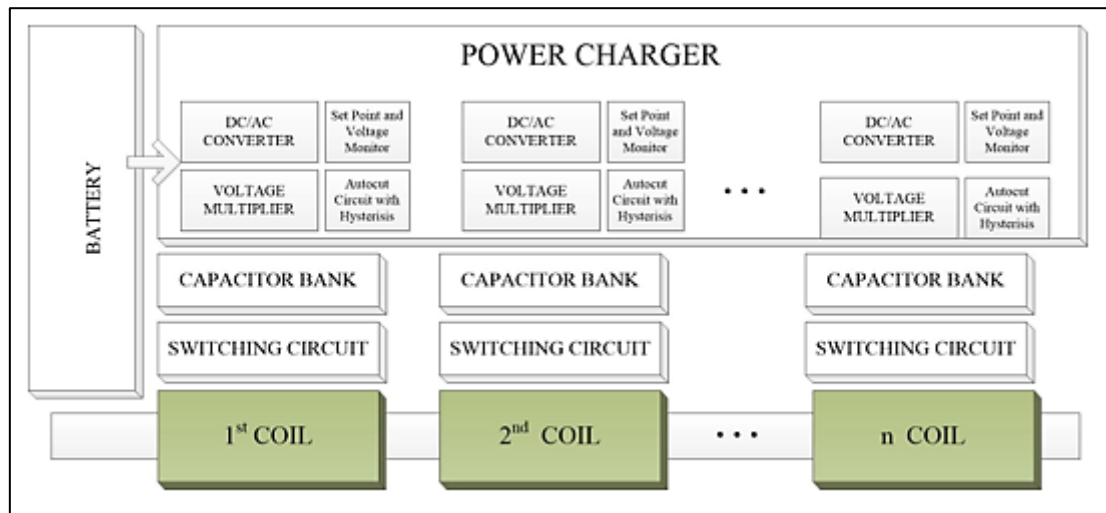

Figure 1. Block system diagram.

2.2. Parameters device
Construction of multi-stage in this study, some of the parameters set is a battery, number of multipliers, charging controllers, DC-AC converter and switching systems are shown in Table 1. While Table 2 is a specification of the bank capacitor used to supply 6 stages with each stage of the required gun coil energy.

Table 1. Specification device.

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

Table 2. Specification capacitor bank.

Stage	1	2	3	4	5	6
Capacity (uF)	1000	1000	400	200	200	100
Voltage Max (V)	120	120	300	700	1000	1500
Energy Max (J)	5	7	15	33	55	75
Total Energy Storage Max (J)				190		

   The energy shown is the maximum energy purposes that can hold capacitor. Calculation of energy (Joule) based on the maximum capacitance and voltage values shown in Equation (1).

$$W = \frac{1}{2}CV^2 \qquad\qquad (1)$$

3. Results and discussion

To design a high voltage capacitor charging system, it starts with making simulation and then applies it to a prototype that is used for multi-stage coil gun charging. In the discussion, the design of each section is reviewed as a representation of the whole system. Charging characteristics for each stage are indicated.

3.1. DC to AC converter

Pulse Generators, Step-Up transformers, and switching are used in the design of DC / AC converter circuits. Figure 2 shows a circuit with an output transformer. This circuit afterward only monitors the ON / OFF device and the peak voltage of the selection system. Every system test with a frequency of 50 Hz produces an output voltage of 380 V.
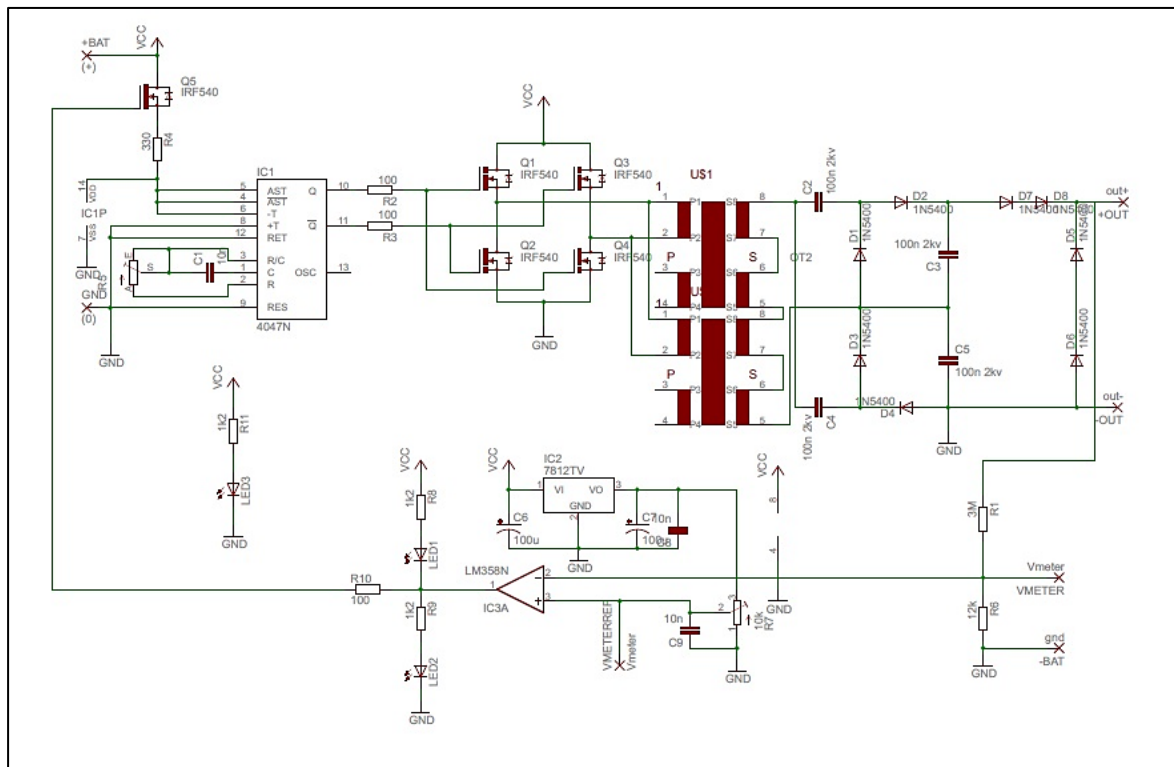

Figure 2. DC/AC converter.

3.2. Voltage multiplier

A 10-level voltage multiplier is used by adjusting the needs at each stage based on the calculation of the maximum voltage needed at each stage. But voltage multipliers do not have a significant effect at lower levels. Figure 3 shows a voltage multiplier with 10 levels.
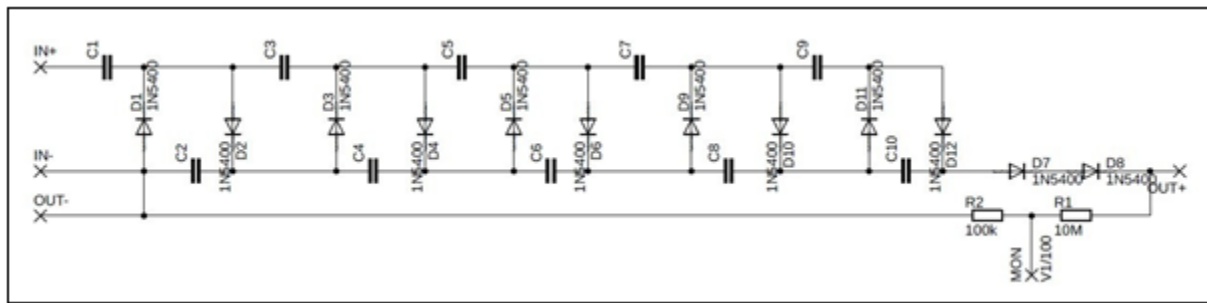
Figure 3. Voltage multiplier.

3.3. Capacitor bank

The specifications of the capacitor bank consists of a series of electrolytic capacitors 1000uF / 100V. The desired voltage can be achieved by arranging capacitors in series by combining resistors in parallel for the voltage regulator shown in Figure 4. This is done so that charging the capacitor is balanced to avoid the risk of of damage to the capacitor.
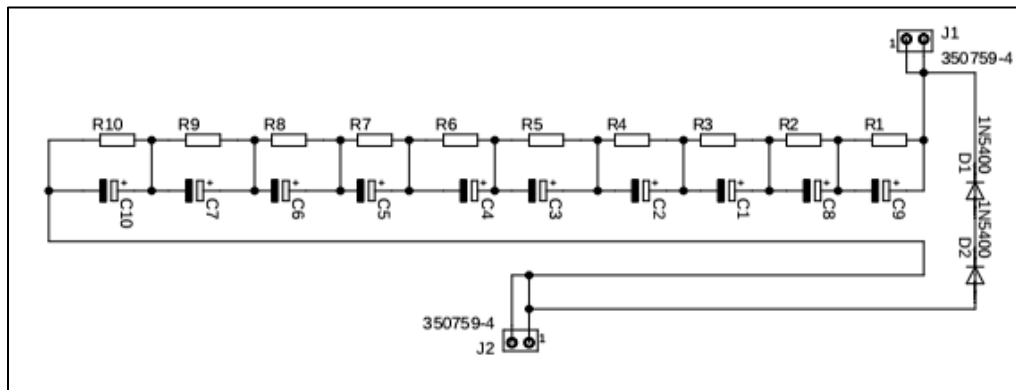

Figure 4. Capacitor bank circuit.

3.4. Charging control circuit

Relay and comparator circuits with hysteresis are used for the charging control circuit and are used to monitor the voltage on the capacitor bank. capacitor bank voltage must not exceed the set point, because the charger circuit is turned off the relay. To avoid oscillation, the comparison uses hysteresis because the capacitor bank voltage is unstable. This comparative function is to provide a lower. To stabilize the voltage can be done by changing the variable resistor according to the reference voltage in Figure 5.
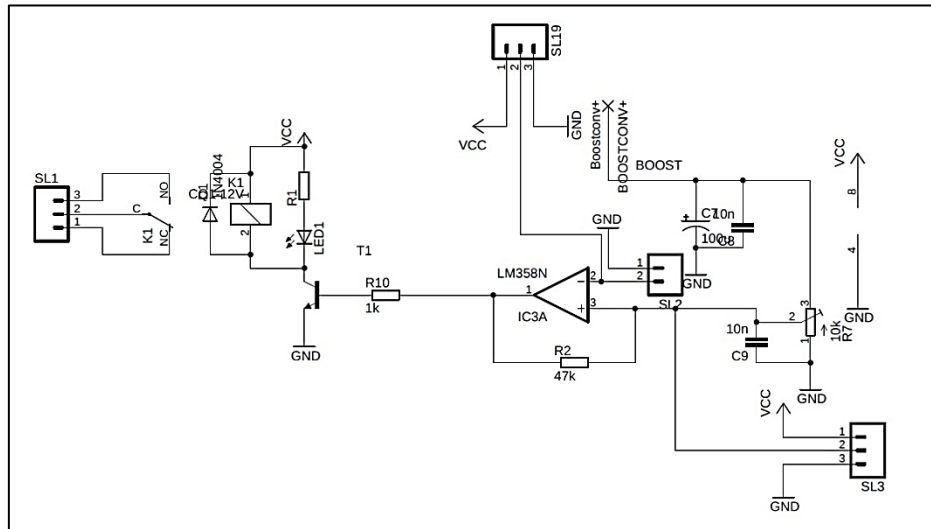
Figure 5. Charging control circuit.

3.5. Switching circuit

Switching works to adjust the discharge time of the capacitor bank to the coil. The greater the capacitor bank capacity, the greater the current that can be passed. IGBT (Insulated Gate Bipolar Transistor) as a component selected with a maximum specification of relatively high voltage and current. In this study IGBT 60A 1300V was used. Whereas a maximum current of 300A, so that the IGBT is arranged in parallel so that there is no reverse current from the high voltage to the low voltage optocoupler. This is used as a connection to the IGBT circuit control unit with the circuit shown in Figure 6.
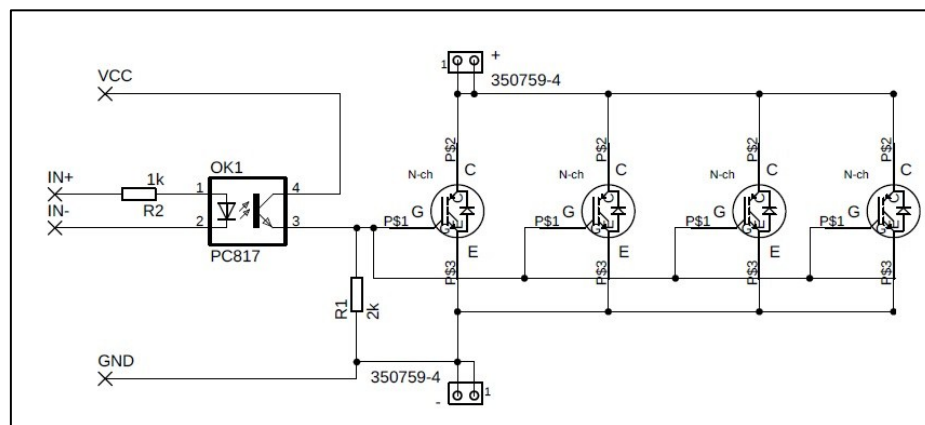

Figure 6. Switching circuit.

3.6. Charging characteristic

Observation of the capacitor bank voltage characteristics at the 6-stage varies. The charging time required to charge the capacitor follows the set-point used following the table in the previous section shown in Figure 7.
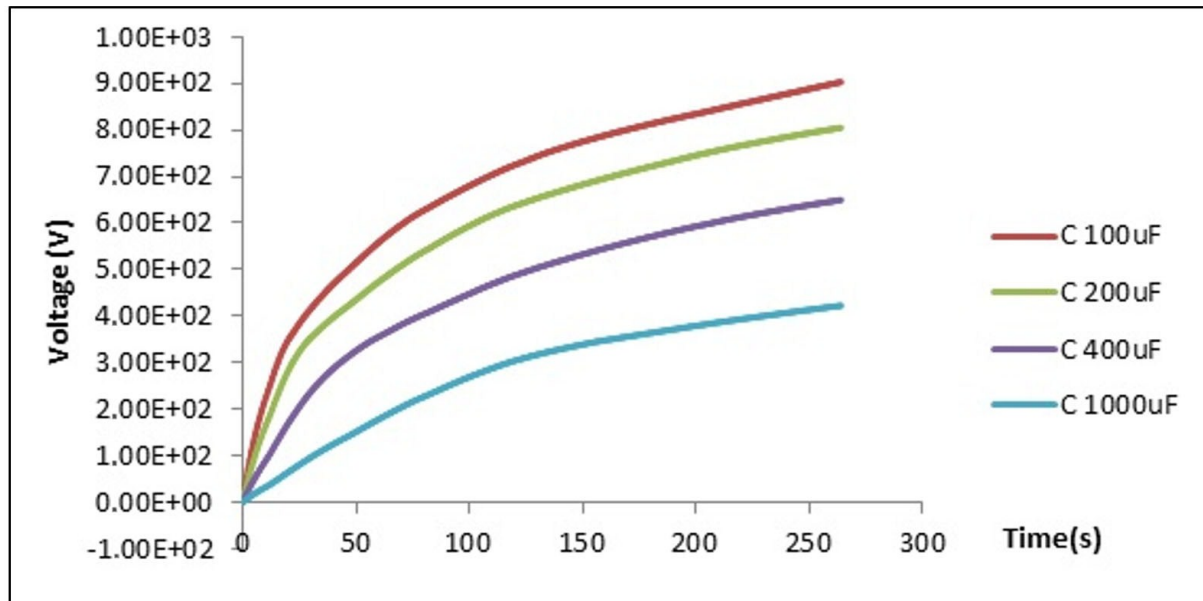
Figure 7. Charging characteristic.

The results of the experiment, charging the capacitor takes time to vary the capacitance as used. The sequential time required in each stage is shown in Table 3. The experiment was conducted 7 times of testing. For stages 1 to 3, the average time is under 1 second, while stages 4 to 6 require time above 60 seconds.

Table 3. Charging capacitors bank.

Trial	Stage											
	1		2		3		4		5		6	
	set-point (V)	Time (s)	set-point (V)	Time (s)	set-point (V)	Time (s)	set-point (V)	Time (s)	set-point (V)	Time (s)	set-point (V)	Time (s)
1	100	30	100	35	300	50	600	99	900	301	1500	401
2	100	31	100	34	300	52	600	100	900	299	1500	402
3	100	29	100	34	300	49	600	102	900	301	1500	404
4	100	32	100	36	300	49	600	99	900	302	1500	402
5	100	32	100	37	300	51	600	101	900	302	1500	402
6	100	33	100	33	300	53	600	103	900	303	1500	401
7	100	31	100	32	300	51	600	102	900	301	1500	403

All DC / AC series converter systems have been implemented and the bank capacitor switching circuit is shown in Figures 8 and 9.
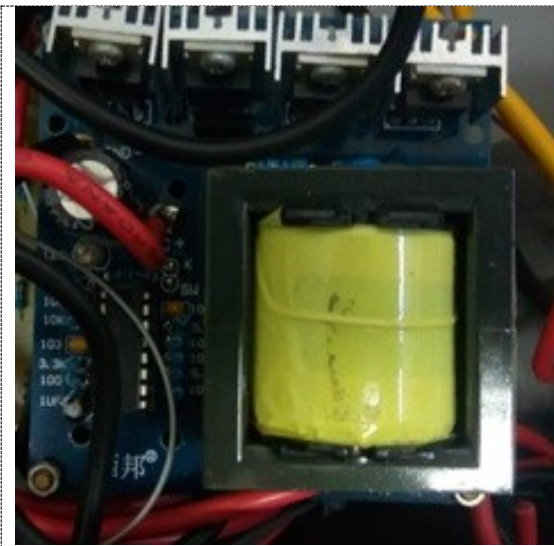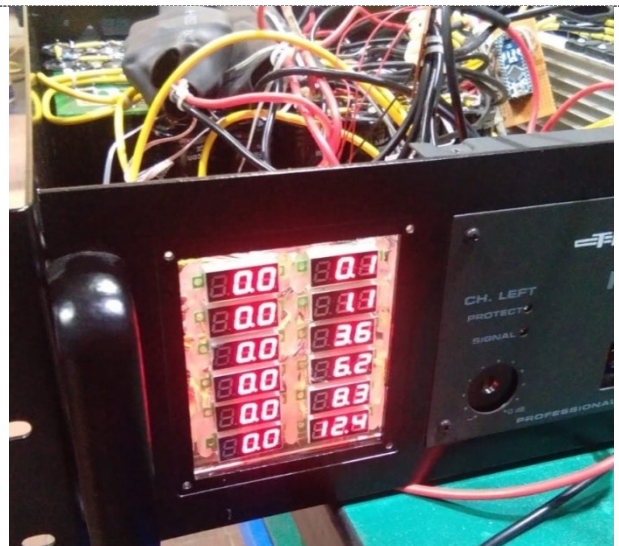
Figure 8. DC/AC converter.

Figure 9. Charging control circuit.

4. Conclusions

Charging high voltage capacitors used a multi-stage DC-DC coil gun been applied. All parts of the system has been tested and works fine. The time required to charge a capacitor bank is linear. The greater the capacitance value, the longer the charging time. The first stage capacitor takes 29 seconds. whereas for the last stage capacitors, it takes more than 400 seconds. Calculation of the overall time for charging a 6-stage coil using the longest time is more than 400 seconds with the ability to reach 190 Joules of energy charging. The resulting charging time is very long so it has not been effective. The next research that needs to be discussed is the mechanism of charging capacitor banks to make other methods faster so that they are more efficient.

5. References

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