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High Voltage Capacitor Discharge during Crash in Automobiles

[1] Sunitha S, [2] Dr. R. Karthikeyan
[1] M.Tech Student [2] Assistant Professor (SG), Vice Chairperson (EI)
[1][2] Department of ECE, Amrita School of Engineering, Bangalore.

***Abstract:* - During a vehicle crash or other vehicle damaging event, may cause unwanted electrical connections and the discharge of various fluids from the vehicle to occur. Because of the significant electrical power that is stored in the HV capacitor connected in parallel with the high voltage battery, it could cause potentially hazardous situations, such as electrifying of vehicle parts, fire hazards etc. The system/method disclosed here is of discharging a high voltage capacitor in the event of a crash. This system includes a discharge circuit having a HV battery, and a load for discharging the battery.**

I. INTRODUCTION

In the event of a crash, hybrid / electric vehicle which posses a high voltage capacitor connected to the high voltage battery (usually placed behind the car) may cause unwanted electrical connections and discharge of various fluids from the vehicle. High voltage capacitor consists of significant electrical power stored (200-400V). Because of this there might e hazardous situation such as electrifying the vehicle parts, fire Hazards etc.

Potential Hazards: High-voltage electricity and unexpected vehicle movement are the two dangers emergency responders should be most concerned with [1]. Although death or serious injury can result from coming in contact with high-voltage electricity, extensive safety systems and strict adherence to proper safety procedures greatly minimize this danger. Although the media and other entities have hyped the dangers of hybrids, proper training and understanding of hybrid technology make them one of the smaller issues with which the fire service must contend.

High voltage: As previously mentioned, the high-voltage battery modules' capacities can range from 144 to 330 volts DC. Some models contain a boost converter that transforms the DC power from the battery to 650 volts AC for the electric motors to operate on. Testing indicates that high-voltage systems can remain energized even after fire exposure, primarily because the relays can melt in the "closed" position and allow the high-voltage circuit to stay engaged. Avoid contact with any high-voltage components, and never attempt to disconnect any high-voltage connections. Although they are not technically high voltage, follow the same precautions for yellow or blue medium-voltage cables as well.

Crash Sensors: Crash sensors must accurately discriminate frontal crashes, side impacts, rear-end collisions and vehicle rollover [3].

1. Inertial sensors to monitor the vehicle movements, both accelerations along and rotations around the vehicle axes.
2. Surround sensors such as radar, laser, ultrasonic and cameras scan the vehicle environment for any hazards.

3. Crash sensors measure how quickly a vehicle slows down in a frontal crash or accelerates to the side in a side-impact crash. Some vehicles are equipped with a sensing system designed to detect the onset of a rollover crash.
4. Frontal crash sensors may be located in the front of the vehicle near the engine, in the passenger compartment, or sometimes in the electronic control unit (ECU).
5. Side-impact crash sensors may be located in the ECU, the door, the doorsill, or between the front and rear doors.
6. Rollover crash sensors may be located in the ECU or at the vehicle's center of gravity. Crash sensors can be fitted in various positions throughout the vehicle. Their location depends upon the direction of deceleration they are designed to detect. These crash sensors can be used to deploy the discharging circuit for high voltage capacitor [3].

The method proposed here is to discharge the high voltage capacitor in the event of a crash. This method includes a discharging circuit with the following equipments: Battery, Parallel capacitor, ***Step*** down transformer, Bridge rectifier circuit (to provide power supply to micro controller, relay circuit, sensors etc..), Piezo Electric vibration sensor, Relay circuit to tap the circuit to Emergency Discharge / Comfort Discharge / Charge based on the crash detected in the vehicle (using vibration sensor) / Touch button, Load Resistor, Micro Controller (PIC16F877A).

II. PROCEDURE FOR DISCHARGING HV CAPACITOR

A. Normal Stage (Capacitor Charging mode) During normal operation of the vehicle, the capacitor will be in charging mode. This means the charge available in the battery will be used to charge the capacitor that is connected in parallel to the battery.

In this project, the power supply to other devices like PIC micro controller, Vibration sensor, Relay circuit is done by the low voltage supply from the battery. Details of power supply and Bridge Rectifier circuit is provided in section D.

A switch is provided to indicate / activate the charging mode of the capacitor. When the switch is pressed, the relay circuit1(Charging mode) will be in “Normally Closed mode” which helps in connecting the capacitor parallel to the battery and in turn helps in charging the capacitor connected parallel to the battery.

The voltage stored in the capacitor, is measured and provided as input to the microcontroller. B. Crash Detected stage (Emergency Discharging mode) Emergency discharge mode is detected in the vehicle when a crash happens in the vehicle with respect to the different sensors positioned in the front and rear of the vehicle. (The sensors which are used for activation of airbag also can be used in this case) In this project, Emergency Discharge mode is detected when the vibration sensor (Piezo Electric sensor) senses some vibration input. The output of the vibration sensor is provided to the microcontroller as input. When the vibration sensor triggers, Relay2 and Relay3 circuit will be turned on, which in turn enables the connection between the five 2.2 K resistors that are connected in parallel and capacitor and therefore the circuit enters into Emergency Discharge Mode. This will enable the voltage / power stored in capacitor to be discharged via the resistor connected in parallel to the capacitor.

Charge stored in capacitor is provided as input to the micro controller, and from there the time duration for the complete discharge of charge stored in capacitor is displayed in the LCD.

C. Service Mode / Stage (Comfort Discharging Mode)

Comfort Discharge mode is Manually Fed using a touch button requesting for a capacitor discharge in case of automobile service etc. In this project, a switch is pressed to indicate that the capacitor needs to be discharged during service. This manual request will in turn activate the Relay2 circuit and therefore enables the connection between the three 2.2 K resistors that are connected in parallel and capacitor and therefore the circuit enters into Comfort Discharge Mode (Total Resistance increased for Comfort Discharge and hence the time taken to discharge the charge stored in capacitor will increase slightly compared to emergency discharge mode). Charge stored in capacitor is provided as input to the micro controller, and from there the time duration for the complete discharge of charge stored in capacitor is displayed in the LCD.

III. IMPLEMENTATION OF DISCHARGING HV CAPACITOR

A. Capacitor Charging Mode

During normal mode of operation (SWITCH 1 mode), the capacitor connected in parallel to the battery will be in charging mode. By pressing Switch 1, the capacitor will be entering into charging mode. This is activated in the project by closing Relay 1. At this point of time, the Relay 2 and Relay 3 will be open. By closing Relay1, connection between the battery and parallel capacitor is established and therefore, the charge from the battery will be available across the parallel connected capacitor in a short span of time. [5] The controller monitors continuously the charge store across the capacitor and the vibration sensor input via the ADC pin of the controller. (In this case RA1 and RA0 respectively is used for this purpose). Block Diagram for the implementation of project is as Figure 1.

Figure 1: Block Diagram

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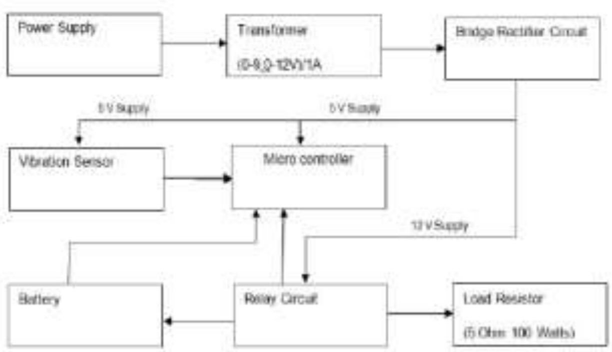


B. Emergency Discharge Mode

When a trigger (Vibration input) is sensed in piezo electric vibration sensor, the RA0 pin of the microcontroller gets a voltage range greater than zero volt. This enables the circuit to enter into Emergency Discharge mode, by closing relay's Relay 1 and Relay 2.

The closure of the two relays will activate the 5 2.2 K resistors connected in parallel. This will enable the discharge of charge stored in the capacitor via the resistors [5]. The charge stored in the capacitor is read via the ADC pin of the controller. When the voltage range reaches less than 1 V, the discharging of capacitor is stopped.

The LCD displays, the mode of operation (as Emergency Discharge), the voltage across capacitor and the time taken for discharging the capacitor from the maximum value to a voltage level lesser than one volt.

C. Comfort Discharge Mode

During service mode request, the charge stored in the capacitor needs to be discharged, since the charge that is available across the capacitor will be dangerous for human handling. By pressing SWITCH 2, the capacitor enters into comfort discharge mode. At this point of time, Relay 2 will be closed and Relay 1 and Relay 3 will be in open state. Closure of Relay 2 enables the activation of three 2.2K parallel resistors connected with the capacitor.

This will enable the charge stored in the capacitor to be discharged via the resistor by taking considerable amount of time [5].

The LCD displays, the mode of operation (as Comfort Discharge), the voltage across capacitor and the time taken for discharging the capacitor from the maximum value to a voltage level lesser than one volt. The circuit diagram for the implementation of project is provided in Figure 2.

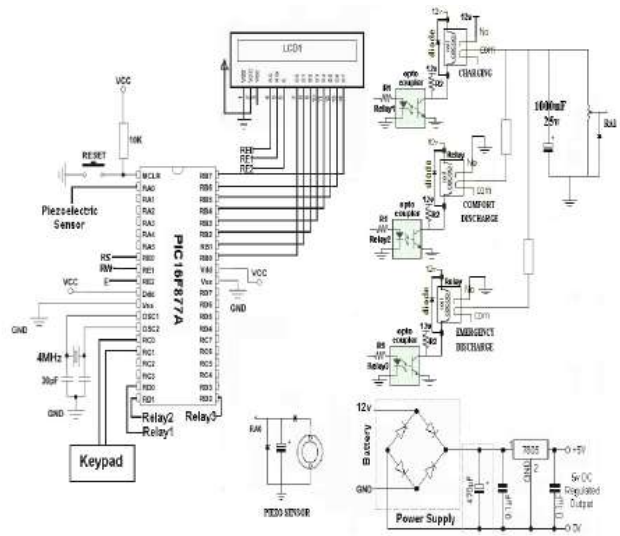
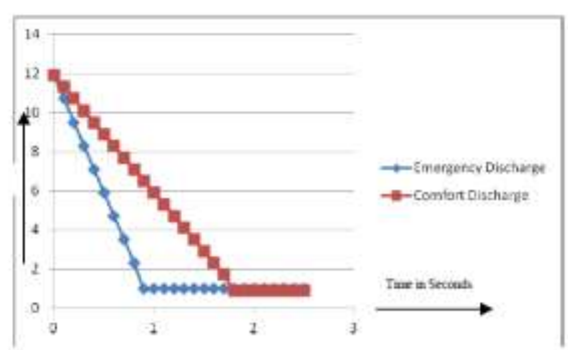


Figure 2: Circuit Diagram Implemented

D. Discharge Response of Capacitor

Based on the design of LV circuit hardware, the following result is obtained for discharging the LV capacitor. This is formulated as a graph as shown in Figure 3.

Figure 3: Capacitor Discharge Response



E. Pseudo-code or Algorithm

STEP 1: Start the Program
STEP 2: Initialize Relay, Delay, LCD, ADC.
STEP 3: Display LCD to press SWITCH 1 for charging operation
STEP 4: If SWITCH 1 pressed, enable Relay 1, disable Relay 2 and Relay 3.
STEP 5: Read if piezo electric vibration sensor triggers via ADC pin 0.

STEP 6: Monitor the capacitor voltage continuously via ADC pin 1.
STEP 7: When Vibration sensor is triggered, Activate Relay 2 and Relay 3.
STEP 8: Activation of Relay 2 and Relay 3 activates all the parallel resistors to be connected in series to the capacitor for discharging.
STEP 9: All The Relays are deactivated when the voltage level is less than one Volt.
STEP 10: If SWITCH 2 is active, then Activate Relay 2, Deactivate Relay 1 and Relay 3.
STEP 11: Activation of Relay 2, activates three parallel resistors in series to the capacitor for discharging.
STEP 12: All The Relays are deactivated when the voltage level is less than one Volt.
STEP 13: Display the mode of operation, Capacitor Voltage level and time taken for discharge in LCD.
STEP 14: Stop the program

IV. THEORETICAL MODELLING OF RESISTOR BASED ON HEAT DISSIPATION THROUGH THE RESISTOR

A. HV Battery Rating

Make (Manufacturer) & Capacity (Ah):
Samsung 28 Ah Energy (in kWh): 9.9
kWh Power (in kW) - peak and rms: 30 kW rms Current (in A) - peak and rms: 330
A (peak for 18s) / 110 A rms Current boundaries (in A) for charging and discharging: +280 / -320 A for 5 sec Minimum voltage for Discharging (in V): 268 V
Maximum charging voltage (in V): 399 V
According to the HV battery Rating specified above [4],
Peak Current (I) = 330A
Power (P) = 30 KW
Maximum Charging Voltage (V) = 399 V

B. Power Rating of the Resistor

Every resistor has a specific maximum power rating. In order to keep the resistor from heating up too much, it's important to make sure the power across a resistor is kept under its maximum rating. The power rating of a resistor is measured in watts, and it's usually somewhere between ⅛W (0.125W) and 1W. Resistors with power ratings of more than 1W are usually referred to as power resistors, and are used specifically for their power dissipating abilities [8]. Therefore, the power that needs to be dissipated in the resistor is: 30 KW

All resistors have a Maximum Dissipated Power Rating, which is the maximum amount of power it can safely dissipate without damage to itself. Resistors which exceed their maximum power rating tend to go up in smoke, usually quite quickly, and damage the circuit they are connected to. If a some form of heatsink or cooling is required. Resistor power rating is an important parameter to consider when choosing a resistor for a particular application. The job of a resistor is to resist current flow through a circuit and it does this by dissipating the unwanted power as heat. Selecting a small wattage value resistor when high power dissipation is expected will cause the resistor to overheat, destroying both the resistor and the circuit.

All resistors whether carbon, metal film or wire wound obey Ohm´s Law when calculating their maximum power (wattage) value. When two resistors are connected in parallel then their overall power rating is increased. If both resistors are of the same value and of the same power rating, then the total power rating is doubled.

C. Calculation of Resistor

Resistance (R) = Voltage (V) / Current (I) (1)
R = 399 / 330 = 1.2 ohms

D. Power Dissipation Calculation

Power rating gets added up, when connected in parallel and therefore 2000*15 = 30000 W power dissipation is achieved [7].

E. Resistance ohmic calculation

A Total of 1.2 ohms resistance is required for dissipation of 30 KW.

If the resistance are connected in parallel, then the below calculation applies for total resistance calculation.

RTotal = (R1*R2*R3*…*R15) / (R1+R2+R3+…+R15) (2) Let us consider, that we use the resistance of same rating, therefore
RTotal = R15 / 15R
RTotal = 1.2 Ohms
R = 1.23 Ohms

Therefore, by connecting Fifteen 1.23 ohms resistor in parallel we may achieve total of 1.2 ohms resistance value. For Dissipating 30000 W, Fifteen 1.23 ohm 2000 W power resistor needs to be connected in parallel [6].

F. Capacitance Rating Calculation (HV Batteries):

C = Q / V (3)
Q = I * t (4)
Q = 28 * 3600
V = 399

A 28 Ah battery has an equivalent charge flow of 28*3600 = 100800 coulombs
So equivalent C = 100800/399 = 252.6F ~= 253 F

G. Time taken to discharge Link Capacitor:

In a RC discharging circuit the time required for a capacitor to discharge itself down to one time constant is given as: Ʈ = R * C (5)

Where, R is in Ω's and C in Farads.
So a RC circuit's time constant is a measure of how quickly it either charges or discharges.

The time constant, T is found using the formula Ʈ = R * C in seconds.
Let us assume R = 2.5 ohms
T = (1.2) * 253 = 303.6 Seconds ~= 5 minutes.

V. CONCLUSION

HV Capacitor Discharge circuit is aimed on discharging the capacitor in an effective manner so that the vehicle is not subjected to any fire hazardous because of the high voltage stored in the capacitor. This approach can be further enhanced in future, by controlling the different parameters like area subjected to crash, measuring the intensity of the crash etc.

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