Performance Enhancement of Electric Vehicle with Super capacitor

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Abstract: This paper investigates the benefits of integrating super capacitor with battery based propulsion system to reduce the overall transient losses and efficiency improvements of electrical vehicles. The super capacitor provides the inrush starting current of the electric vehicle (EV) due to its high rate of discharge current characteristics, and thus, inrush current from the battery is avoided. This results minimum voltage drop due to battery internal resistance across battery terminal while electric vehicle accelerates. The EV motor dynamic torque is increased which is especially useful for racing cars. The regenerative braking is utilized to charge the battery while EV decelerates during brakes are applied. This also enhances the battery efficiency and makes the battery long lasting.

1. INTRODUCTION

The global warming concerns, limited stock of exhaustible fuels and embargo compels to adopt the electric vehicles. This has revolutionized the mobility industry. The EV market is growing exponentially and people are always comparing the performance of EV with fossil fuel based automobiles [1]. The overall efficiency of electric vehicles are 75-80% and gasoline engine are 30-35% **[2]**. The racing car industries demand high performance and brilliancy of engineering to achieve the goals. The current scenario in the field of electric vehicles and powertrain has observed the emergence of utilizing battery and super capacitor in hybrid model. The basic structure includes the parallel operation of battery and super capacitor, which are connected at DC bus and utilizes a DC bus controller to deliver power.

The starting current of the electric motors is very high till it reaches to base speed **[3]**, this causes the bandwidth of transient state to expand causing the battery to provide high current for longer time period**.** Thus, battery life reduces due to overheating caused by battery internal resistance [4]. The motor dynamic torque is limited due to insufficient battery current [5], and the battery high discharge current decreases the power backup of battery and range [6]. These shortcoming are overcome by utilizing the super capacitors. The properties of charging and discharging of super capacitor at high rate is used to deliver the required current surge at the transient state of the circuit [7]. Moreover, the super capacitor high power density and short charging and discharging time capability meets the dynamic current demand of electric vehicles without loss of energy in internal resistance beside facilitates rapid energy recovery associated with regenerative braking and rapid energy dissipation associated with sudden torque requirements [8]. The Charging time of capacitor is 5RC and discharging time is RC where R is active part of load impedance [9].

This paper investigates the use of super capacitor in addition to battery to feed the electric vehicle, and thus, to improve the dynamic torque performance of the vehicle. Moreover, the electric vehicles are prone to sudden jerks and continuous vibrations which increases the chances of internal damage. Thus, a flexible polymer based double layered super capacitor is utilized in this work.

2. PROPOSED PROPULSION SYSTEM BLOCK DIAGRAM

The block diagram of the proposed propulsion system is depicted in Fig.1. This block diagram includes battery charger, battery, super capacitor charger, super capacitor, Induction Motor controller, Regenerative braking system and the induction motors (M1 and M2). The regenerative braking system converts the kinetic energy of vehicle to charge the battery and thus, the overall efficiency of vehicle is increased. Typically, a C5 rating battery is used. The efficiency drops during transient state of vehicle and optimum level of performance is not achieved. The higher C rating battery increases the cost of vehicle. The Super capacitor is used to achieve similar performance to that of higher C rating battery, which results in significant decrease of cost, weight and power loss.

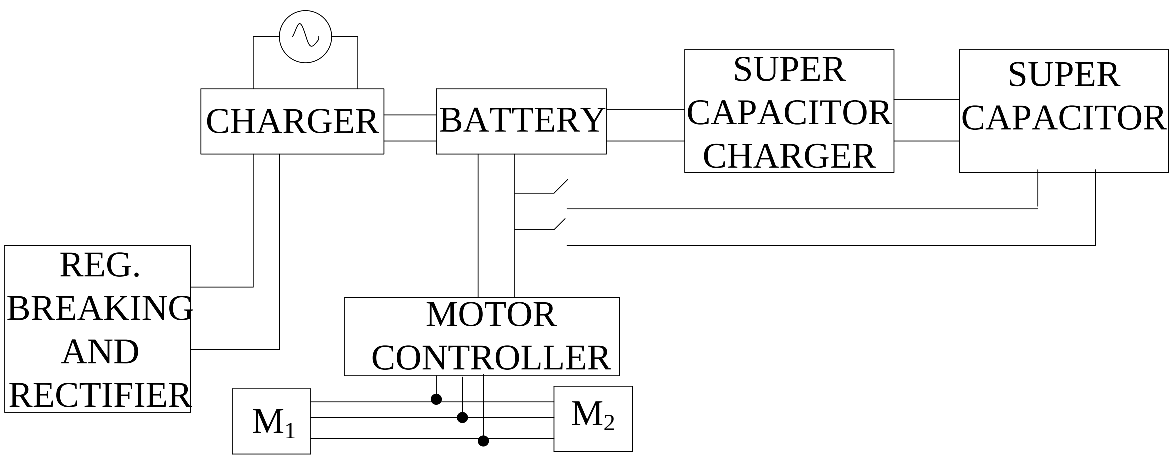


Fig.1 Block diagram of propulsion system

3. METHODOLOGY

The torque produced by induction motor is given [5] as,

$$T_m = \frac{3P}{2} \times \frac{L_m^2}{L_m + L_R} i_{sd} \times i_{sq} \tag{1}$$

Thus, torque produced by motor is proportional to the product of currents. The motor requires higher torque at the time of initiation of motion and acceleration. Which results in higher discharge rate of battery and therefore rapid decrease of battery efficiency. This is clear from the plot of battery discharge rate and efficiency for various C rate battery as depicted below,

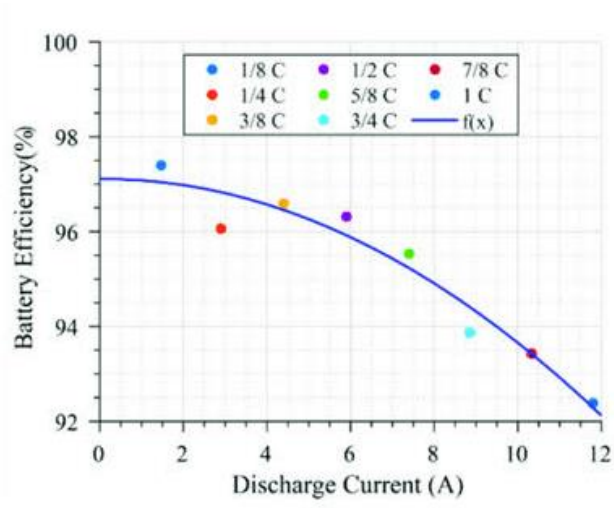


Fig. 2 Discharge current and battery efficiency

The super capacitor is integrated to the battery to overcome these draw backs. The charging and discharging equations of capacitor are given as,

$$i_c = i_0(1 - e^{-t/T}) \tag{2}$$

$$i_d = (\frac{i_0}{T})e^{-t/T} \tag{3}$$

The super capacitor is simple capacitor but have very high capacitance which make it effective for storing energy in form of electric field. The capacitance of super capacitor is increased by

a) Use of graphene allotrope of carbon which is conducting in nature so that equivalent distance (**d**) is reduced and capacitance is increased.
b) Use of activated carbon which increases the surface area (**A**) and increases capacitance.
c) Use of dielectric material of high dielectric constant so that relative permittivity(**εr**)is increased and capacitance is increased

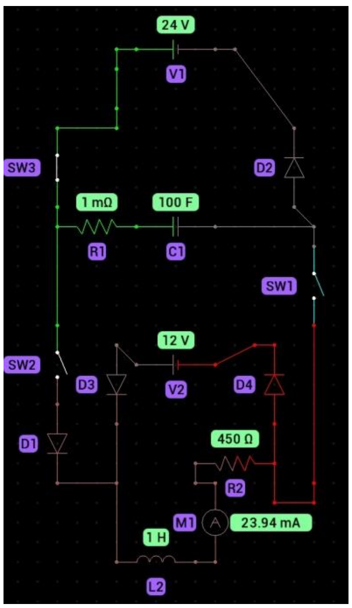
The energy stored by super capacitor is given as,

$$E = \frac{1}{2} \times C \times V^2 \tag{4}$$

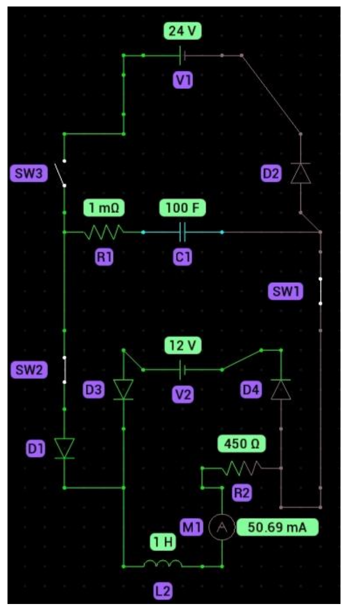
4. CIRCUIT DIAGRAM AND IMPLEMENTATION

The circuit diagrams of electric vehicle propulsion system is depicted in Figs. 3(a)-(b). Inductor and resistor connected in series represents the motor parameters connected to 12 V battery supply.

Fig. 3(a) illustrates charging of the super capacitor to its full potential while switch SW1 and SW2 are open and main motor circuit (SW3) is closed. The constant current of 23.94mA flows, and the super capacitor charges to 24V. This is achieved by controlling the operation of switch SW3.The open state of switch SW1 and SW2 prevents leakage current of main motor circuit. Fig. 3(b) depicts that super capacitor is fully charged and SW3 is open while SW1 and SW2 are closed which is creating the pathway through the motor for the discharge current of super capacitor and the current has reached the value of 50.69mA. The switch SW1 and SW2 are the boost converter switches. The unipolar voltage switching concept is used to control the switching of the switches. Diode provides restriction in backward flow of current or shorting of capacitor through the battery. The MATLAB code to realize the electric vehicle is given in Appendix.



(a)



(b)

Fig.3 Circuit diagram of electric vehicle propulsion system (a) Switch SW1, SW2 open and SW3 close (b) SW1, SW2 close and SW3 open

5. RESULTS AND DISCUSSIONS

Fig.4 depicts the plot for variation of motor current, motor torque and motor speed with respect to time in both the conditions while super capacitor is integrated with battery and super capacitor is not integrated with battery. It is observed that the torque produced by motor while super capacitor is integrated during transient conditions is much more than the super capacitor is not integrated to battery. Moreover, the stress on the battery, especially, during transient conditions is reduced because major part of the motor current is fed by the super capacitor. The quick acceleration is also observed while the super capacitor is integrated.

6. CONCLUSION

The performance of the electric vehicle integrated with super capacitor is investigated. The super capacitor provided the inrush current required by the electric vehicle motor during dynamic conditions such as during initiation of motion and acceleration. Thus, rapid increment of electric vehicle torque is achieved which results in quick acceleration of vehicle. Furthermore, the control circuit and super capacitor add on to the total cost. The implementation of more effective control unit is still in research.

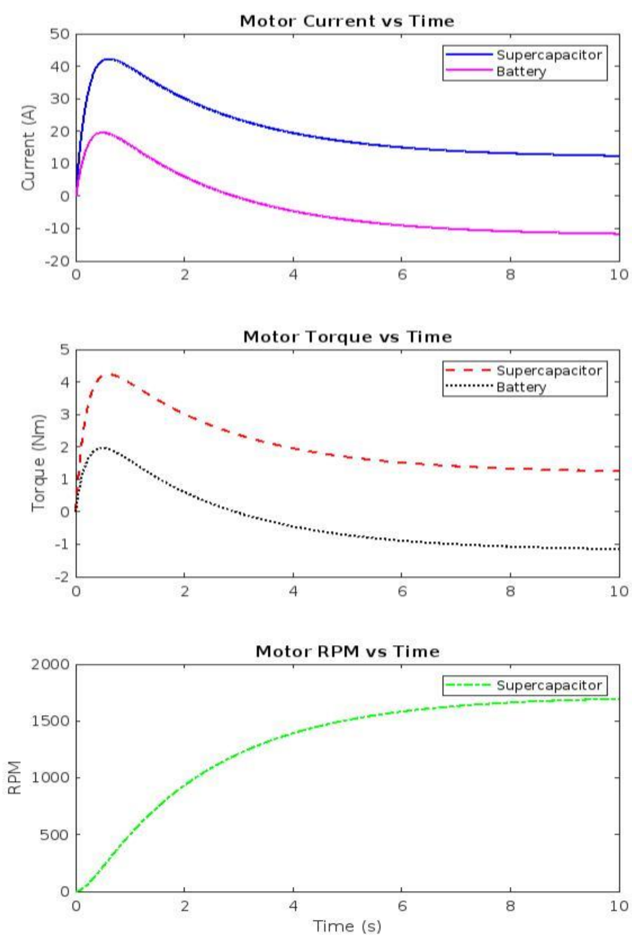


Fig.4 Plot of motor current vs time, motor torque vs time and motor speed vs time

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Appendix

MATLAB code

```
>> % Parameters
   total_time = 10; % Total simulation time (in seconds)
   dt = 0.01; % Time step (in seconds)
   time = 0:dt:total_time; % Time vector
   % Motor parameters
   motor_constants = struct();
   motor_constants.R = 0.5; % Motor resistance (in ohms)
   motor_constants.L = 0.1; % Motor inductance (in Henry)
   motor_constants.kt = 0.1; % Motor torque constant (in Nm/
   A)
   motor_constants.ke = 0.1; % Motor back EMF constant (in V/
   (rad/s))
   % Fully charged supercapacitor parameters
   supercap_voltage = 24; % Voltage of fully charged
   supercapacitor (in volts)
   supercap_capacity = 2000; % Capacitance of supercapacitor
   (in Farads)
   % Battery parameters
   battery_voltage = 12; % Voltage of the battery (in volts)
   % Initial conditions
   initial_conditions = struct();
   initial_conditions.i_supercap = 0; % Initial current
   through motor with supercapacitor (in amperes)
   initial_conditions.i_battery = 0; % Initial current
   through motor with battery (in amperes)
   initial_conditions.omega = 0; % Initial motor speed (in
   rad/s)
   % Initialize arrays to store data
   torque_supercap = zeros(size(time));
   torque_battery = zeros(size(time));
   current_supercap = zeros(size(time));
   current_battery = zeros(size(time));
   rpm = zeros(size(time));
   % Simulation loop
   for idx = 1:length(time)
       % Calculate torque with supercapacitor
       torque_supercap(idx) = motor_constants.kt *
   initial_conditions.i_supercap;

       % Calculate torque with battery
       torque_battery(idx) = motor_constants.kt *
   initial_conditions.i_battery;

       % Store current with supercapacitor
       current_supercap(idx) = initial_conditions.i_supercap;

       % Store current with battery
       current_battery(idx) = initial_conditions.i_battery;

       % Update motor current and speed using dynamic
   equations with supercapacitor
       voltage_supercap = supercap_voltage -
   motor_constants.ke * initial_conditions.omega;
       dcurrent_dt_supercap = (voltage_supercap -
   motor_constants.R * initial_conditions.i_supercap) /
   motor_constants.L;
       domega_dt_supercap = (motor_constants.kt *
   initial_conditions.i_supercap) / motor_constants.L;
```

```
    % Update motor current and speed using dynamic
equations with supercapacitor
    voltage_supercap = supercap_voltage -
motor_constants.ke * initial_conditions.omega;
    dcurrent_dt_supercap = (voltage_supercap -
motor_constants.R * initial_conditions.i_supercap) /
motor_constants.L;
    domega_dt_supercap = (motor_constants.kt *
initial_conditions.i_supercap) / motor_constants.L;

    initial_conditions.i_supercap =
initial_conditions.i_supercap + dcurrent_dt_supercap * dt;
    initial_conditions.omega = initial_conditions.omega +
domega_dt_supercap * dt;

    % Update motor current and speed using dynamic
equations with battery
    voltage_battery = battery_voltage - motor_constants.ke
* initial_conditions.omega;
    dcurrent_dt_battery = (voltage_battery -
motor_constants.R * initial_conditions.i_battery) /
motor_constants.L;
    domega_dt_battery = (motor_constants.kt *
initial_conditions.i_battery) / motor_constants.L;

    initial_conditions.i_battery =
initial_conditions.i_battery + dcurrent_dt_battery * dt;
    initial_conditions.omega = initial_conditions.omega +
domega_dt_battery * dt;

    % Calculate RPM
    rpm(idx) = initial_conditions.omega * 60 / (2 * pi);
end
% Plotting
figure;
subplot(3,1,1);
plot(time, current_supercap, 'b', 'LineWidth', 1.5);
hold on;
plot(time, current_battery, 'm', 'LineWidth', 1.5);
ylabel('Current (A)');
legend('Supercapacitor', 'Battery');
title('Motor Current vs Time');
subplot(3,1,2);
plot(time, torque_supercap, 'r--', 'LineWidth', 1.5);
hold on;
plot(time, torque_battery, 'k:', 'LineWidth', 1.5);
ylabel('Torque (Nm)');
legend('Supercapacitor', 'Battery');
title('Motor Torque vs Time');
subplot(3,1,3);
plot(time, rpm, 'g-.', 'LineWidth', 1.5);
ylabel('RPM');
legend('Supercapacitor', 'Battery');
title('Motor RPM vs Time');
xlabel('Time (s)');
```