Solar Powered Integrated Electric Vehicle

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Abstract— This paper presents software and hardware development of controller for solar powered electric vehicle. The proposed system consists of solar panel, battery bank, charge controller, ultra capacitor, bi-directional DC/DC converter and DC series motor. Here PWM technique is used to control speed of the DC series motor. The DC source is a set of lead-acid batteries and ultra capacitor which are charged by solar PV panels. The solar charge controller charges the lead acid battery (with rated voltage of 12V) and Ultracapacitors (UC) for Integrated Electric Vehicle applications. Using the Integrated energy source UC and battery and with a proper energy management improves the INTEGRATED performances. The battery and Ultra capacitors are coupled to DC-bus using buck-boost converters. Ultra capacitors have low energy density but it's have property of quick charge, large power density, and long cycle life. MATLAB Simulation result and practical hardware results are discussed.

Key words: Solar Powered, Integrated Electric Vehicle

I. INTRODUCTION

In recent years, integrated electric vehicle has increasing attentions and many automobile companies have put large investment in this area. The reason is not only the coming energy crisis, but also the global effort of cutting down the carbon dioxide emission to prevent the global warming.

The solar panel absorbs the solar energy during the day to supplement the energy cost of battery. The battery feed the power demand of the dc series motor directly which requires 12V DC source. As the energy demand is not large when the vehicle is cruising, the voltage drop of the battery is negligible. When the vehicle is climbing on slope or accelerating, the motor would cause a big current impulse. This current impulse may lead to big voltage drop on battery which would affect the power quality of the DC source. Besides, large current discharge would also shorten the life-span of battery. Thus, we employ the ultra-capacitor and its bi-directional DC-DC converter in parallel with the battery. When the vehicle is cruising, the ultra-capacitor is charging until to its rated voltage. When there is a current pulse, the bi-directional DC-DC would be controlled as a current source to supply the extra load current in order to prevent the battery current from exceeding certain value, thus the voltage drop is avoided and longer life-span of battery is acquired.[1]

Ultra-capacitor has the features of high specific power, low internal resistance, capable of quick charge with high current and perfect characteristic in wide temperature range. Moreover, it has long cycle life (more than 100 thousand times) and capable of deep discharge. But the problem is its low energy density, which constrains it driving distance. Some researchers are doing research to improve the energy density of ultra-capacitor to make it work like a battery. But a more practical way is to incorporate the battery with a supper capacitor in a vehicle, where each device performs their own duty based on their own characteristics.

Fig.1 shows the general arrangement of the proposed control scheme solar powered electric vehicle.. There are photovoltaic (PV) panels, solar charge controller, voltage controller, DC-DC converters, battery bank, DC motors, Pulse Width Modulation (PWM) for regulation of speed.

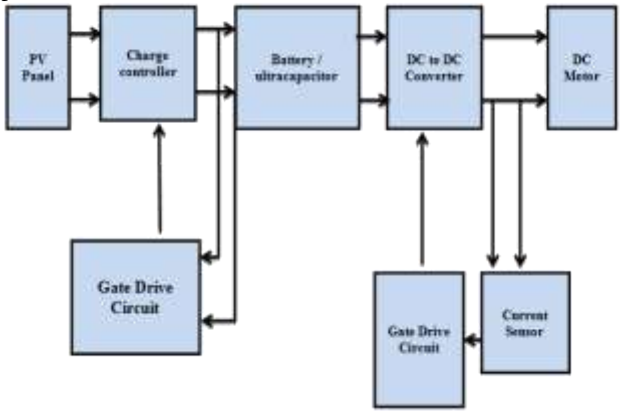


Fig. 1: Block Diagram of proposed system

II. DESIGN OF PROPOSED SYSTEM

Proposed system works on DC output from PV panel to charge the battery and DC motor operated through the battery and UC.

It is divided in to two parts

1) Charger for Charging of battery through PV pane
2) Controlling of the DC motor

A. *Charge Controller*

When connecting a solar panel to a rechargeable lead acid battery, a PV charge controller circuit usually necessary to use to prevent the battery from overcharging. The complete block diagram of charging part is shown in fig.2. The DC to DC buck converter is used to regulate the voltage from the solar panel which output is fed to the lead acid battery. Here the constant voltage charging method is used to charge the battery.

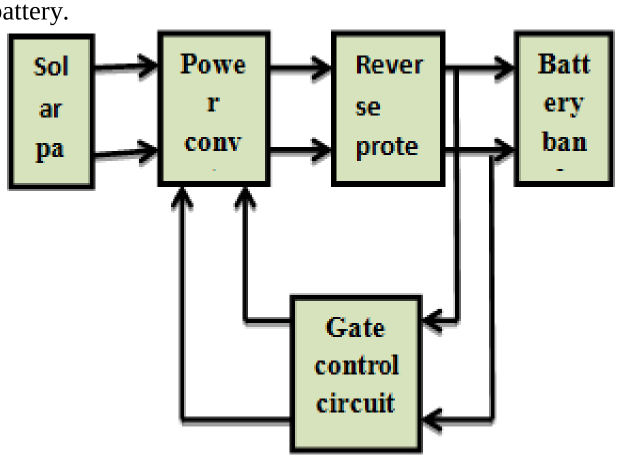


Fig. 2: Block diagram of charge controller

1) Description of Charge Controller

Here 5.0A step down buck converter (LM338IC) is used to regulate voltage. It has many features like adjustable voltage range 1.2V to 32.0V, guaranteed 5.0 Amp output load current. Solar panel gives unregulated voltage output which is fed to the voltage IC, this IC provides the required regulated voltage output to charge the battery. This PV charge controller has many features:

- Low dropout voltage
- Reverse Protection of circuit from battery.
- Indicate the battery status
- Automatic cutoff when battery is charged and auto connect when battery is discharged
- Minimize the voltage and current fluctuations.

To include all this feature following components are used:-Current sensor, Diode, Relay, Opamp, MOSFET, Voltage regulator ICs (LM317, LM7805, and LM338), LED, Potentiometer resistor, Inductor, capacitor, resistors.

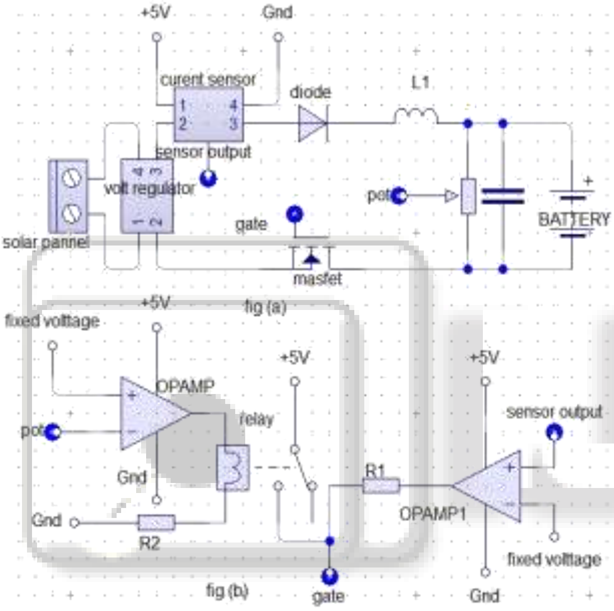


Fig 3: (a) Charging circuit and (b) gate control circuit for charging

In this circuit, Opamp is used to control the ON and OFF switching of MOSFET, MOSFET is automatically on through the pot resistor. Potentiometer gives variable output which depends on the battery voltage. The OPAMP is compare the output of potentiometer resistor and fixed voltage. When the potentiometer resistor output is less than the fix voltage, then output of the comparator is goes to high and its will switch on the relay through which the MOSFET will be on. In this condition the charging will be started. Once the charging will be start relay leaves the control on MOSFET.

Now the Opmap2 control the switching of MOSFET. Output of Opamp1 depends on current sensor, it will be high in charging condition. As the battery is rated fully charged, the output of opamp2 will be low. This turns off the MOSFET.

B. Controlling Part of the DC Motor

1) Battery/UC Configuration with Controlling

To drive DC motor from electrical sources (battery and UC) it is very important to decide the configuration of UC and battery for efficient energy management. In proposed system parallel configuration of UC and battery is used shown in fig.6. Single quadrant (step down) converter is used to drive DC motor. In this configuration voltage of the UC can vary in a wide range so the capacitor is fully used.

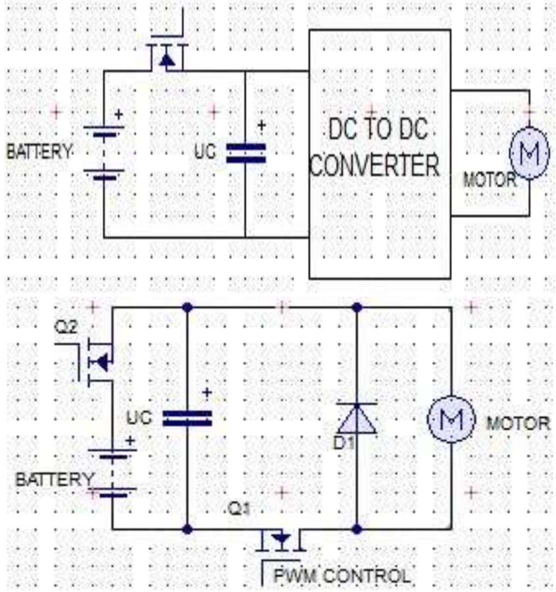


Fig. 4: Proposed UC and battery configuration

2) Advantages of Proposed Circuit

This circuit is parallel combination of Battery and ultra – capacitor in such a way that when load (DC motor) is connected initially surge current drawn by UC only, at that time battery provides a linear current to the load shown in the graph. After some time load current set to constant this time only battery will supply the current.

When the vehicle is climbing on slope or accelerating, the motor would cause a big current impulse. in this case only UC will provide current so that other benefit is as the large current discharge would also shorten the life-span of battery.

The advantage of this strategy is the possibility of using a full range of the UC.

C. Circuit Explanation:

The circuit shown in fig.7 a MOSFET switch is used in a series with battery. When high current will be drawn from the load side, MOSFET connection will be switched off by current sensor sense the load current accordingly provides output voltage and its will compare to the Opamp. Opamp will control the switching of MOSFET.

The PV module converts solar radiation to the electrical energy. The energy comes from the sunlight stored in the lead acid battery bank that is controlled by charge controller. This type of battery is used for its low cost, high current, low initial impedance, tolerance to overcharge capabilities. The charge controller protects the battery from being over charged. PWM is used for regulation in speed, it controls the duty cycle of the dc motors situated at the bottom of the structure. There is also an emergency power system to charge the battery from the supply lines. So the battery can be charged in both ways.

D. Speed Control Strategies:

The Pulse Width Modulation (PWM) techniques are used to regulate the speed of DC motor. PWM square waves are generated and control by SG3524 IC.

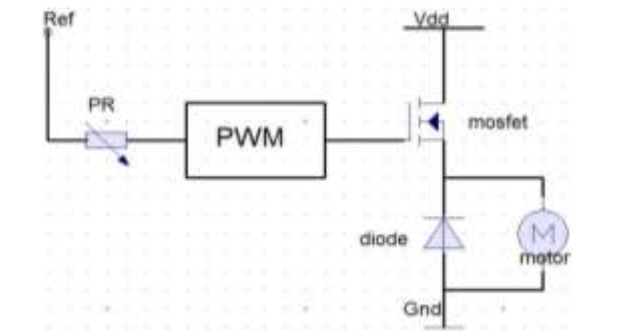


Fig. 5: Block Diagram of proposed solar powered vehicles

1) PWM motor control:

The PWM method of current control will be considered the conditions at motor start-up for a simple arrangement, shown in Fig.6, where the duty cycle is controlled using the DC control voltage, VREF. At start-up the duty cycle is adjusted to be long enough to give sufficient motor starting torque. At zero rotational velocity (ω=0) the back EMF, Ea, is zero and so the full DC voltage appears across the series Ra/La impedance. The initial motor current is determined according to the equation:

$$L_a.\frac{dI_a}{dt}+R_a.I_a=V_{dc}\text{……………………………….(1)}$$

$$I_a=\frac{V_{dc}}{R_a}.\left(1-e^{-t/\tau}\right)\text{…………………………………..... (2)}$$

a) Converter topologies for DC motor drives Single quadrant (step down) converter:

Depending on the load buck, boost and buck boost converters are used. In this paper 12 volt DC motor is operated using 12 volt source, so I have used step down converter to drive dc motor. The average voltage is applied to the motor, and hence the motor speed, is controlled by varying the duty cycle of the switch. During the on time, ton, the supply voltage, V_{dc}, is applied to the motor and the armature current starts to increase. Neglecting the on-state resistance of the switch and the armature winding resistance the voltage across the armature inductance is V_{dc}-E_a and so the rate of rise of armature current is given by:

$$\frac{dI_a}{dt}=\frac{(V_{dc}-E_a)}{L_a}\text{ .... (1)}$$

When the switch turns off the energy stored in the armature inductance must be dissipated. The polarity of the voltage across La reverses, the diode D becomes forward biased and the armature current continues to flow. Assuming that the motor speed remains constant and neglecting the forward voltage drop of the freewheeling diode the inductor voltage is equal to –Ea. The rate of fall of armature current is given by:

$$\frac{dI_a}{dt}=-\frac{E_a}{L_a}\text{ .... (2)}$$

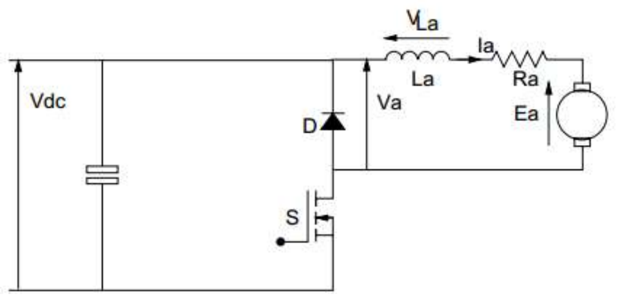


Fig. 6: Buck converter circuit for integrated electric vehicle

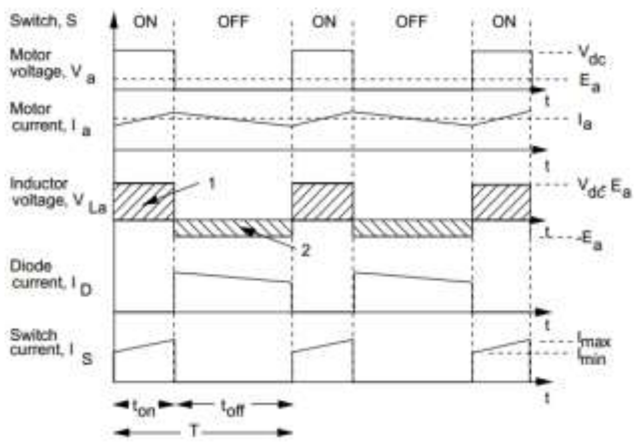


Fig: 7 Buck converter switching waveforms

If this switching sequence is repeated at some frequency, then the motor voltage can be controlled by altering the relative duration of the on period and off period. Variation of the duty cycle of the switch (ton/T) to control the motor voltage is referred to as Pulse Width Modulation (PWM) control.

As the average voltage across the inductor over a period must be zero then:

$$\int_t^0 V_l.dt=\int_0^{t_{on}} V_l.dt+\int_{t_{on}}^{T} V_l.dt=0\text{……………....... (3)}$$

Therefore the controlled output DC motor voltage Va Can be written as

$$V_a=\frac{t_{on}}{T}.V_{dc}\text{…………………………………….... (4)}$$

For single quadrant operation the chopper circuit can be used. The average voltage applied to the motor, and hence the motor its speed, is controlled by varying the duty cycle of the switch. During the on time, ton, the supply voltage, V_{dc} is applied to the motor and the armature current starts to increase. Neglecting the on-state resistance of the switch and the armature winding resistance the voltage across the armature inductance is V_{dc}-E_a and so the rate of rise of armature current is given by:

$$\frac{dIa}{dt}=\frac{(Vdc-Ea)}{La}\text{………………………………. (5)}$$

(4) When the switch turns off the energy stored in the armature inductance must be dissipated. The polarity of the voltage across L_a reverses, the diode D becomes forward biased and the armature current continues to flow. Assuming that the motor speed remains constant and neglecting the forward voltage drop of the freewheeling diode the inductor voltage is equal to –E_a. The rate of fall of armature current is given by:

$$\frac{dIa}{dt}=-\frac{Ea}{La}\text{…………………………………….... (6)}$$

If this switching sequence is repeated at some frequency, then the motor voltage can be controlled by altering the relative duration of the on period and off period. Variation of the duty cycle of the switch (ton/T) to control the motor voltage is referred to as Pulse Width Modulation (PWM) control. As the average voltage across the inductor over a period must be zero then:

$$\int_t^0 Vl.dt=\int_0^{ton} Vl.dt+\int_{ton}^{T} Vl.dt=0\text{……… (7)}$$

$$Va=\frac{ton}{T}.Vdc\text{……………………………….... (8)}$$

III. PWM DC MOTOR CONTROLLER:

The SG3524 IC chips are a fixed frequency PWM (Pulse Width Modulation) voltage regulator control circuit. The

SG3524 IC integrated circuit has all the functions necessary for the production of a regulating power supply, or switching regulator on a single chip. Moreover it can be used as the control element for high power output purposes. Pulse width modulation is a method of adjusting the width of the pulses in a pulse train relative to a control signal. If greater the control voltage, wider is the resultant pulses.

		Specification	
1.	Panel	Power Open circuit voltage Short circuit current	50 W 21.0 V 3.15 A
2.	Battery	Voltage Capacity	12 V 17 Ah
3.	DC Motor	Voltage Current Power	12 V 5 amp 50 watt

Table 1: Specifications of component used in integrated electric vehicle

Duty cycle	Input voltage	Average output Voltage of controller	Load Current	Motor Rpm
97%	13.5	13	2.8	1290
88%	13.5	12	2.6	1210
81%	13.5	11	2.4	1100
74%	13.5	10	2.2	990
66%	13.5	9	1.89	880
59%	13.5	8	1.7	750
51%	13.5	7	1.52	660
44%	13.5	6	1.37	570
37%	13.5	5	1.22	460
29%	13.5	4	1.08	330
22%	13.5	3	0.96	240
15%	13.5	2	0.92	110
7%	13.5	1	0.80	60

Table 2.Testing of PWM speed controller with DC motor

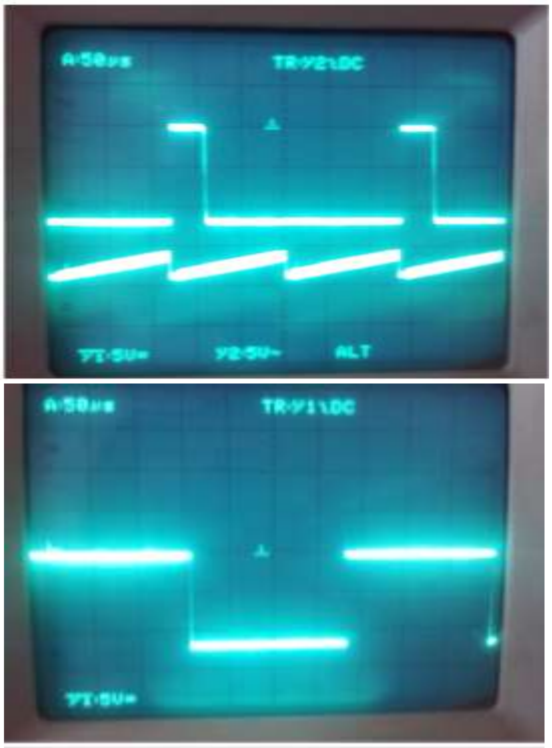


Fig. 8: PWM output on CRO for Speed control with variable duty cycle

IV. MATLAB SIMULATION

This paper shown the MATLAB simulation of my circuit configuration, for this I considered the following parameters for the simulation. UC and battery are parallel connected to the DC motor.

		Parameters	
1.	**Battery**	Voltage Capacity	12 V 40 Ah
2.	**Ultra Capacitor**	Capacitance No. of capacitor in series Rated voltage	300 F 5 13.5 V
3.	**DC Motor**	Voltage Current Power	12 V 30 amp 250 watt

Table 3.specification of component used in MATLAB

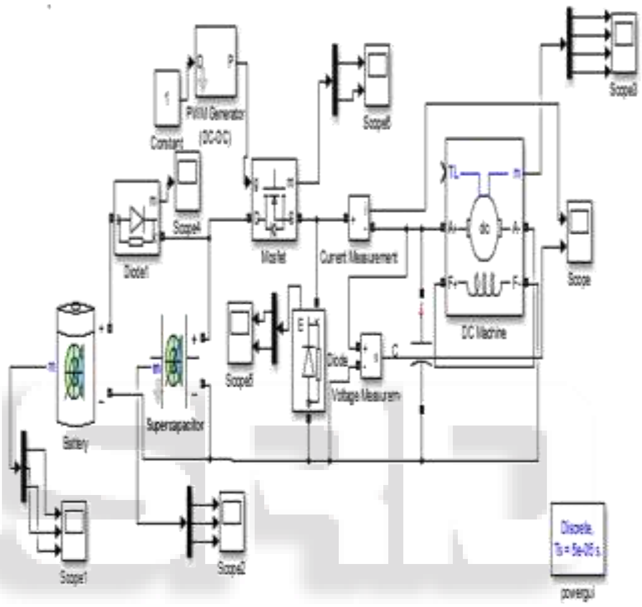
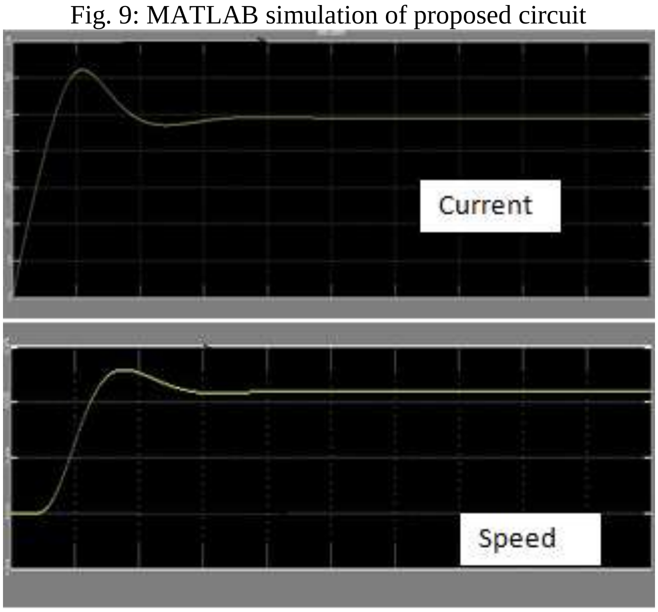


Fig. 9: MATLAB simulation of proposed circuit



→ time in sec.

Fig 10 Wave forms of speed and current of Motor in MATLAB

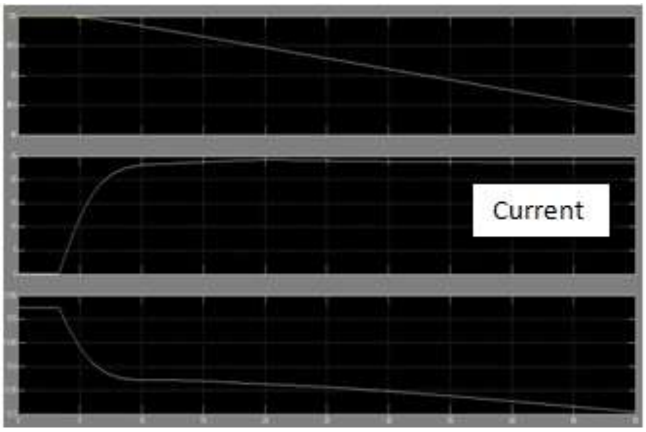


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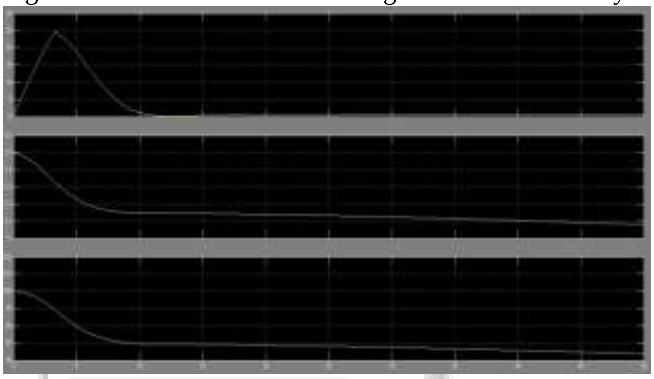
Fig. 11: Waveform of Current voltage and SOC of Battery



→ time in sec.

Fig. 12: Waveform of Current voltage and SOC of UC parameters

V. RESULT EXPLANATIONS

As the MATLAB simulation we performed the parallel combination of Battery and ultra –capacitor in such a way that when load (DC motor) is connected initially surge current drawn by UC only, at that time battery provides a linear current to the load shown in the graph. After some time load current set to constant this time only battery will supply the current.

VI. CONCLUSIONS AND FUTURE SCOPE:

Solar powered electric vehicle is design based on 12 volt 5 amp. In the paper, the combinations of battery and ultracapacitor charging performance was studied in detail, the result can be used for the design of the controlling the load. The combination of UC with battery improves the performance of solar powered electric vehicle. Compared to the conventional vehicles, this design has lower cost and extends the battery life. The operating fundamentals of the proposed integrated electric vehicle were explained in detail. The proper regulation of charge controller assures maximum of the energy transferred to the battery and UC. The testing results verify that use of proposed method results in better exploitation of the available PV energy. There are many other charging methods for the ultracapacitor, such as constant power charging, pulse charging and so on, the more charging methods will be studied in the future work.

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