Feasibility Analysis of Solar Powered Vehicle with Integrated MPPT Based Charging Controller

Muzammil Kashan[1*], M. Ihsan Ul Haq[2] and Muhammad Mansoor[3]

[1] Distribution Strategy and Planning Department, K-Electric, Karachi-74400, Pakistan (muzammil.kashan@ke.com.pk)

* Corresponding author

[2] Engineering Sciences Department, Pakistan Navy Engineering College, National University of Sciences and Technology, Karachi-75350, Pakistan (ihsanulhaq475@gmail.com)

[3] Generation and Transmission Department, K-Electric, Karachi-74000, Pakistan (mansoor.muhammad@ke.com.pk)

Abstract: The increasing number of conventional vehicles based on fossil fuels have been a threat to human being due to hazardous emissions in environment. The integration of renewable energy for sustainable transportation systems is a viable solution to control the hazardous emissions in the environment. Solar powered vehicles (SPVs) are among the emerging systems of sustainable transportation. However, low efficiency of photo voltaic (PV) cells, fluctuations in output power, area constraint in vehicle and power losses during charging of batteries are among the major problems in practicability of SPVs. The power losses during charging of batteries can be encountered by integration of maximum power point tracking (MPPT) based charging controller for improving the electrical efficiency of SPVs. In this paper, feasibility analysis for improving the electrical efficiency of SPVs with integrated MPPT based charging controller is presented. Moreover, selection of material, design and life cycle cost analysis for a prototype solar car are also briefly discussed.

Keywords: Solar powered vehicles, maximum power point tracking, photo voltaic cells, life cycle cost analysis

I. INTRODUCTION

Solar electric vehicle is capable of running on electrical tractive system while obtaining energy from solar panels installed on its roof. Prototype Solar car is a one man vehicle which is capable of running completely on solar panels attached to its roof. Moreover, it has back up battery bank to run the car in shadow or at night. It contains all indispensable features of a commercial car like lights, horn and indicators. Propulsion of car is done by a brushless dc (BLDC) motor with maximum rating of 1000 watt. Motor is equipped with a drive which allows the operation of variable speed. Solar panels installed on the roof covering 7.5 m^2 areas are rated 1000 watt. Panels are placed flat in order to face maximum solar energy on the road. These panels provide power to motor and batteries either car is running or stopped.

Batteries of 48V/40Ah provide backup and assistance in case of large power demand. Charging of batteries is done by solar panels and controlled by charging controller. Controlled and efficient charging of batteries is performed by MPPT based charge controller. This technique is used to supply maximum energy to batteries for charging from solar panels.

The design specifications of the solar car are according to the specifications defined by the rule book of The Cyprus Institute Solar Car Challenge 2014 [1]. Therefore, all calculations are based on the parameters of Nicosia, Cyprus.

MPPT works on the principle of buck boost chopper. It is similar to ideal step down transformer. If solar panels are directly connected to the batteries voltage of solar panels drop down while keeping the current same. It results in power loss. While on the other hand ideally buck boost chopper has power input equal to the power output [2]. It also performs the operation of controlled charging.

From the mechanical point of view, the demands of customers in the field of automobiles are varying vividly. Continuous demands for fuel efficient, less emissions, weight and space for installation as well as dynamics, safety and comfort are the required development in automobile sector. These features have been incorporated in our design.

II. MATERIAL AND METHOD

A. Electrical design parameters

BLDC motor

Hub BLDC motor is used in this vehicle. It is a common type of BLDC motor which is specially designed for electric vehicles [1]. It fits into hub of the wheel and provides high torque at zero speed. Moreover, no transmission chain is required with hub motor. Motor drive is also embedded in the hub. The specifications of hub motor are given in Table 1. Moreover, it has solid state commutation, hall-effect sensors for detection and variable speed.

Table 1 The specifications of hub motor

	Parameters	Value	Unit
(i)	Power	1000	Watt
(ii)	Voltage	36/48	Volt
(iii)	Current	20-25	A
(iv)	High rotational speed	2500	rpm
(v)	High efficiency	>90	%

Solar panels

The output power of solar module is rated at standard test conditions which range from very small to large thus allowing a wide range of applications. Area of module is determined by its efficiency. Due to low efficiencies a single module produces very small amount of power. Therefore a large number of modules are connected in a way to provide the required power output. Output power of module fluctuates randomly because of variation in solar irradiation. Temperature also affects the power output. Therefore in order to get maximum power output of solar panels they must be oriented at proper angle facing to sun and temperature of cell must be nominal. There should be no dust or shadowing effect on panels which might cause reduction in power output. Polycrystalline solar panels having maximum efficiency of 17% are used in this vehicle. These solar panels were designed to give maximum power at 1000 watt/m^2 and 25 °C. Therefore temperature and solar intensity are two main factors which would reduce maximum attainable power from solar panels.

Solar intensity (average)	=	700 w/m^2
1000w/m^2	=	1000 watt
700w/m^2	=	700 watt
Temperature (average)	=	40 °C
%Power drop = -0.47*(40-25)	=	-7.05%
Power drop = 1000*(-7.05%)	=	-70.5watt
Net Power of 1000watt array	=	630 watt

Thus, only 630 watt could be extracted from solar panels and remaining power is supplied by batteries.

Battery

The battery used in the vehicle is lead acid dry cell battery. Lead acid batteries are cheap on cost per watt base and commonly available. Deep cycle battery is used in electric vehicle [3]. The specifications of battery are given in Table 2. Solar panels can provide us with approximately 630 watt while actually we need 1000 watt to extract full power from motor, therefore this remaining power of 270 watt is supplied by battery backup.

In our design, we have 48 v BLDC motor. Therefore, we are connecting 4 batteries in series to get total of 48 v. Ampere hour capacity of battery is given below:

Power requirement:	1000 - 630 = 270 watt
Voltage requirement:	12v * 4 = 48 volt
Current requirement:	20 - 13= 7 Amp.
Min. capacity:	7 A * 3 hour = 21 Ah

However, because of sudden variations of weather there is a possibility of clouds and mist which would reduce solar intensity to much less value, therefore keeping in view the safety factor, battery backup with reserve capacity of 40 Ah is used.

Table 2 The specifications of battery

	Parameters	Value	Unit
(i)	Nominal operating voltage	12	Volt
(ii)	Nominal operating capacity	40	Ah
(iii)	Internal resistance	<8	mΩ
(iv)	Max. discharge current	12	A
(v)	Temperature range	0 – 40	C

MPPT

MPPT uses an algorithm to select a voltage at which photovoltaic module provides maximum power output [3]. The output voltage of solar module varies in the range of 18V to 15V depending upon the solar irradiance and surface temperature of solar cell [4]. The algorithm provides electronic tracking by comparing solar module and battery voltage, it then calculate the maximum power output that can be supplied at that voltage. The information is used by controller to change waveform of buck-boost convertor and thus supplying maximum power output by operating at voltage close to maximum power point. The specifications of components used in the design of MPPT based charger are given in Table 3. Moreover, the design of MPPT based charger is shown in Fig. 1. The perturb and observe algorithm is shown in Fig. 2.

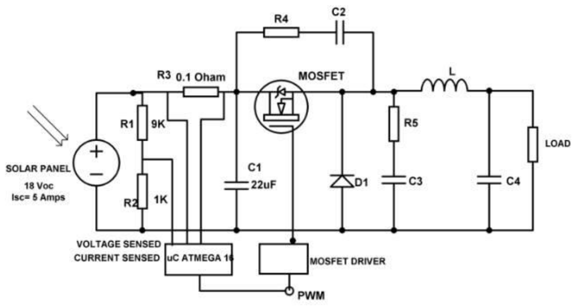

Fig. 1 The design of MPPT based charger

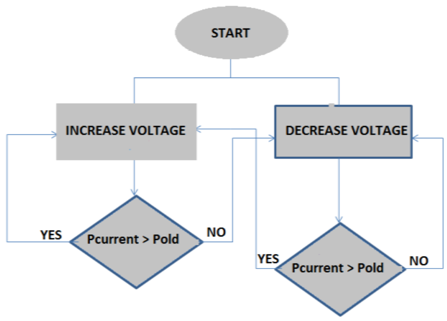

Fig. 2 Perturb and observe algorithm

Table 3 The specifications of MPPT

	Parameters	Value	Unit
(i)	Inductor for buck	100	μH
(ii)	Capacitor for buck	1000	μF
(iii)	MOSFET	IRFP150	-
(iv)	MOSFET driver	IR2109	-
(v)	AVR microcontroller	ATMEGA16	-
(vi)	Crystal	8	MHz
(vii)	Frequency	10	kHz

B. Mechanical design parameters

The selection of the parts and material is an important factor which has ultimate effect on the cost and performance of the car. Chassis can be made of carbon fiber composite material which is generally referred as monocoque chassis [4]. Aluminium was selected for fabrication of chassis of solar car to make a light weight chassis. Thus, less energy will be consumed during the race.

The top frame for solar panels was made of angle irons of aluminium as compared to square channels to save 50 % of weight to build the top frame. The dimensions of angle irons were 1”x 1” with thickness of 3 mm. The bottom frame and supports which connect top fame with bottom frame were constructed of aluminium tubes with 1 inch outer diameter and 3 mm thickness, the total weight of chassis was 38 kg. 1 mm thickness aluminium sheet was used to make body of the car. Safety roll bar was made of round aluminium tubing of 50 mm diameter and 3 mm thickness. The standard coil out dampers were used in the suspension system. The stiffness of the springs was 80 lb per inch. Both the jounce and rebound were 1 inch. Disc brakes were used on both of front wheels.

The wheelbase for current design of car is set to be 5 meters. Turning radius of the solar car is designed so that it can make U-turn in a lane of 15 meter width. The track width of tri-wheeler vehicle is determined from the front wheels and its value is set to be 1.8 meter because of packaging of solar panels. Aluminium sheet of 5 mm thickness was used to make the seat. The 100 percent Ackerman steering system was decided for effective steering and less chance for slip during cornering. Zero backlash is considered between shaft of pinion and steering wheel. The length of tie rods was 600 mm. The scrub radius was 50 mm.

III. FUNCTIONALITY WITH BLOCK DIAGRAM

Functionality of solar car can be presented with the help of main and sub-system block diagrams as shown in Fig. 3 ~ 5. Block diagram of complete system is sho wn in Fig. 3. It can be seen from the block diagram of solar system that power from solar panels is used to charge the batteries and simultaneously supply power to motor, MPPT extracts maximum power out of solar panels and controlling is done by charge controller and battery management system [5].

In microcontroller based system, all parameters are controlled by AVR microcontroller. It provides flexible programming and to perform multiple operations in same module. It contains built in ADC which helps in easy interfacing of analogue sensors (temperature, voltage and current) and as well the data can be displayed on LCD simultaneously. Parameters of over current, over/under voltage and over temperature are programmed and it performs reliable operation [6].

Solar panels supply power to L-C filter to avoid any ripples in the system. MOSFET performs the operation of controlled switching in response to the duty cycle from microcontroller. MOSFET driver is used for providing PWM at gate of MOSFET. This controlled switching performs the operation of buck chopper and steps down the voltage [7]. Second L-C filter performs the continuous mode of operation hence avoiding any ripples and restores energy stored in inductor. MPPT supplies controlled power to the battery bank for charging. Relay “A” cut offs the solar panel in case of overcharging. Voltage and current sensor performs the operation of predetermined parameters detection and control operation is performed by microcontroller via relay driver which actuates the relay. Low voltage detection is also performed by second voltage sensor and microcontroller performs the operation of controlled charging. Block Diagram of MPPT based charge controller is shown in Fig 4.

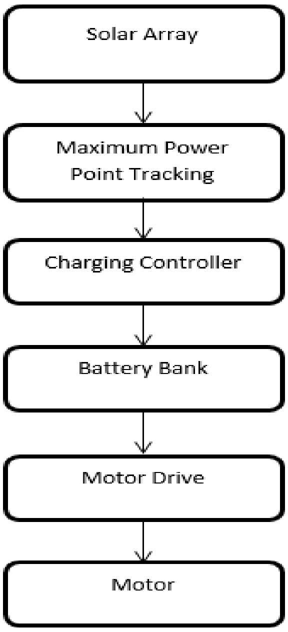

Fig. 3 Block diagram of complete system

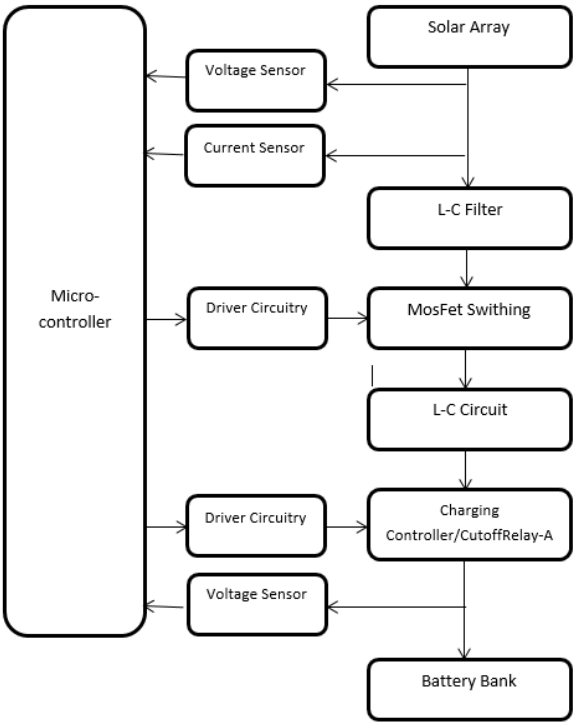

Fig. 4 Block diagram of MPPT based charger

Block diagram of motor with drive is shown in Fig 5. Battery Bank supplies power to the motor via motor drive. Temperature sensor attached to the battery bank supplies analog signal of temperature to the microcontroller unit which performs the operation of load cutoff in case of over temperature detection. This information is sent to Relay B which cutoffs the load. Motor drive performs the operation of variable speed in response to throttle pushed by driver.

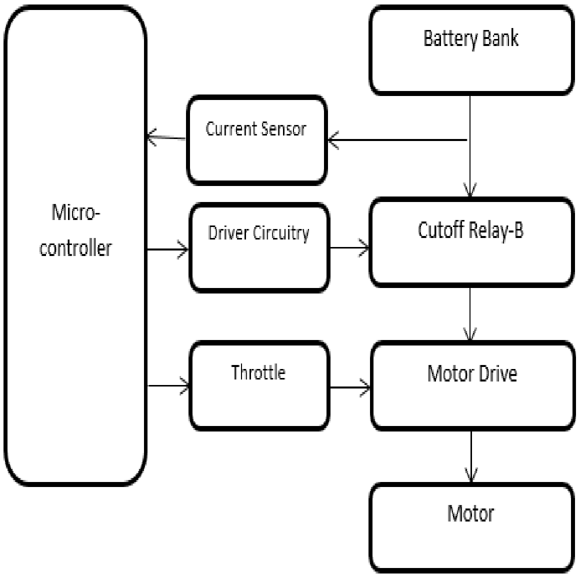

Fig. 5 Block diagram of motor with drive

IV. DESIGN FEASIBILITY

The whole system can be divided in two sub-systems which are known as propulsion system and accessory system.

Propulsion system is used to run the car with the help of solar panels and battery. Whole roof of the car is composed of 8 solar modules out of which four are 100 watt and other four are of 150 watt. These 8 modules are further divided into four sections and each section contains one 100 watt and one 150 watt solar module. This combines to form 250 watt and charges a single battery. It not only helps in cell balancing but also able to track maximum power point to extract maximum power out of the solar panels. Isolation switch allows to isolate the solar panels in case of emergency and maintenance [8]. MPPT tracks the maximum power point and helps to use solar energy at maximum efficiency. It also brings the solar panels voltage to battery voltage.

The design layout of accessory system of solar car is shown by the Fig. 6. It also performs the operation of overvoltage charge controller by disconnecting the solar panels to avoid over charging. Battery also contains fuse for overcurrent protection. Kill switch allows disconnecting the power supply in case of emergency [9]. This controlled power is supplied to motor driver which is a type of variable speed drive. Throttle is used to control the current supplied to the motor. Motor run to provide necessary propulsion to the car.

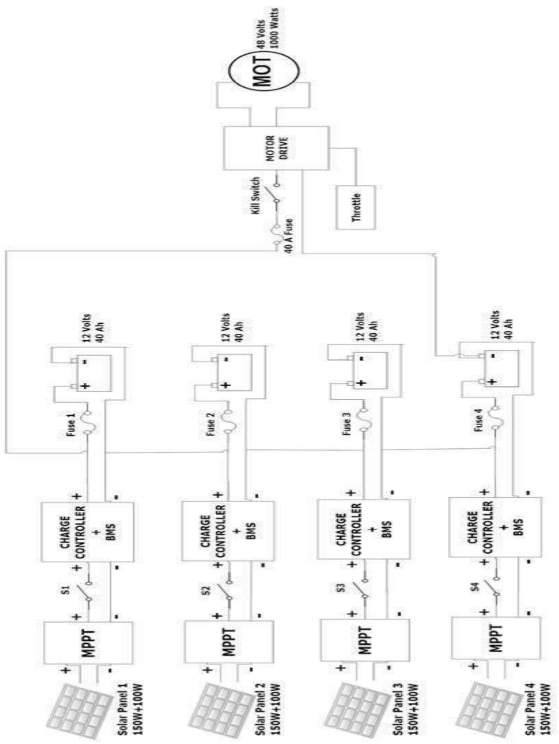

Fig. 6 Design of accessory system of solar car

Solar car brings the new idea in commercial cars therefore it contains all accessories of a commercial car. It contains two head lights, two back red lights, indicators, dash board instruments and cooling fans. All of these accessories are powered by an accessory battery which is separate from main battery. Each accessory is turned on and off with a separate switch. Selection parameters and calculation of solar modules are briefly described. During the month of June and July we get maximum irradiance out of sun. Average value of irradiation at Cyprus is 750 W/m^2 during the month of May when solar panels are kept horizontal as in our solar car [10].

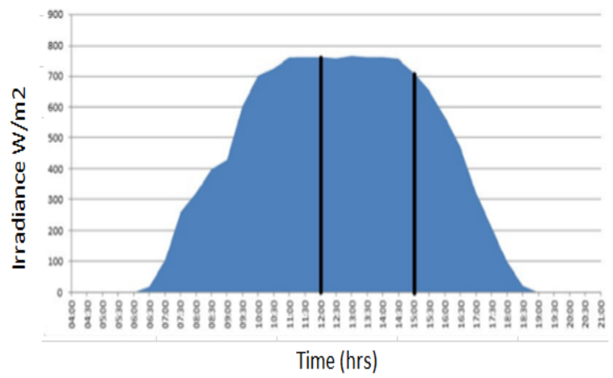

Fig. 7 Wh graph of mono-crystalline solar panels

Calculations are as follows:

Motor Specifications (Requirement of Power)
Motor Power = 1000 watt (average) & 1500 watt (peak)
Energy required = 3000 Wh

Battery Specifications:

Lead Acid (deep cycle) = 4*40 = 160 Ah
Total Watt hour = 1920 Wh
Useable Watt hour at 50% DOD = 960 Wh

Solar Panel Specifications:

Power = 1000 watt
Total Wh at 750w average in 3 hours = 2250 Wh.
Total available Energy = 960+2250 = 3210 Wh
This can easily deliver 3000 Wh for motor.

V. RESULTS

A. MPPT board testing

MPPT board was tested after successful hardware fabrication. Results for 250 watt solar panels with MPPT and without MPPT are shown in Table 4 and Table 5 respectively.

Table 4 Results for 250 watt solar panels with MPPT

	Panel Voltage (V)	Panel Current (I)	Output Voltage (V)	Output Current (I)	Output Power (W)
(i)	19	10.3	14	13	182
(ii)	18.7	10.1	14	12.57	175.9
(iii)	17	10.59	13.5	12.33	166.45

Table 5 Results for 250 watt solar panels without MPPT

	Panel Voltage (V)	Panel Current (I)	Output Voltage (V)	Output Current (I)	Output Power (W)
(i)	19	10	12.5	10	125
(ii)	18.7	9.8	11.8	9.8	115.64
(iii)	17	9.2	11	9.2	101.2

B. Results of solar car testing

Solar car was tested with and without battery so that we can make sure the feasibility of design. We recorded very good results that were according to our expectations.

Without battery

Running of car without battery adds an extra benefit of low weight. This loss of weight results in more speed. Maximum achievable speed without battery is 25 Km/hr because maximum supply current of solar panels is about 15 ampere on 48 volt. As motor is adjustable power, it allows to run the car under different solar irradiance or in shadows. Only 750 watt of solar panels were connected in the combination of three units of 250 watt in series other open circuit voltage of the series combination of all four units results in rise of voltage above 70 volt which is not a safe voltage for motor.

With battery

While running the car without batteries maximum current is limited but when we add battery in the system it allows running the motor on its full power. 15 ampere current is supplied by solar module while 12 ampere current is supplied by battery and total of 27 ampere current allows the motor to run on full power. In this way, we achieved speed of 45 Km/hr. Current variations were as shown in Table 6.

Table 6 Current variations with speed of SPV

	Speed	Voltage (V)	Current (A)	Power (W)
(i)	Initial	54	17	918
(ii)	Average	54	13	702
(iii)	Peak	54	27.7	1500

The extra feature of 1500 watt peak power allows to go on slopes and to run the car on un-even surfaces. The life cycle cost analysis and running cost of SPV is evaluated in Table 7 and Table 8 respectively.

Table 7 Life cycle cost analysis of SPV

	Parameters	Value	Unit
(i)	Sample time	3	hr
(ii)	Average speed of car	40	Km/h
(iii)	Distance covered	120	Km
(iv)	Average fuel consumption of conventional vehicle	12	Km/lit
(v)	Fuel price	0.75	USD/lit
(vi)	Fuel cost per sample time	9	USD
(vii)	Fuel cost per month	270	USD
(viii)	Fuel cost per annum	3240	USD
(ix)	SPV running cost per annum	1019.01	USD
(x)	Annual saving	2220.99	USD
(xi)	Monthly saving	185.08	USD

Table 8 The running cost of SPV

	Parameters	Value	Unit
(i)	Cost of solar panels per decade	1500	USD
(ii)	Cost of battery bank per annum	600	USD
(iii)	Cost of battery bank per decade	6000	USD
(iv)	Running cost of SPV per decade	7500	USD

VI. CONCLUSION

Solar car is a best alternative to conventional car and can be commercialized in near future. It helps you to run without any conventional energy resource. Keeping in mind that mechanical solar panel tracking is not possible as solar car always changes its direction on ground electrical maximum power point tracking is the best solution to attain maximum power coming out of the solar panels. To protect the system from electrical hazards battery management provides adds an extra feature of safety which helps to protect the system in case of over temperature and over current. Charge controller performs controlled charging hence resulting in rise of battery life.

As it was for the very first solar car therefore there are some improvements which must be made in upcoming models. Li-ion batteries must be used which will allow to reduce the weight much further. Battery backup must be increased so that more mileage could be achieved in dark. Capacity of sitting persons must be increased to at least four and for that huge motor of 5000 watt will be used.

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