Intelligent Power Management for Optimal Battery Charging in a Solar-Powered Mine sweeping Robotic Vehicle by means of Tracked Solar Panel

E. Akhil Madhavan and Aby Mathew

Abstract— *This paper focuses on the design and construction of an Intelligent Power Management for Optimal Battery Charging in a Solar-Powered Mine sweeping Robotic Vehicle by means of Tracked Solar Panel. Thus, the implementation of a complete energy management system applied to a robotic exploration vehicle is put forward. The proposed system was tested on the MINE SWEEPING robotic platform—an autonomous unmanned exploration vehicle specialized in mine detection. .On the one hand, it presents the construction of a solar tracking mechanism aimed at increasing the rover's power regardless of its mobility. The design implemented in this paper proposes the use of two separate battery units working alternately. The aim is completing the process of charging a battery independently while the other battery provides all the energy consumed by the robotic vehicle.*

Keywords— *Li–Po Battery, Mechatronic System, Photovoltaic(PV), Robotic Vehicle, Solar Tracker*

NOMENCLATURE

A. Current through the load system

*I*scShort circuit current.

*t*Time for battery charging and discharging.

*t*on Backup time for a battery.

*t*trans Time for the battery switching.

*V*oc circuit voltage.

*V*upProtection condition voltage for batterycharging

*V*end Maximum voltage for thebattery discharging.

B1 Battery 1

B2 Battery 2

I. INTRODUCTION

SOLAR power systems in autonomous robotic vehicles havebeen often used for some years. A real example is the So-journerrover, in which most of the supplied energy is generatedby a reduced-size photovoltaic (PV) panel [1]. However, in case of scarce to no solar light, the rover should minimize consumption, since its batteries in line could not be recharged when depleted [2]. The use of rechargeable batteries in a space mission was used for the first time in the Mars Exploration Rovers. Nevertheless, the need for greater operation autonomy by Spirit and Opportunity was solved by means of larger deploy solar panels [3]. This solution works as the basis for the design of solar panels for the future ExoMars mission. This rover, thanks to its high-efficiency ultrathin-film silicon cells constructed on carbon-fiber reinforced plastic, is capable of providing higher power [4], [5]. NASA designs inspired different generations of exploration vehicles [6]. This is the example of K9, a rover for remote science exploration and autonomous operation [7];field integrated design and operations, an advanced-technology prototype by Jet Propulsion Laboratory for long-range mobile planetary science [8]; and Micro5, a series of robotic vehicles devised for lunar exploration [9]. As its main design advantage, this rover series has a dual solar panel system coupled to an assisted suspension mechanism. This prevents the manipulatorarm mounted on the middle of the rover from having to minimize solar panel-generated power and allows it to dust solar panel surface other robotic exploration vehicles have also been developed in academic spheres. This is the case of SOLERO, which reached optimal energy consumption by a combination of a smart power management and an efficient locomotion system [10], [11]. On the other hand, the Carnegie Mellon University developed Hyperion, a rover in which the major technological milestone was the implementation of solar-synchronous techniques to increase the amount of energy generated by solar panels [12]; a rover capable of long-distance traverses under extreme environmental conditions devoted to science investigation at the Atacama Desert [13].

The minesweeper robotic exploration vehicle aims to improve various aspects of the aforementioned rovers with scientific and academic purposes. To introduce the developed robot (see Fig. 1).

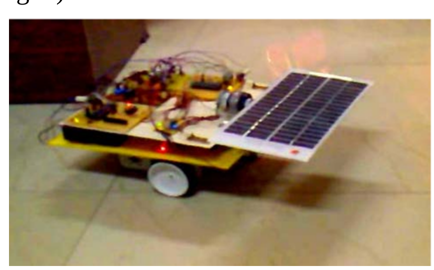

Fig. 1.a Solar-Powered Minesweeping Robotic Vehicle

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The design implemented in this paper proposes the use of two separate battery units working alternately [see Fig.2(a)]. Thus, one of the batteries receives the charge current from the PV system while the other provides mine sweeping robot with all the energyit requires. Unlike other designs, in a conventional system the power source is used to recharge a single battery [see Fig.2(b)].As a disadvantage, the robot can only be used when the battery is fully charged and must remain idle during the recharging process. On the contrary, in load sharing systems whose delivered solar energy is shared with the load while the battery is charging, power requirements at the source are higher [seeFig.2(c)]. This means larger surface and therefore heavier solar panels. However, space and weight are critical design requirements in many small robotic vehicles. The implemented design in this paper proposes independent charging and discharging processes, thus dividing the problem into two batteries. A relatively good compromise between total weight, available capacity, and source-required power is reached. This strategy implies a smaller PV system to power a single smaller battery at a time and, therefore, solar panels are more economical. This goal was prioritized in this project.

The rest of this paper is organized as follows. Section II presents the mobile robotic system. Its main features are described and its hardware and software architecture are presented. In Section III, introduces the concept of intelligent power management applied to a mine sweeping exploration vehicle.. Section IV concludes this paper.

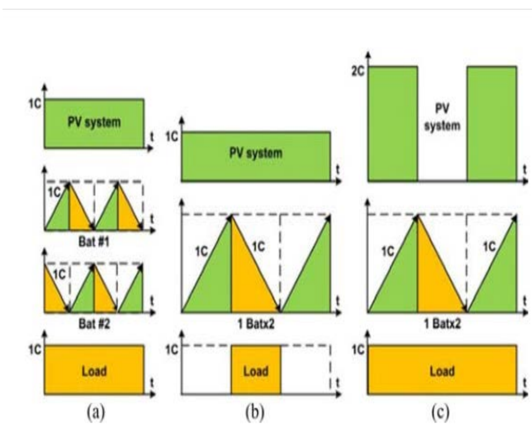

Fig. 2. Different strategies of solar-powered robots with battery system:(a) dual battery system, (b) conventional system, and (c) load sharing system.

II. MINESWEEPING ROBOTIC PLATFORM

Mine sweeper —is a robotic exploration mine sweeping vehicle developed to detect hidden mines in the field. The rover was developed to be guided and has a pair of wheels and free rotating front wheel coupled to a plane chassis .The back two wheels that can rotate independently. Each wheel consists of two motors, one for rotation and another for driving. On the one hand, forward movement is produced by means of dc motors (12 V and 60 mA) that provides 120 r/min with a torque of 8.87 kg/cm. On the other hand, the rotation motor provides a speed of 152 r/min. Its reduced weight, small dimensions, and versatility make mine sweeper robot suitable as a robotic exploration vehicle. The robotic system programming is divided into two main levels and its hardware was designed with a structure based on two independent microcontrollers.The mine sweeping robotic vehicle can be controlled and monitored with the help of a remote PC by using HyperTerminal software.Microcontroller2 fully dedicated to perform the robotic functionality. The second code level, programmed in embedded C language, runs autonomously on a PIC16F877A microcontroller to perform remote manipulation, and power management aboard mine sweeper robot.

All the programs complied and simulated in microC. Communication with the remote PC is performed by using a 802.15.4 Protocol for the centralized control of rover functions.

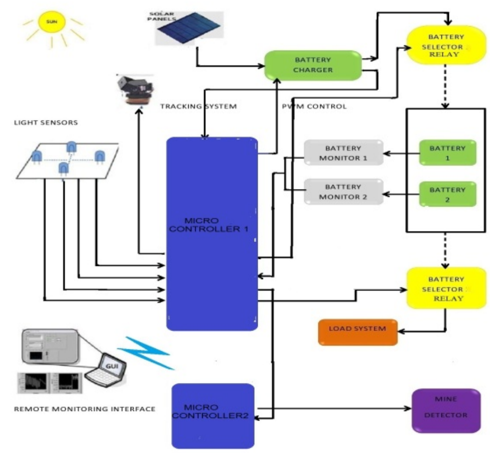

Fig.3. Overall scheme of the power management system of minesweeper robotic vehicle

III. ROBOTIC MECHATRONIC SYSTEM DESIGN

A typical power management design consists of smart batteries integrating both communication devices and electronics able to control the charge. However, when an economical system is required, the concept of intelligence should be applied to software design for simple batteries. One of the main objectives of this paper is the implementation of todevelop a low-cost power management system aboard a robotic vehicle. The system consists of an electrical circuit interconnecting a PV system, a charger device, a selector system, a batteries monitor system, and a battery system.

TABLE I

DESIGN FEATURES OF MINE SWEEPER

Name	CPU	Battery System ery System	Solar Panel	Size & Weight	Wheels	Speed
MINE SWEEPER	2 x 8-bits Microcontrollers	2 x Li-Po (0.15kg/u, 2400 mAh) 0.036 x 0.035 x 0.065 m^3	PET 0.2 x 0.25 x 0.0032 m^3 14 V,6W,0.7 Kg	0.35 x 0.75 x 0.3 m^3, 3.5 Kg	3	0.6 m/s

A. Photovoltaic System with Solar Tracking

A solar cell (also called a photovoltaic cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell (in that its electrical characteristics—e.g. current, voltage, or resistance—vary when light is incident upon it) which, when exposed to light, can generate and support an electric current without being attached to any external voltage source. The panel weight is a factor that limited its mechanical design; light-weight panels provide lower power consumption and require optimizing the robot’s overall performance. The proposed PV system consists of mono crystalline solar panels with laminated PETwhose dimensions are200 mm × 250 mm × 3.2 mm and its weight is 0.7 kg perPanel. The design of Solar Tracker is to develop and implement a simplified diagram of a horizontal axis and active tracker method type of solar tracker fitted to a panel. It will be able to navigate to the best angle of exposure of light from the torchlight. The efficiency of the solar energy conversion can be optimized by receiving maximum light on the solar panel [14]. A pair of sensors is used to point the East and westof the location of the light. The center of the drive is a DC motor. Figure 5 shows a schematic diagram of a horizontal-axis solar tracker. This will be controlled via microcontroller program. The designed algorithm will power the motor drive after processing the feedback signals from the sensor array.

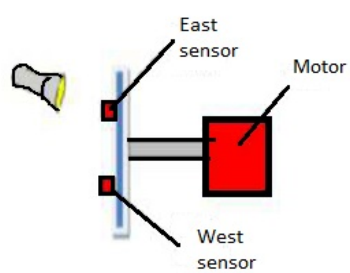

Fig.4. diagram of solar tracker mechanism

The Microcontroller program will also include monitoring and display of light intensity output from the photodiodes. The light detected by the Eastward-facing sensor is at a lower intensity to that detected by the Westward-facing sensor. Hence, the sensor must be turned westwards (by the motor controlled by the solar tracker circuit) until the levels of light detected by both the East and the West sensors are equal. At the point of the solar panel will be directly facing the light and generated electricity optimally. Obviously real world solar trackers are not so simple. A solar tracker must be able to reset itself at sunset so it is ready for sunrise, it must cope with heavy cloud, and it. In addition a mount for the solar panel must be constructed which can cope with strong winds and a suitable motor found. The tracking system design is based on solar-type CdS photoconductive cells. This consists of two cds photoconductive cells PDV-P9203 photosensors mounted on a PCB attached to one solar panel . The advantage of the selected devices is that they have a spectral sensitivity peak near 600 nm where light is considered to have more energy.

B. Battery Switching System

The switching system consists of O/E/N 40dual mini relay selectors with break-before-make operation logic. Their function is connecting electrically the charge and discharge paths between the batteries, the charger module, and the load system . That is, selector dual relay is inserted between the charger, dual-battery pack and the load. Its function is routing the current from the PV panels to the input of the charger and, from there, to the battery selected in each moment and to the load. Therefore, the dynamic connections of the electric circuit are carried out according to the microcontroller 1 control signal. The battery status can be monitored at any time by sending a character “t”. The replay from the microcontroller 1 will be “B1 USING B2 CHARGING” or “B2 USING B1 CHARGING”.

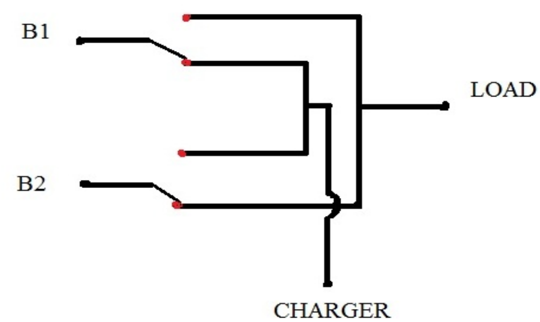

Fig. 5.Diagramof battery switching system.B1-battery1,B2-battery2

C. Optimal Battery Charging System

The charger system consists of a Ćuk converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. The algorithm implemented consists of a charge regulation by increasing or decreasing the output current of the charger module according to the MPP. The MPP-tracking scheme is based on the dynamic power path management (DPPM) function described by Texas Instruments Incorporated [15]. This low-cost solution is a simplified MPP tracker able to harness90–95% of maximum power. On this basis, a voltage variation in the Ćuk converter is detected by theI/V sensor as a power variation (see Fig. 6).Because theĆuk converter output is proportional to the PV panel output variations. The charger system is controlled by the microcontroller 1 using a PWM signal applied to one of its terminals and supplies each battery according to a programmed algorithm. These signals are used by the microcontroller1 to enable, disable, and control the charge current of the charger by means of a PWM signal. If the algorithm detects that light conditions provide higher output power at the PV panel, the microcontoller1 increases the output current of the charger up to the maximum regulation current. If light conditions cause a power drop in the PV panels, the microcontroller 1 staggeringly reduces the current drawn to the battery until power stabilizes at the PV panels.. In case of reaching the maximum allowable voltage for battery charging, the algorithm drops out generated power reducing the output current of the charger device. Subsequently, the microcontroller 1 proceeds to search a new maximum efficiency point as described previously. Consequently, the solar panels were sized to obtain a voltage suitable for this operation; therefore, the MPP is set with a voltage higher than the cutoff level of the dc–dc converter. This allowed us to implement a protection scheme against drops in solar power input to improve system performance and reliability

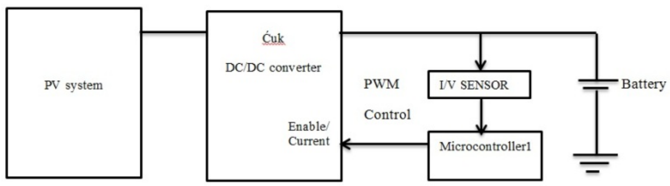

Fig. 6.Connection diagram of the charger system

D. Remote Monitoring Interface

The mine sweeping robotic vehicle can be controlled and monitored with the help of a remote PC byusing HyperTerminal software. The aim of the monitoring system is maximizing the life and energy storage of Li–Po cells. Therefore, the main function of this system is monitoring the state of charge (SoC) of the batteries and accurate control of the charging–discharging cycles. The use of a dual battery monitor system was required for control and parameter measurement. The forward motion is achieved sending a character "f", backward motion by sending "b", Right and Left rotation by sending "r","l" respectively .when the mine detected by the mine sweeper robot it will send " MINE FOUND" to the remote PC. The battery status can be monitored at any time by sending a character "t". The replay from the microcontroller 1 will be "B1 USING B2 CHARGING" or "B2 USING B1 CHARGING".

E. *Algorithms*

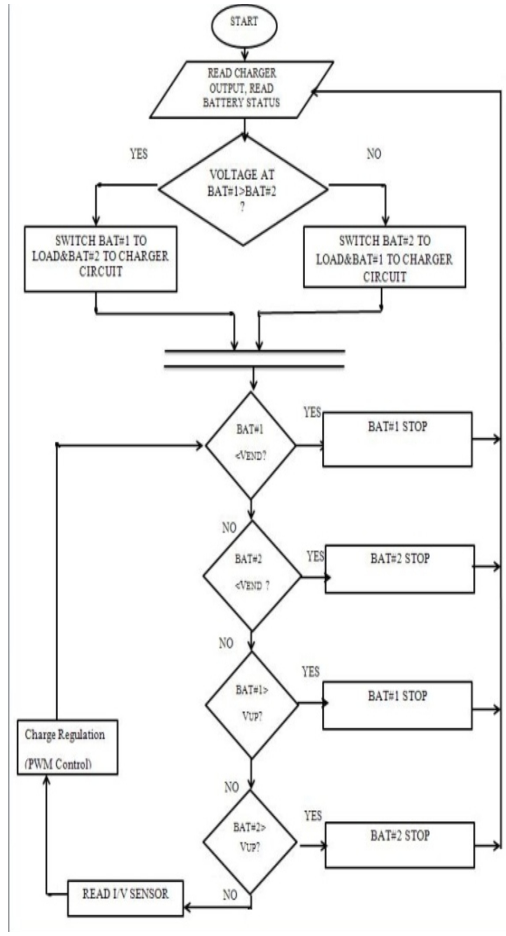

Fig. 8.Algorithm of the charging and discharging cycle

IV. Experimentation

Different tests with the three solar panels were completed to assess power generation under different lightning conditions (see Table II). Thus, Fig. 11 shows the output power versus current and voltage of a PV panel where the MPP is achieved at 23∞C with solar irradiance of 940 W/m2.

As an example of the battery system working in an alternate way Figs. 11–13 represent the charging and discharging operation proposed in this paper.The capacity stored and delivered to the load system in terms of power during the charging and discharging states is shown in Fig. 11.

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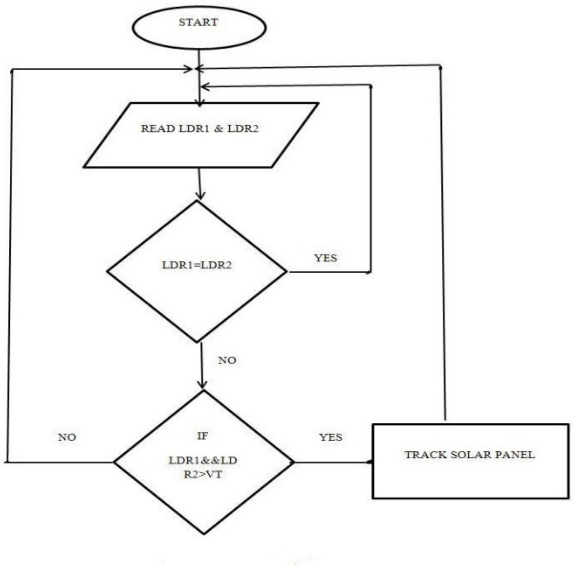

Fig.9 Algorithm of solar tracking

TABLE II
CAPACITY OF GENERATION OF EACH PV PANEL BASED ON THE RESULTS ACHIEVED FROM GROUND TESTING

Type of Light	V_{oc}	I_{sc}
UV ligh (100 W)	14.0 V	40 mA
Solar radiation	14.8 V	493 mA
Halogen light (1500 W)	15.2 V	400 mA
Halogen light (100 W)	15.2 V	340 mA

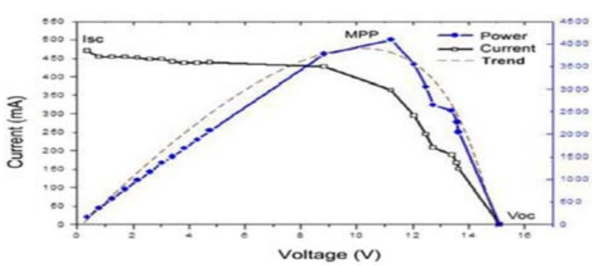

Fig. 10.*I–V* characteristic and output power of a solar panel at 23 ◦C and solar irradiance of 940 W/m2.

Initially, the algorithm detects the battery with lower capacity and carries out its charging while the battery with higher capacity supplies the load system. Thus, in the first tract of Fig. 12 battery 1 receives the charge current until reaching a set rate of∼2A,while battery 2 is only supplying mine sweeper active electronics (*IL* ∼250 mA). The graph illustrates how battery 1 passes from the constant current charging phase to the constant-voltage charging phase when *V*up reaches 12.15 V for this test (see Fig. 13).

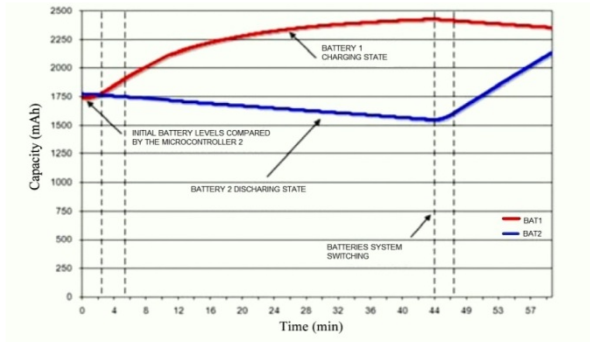

Fig. 11. Capacity curves in the batteries for a charging and discharging cycle.

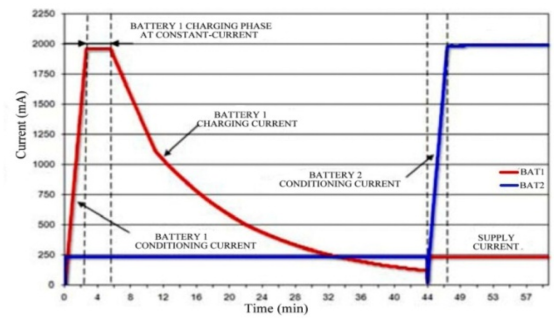

Fig. 12. Current curves in the batteries for a charging and discharging cycle.

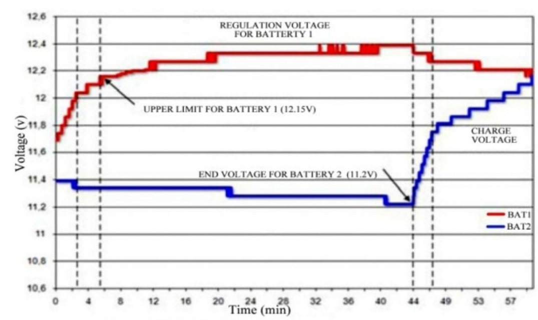

Fig. 13. Voltage curves in the batteries for a charging and discharging cycle.

Then, the charge current of battery 1 begins to drop while stabilizingthe voltage and battery 2 continues in discharge until the endvoltage is reached (*V*end = 11.2 V for this test). In this point, at *t*=44 min the switching of the batteries system is observed. The turn-OFF and turn-ON times of the batteries take place in a time *t*trans = 6 μs in which no supplies are connected to each other during the transition. In summary, the constant-current charging phase—in which the Li–Po battery is considered charged to a 75–80%—takes up relatively short time, while the following phase (80% to 95–100%) takes much longer as shown.

V. CONCLUSION

This paper has presented a smart energy management systemapplied to a robotic mine sweeping platform, an autonomousunmanned vehicle devoted to mine sweeping tasks. The proposalincludes the construction of a solar tracker mechanism based onmobile PV panels aimed at increasing system energy. Its mainadvantage is that the amount of generated power is independentfrom the rover's mobility, since the proposed mechanism iscapable of tracking maximum light intensity.Delivering the system's energy requirements while rechargingthe backup battery was made possible by implementing adual system of selector relays, monitors, and batteries. This strategyimplies small solar panels to power a single battery at a time.A relatively good compromise between total weight, capacityavailable, and source-required power is reached. This solutiondoes not attempt to achieve high charging times or great operatingtimes but to prove a sustainable and commercially feasiblesolution applied to a robotic vehicle.

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