

Cost Effective Solar Charge Controller for Lithium Ion Battery Using 555 Timer IC

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Abstract

In this work, an 8 Watt Photovoltaic (PV) panel was successfully used to charge Lithium Ion battery (LIR-18650, 3.7V) using a custom designed and constructed Pulse Width Modulated (PWM) solar charge controller. The PWM charge controller is based on NE555 IC configured in astable mode of a variable pulse width. The charge controller includes automatic cut-off to prevent battery overcharge, achieved using the reset pin of the timer IC. The design of the charge controller makes it versatile, and able to charge Lead acid batteries and Li-Ion type batteries alike. In this report, the various ways in which the charge controller can be re-tasked for charging different types of rechargeable batteries are also presented.

Keywords: solar, charge controller, PWM, Lithium-ion battery, pv.

1.0 Introduction

Good percentage of portable devices in the market today is battery powered. As solar energy price/watt is reducing, more and more of these devices are converted to inexpensive solar charged battery powered devices.

More often than not, the users of these products end up discarding them, as the cost of maintaining the system gets formidably high, partly because they lack electrical power to recharge the batteries when needed.

Most portable devices use lead acid batteries, but Li-Ion batteries being superior in performance are gaining ground over lead acid batteries. [1]- [2]

The charge or energy stored in a battery is not expected to last forever, [3] but every user wants to get a good run for the money spent on a portable system, therefore portable systems, though running on batteries are expected to perform creditably well. Aside from the reliability of other components that make up a portable system, the life span of a rechargeable battery depends on its use cycle [2]. Use cycle refers to the discharge and recharge cycles of the battery.

Battery chargers are generally designed to use one or two modes for charging, constant current (CC) or constant voltage (CV) modes. Sophisticated battery chargers may offer other types of charging modes like trickle and float

charge modes [4]. No matter the method adopted, the aim is to restore the energy of the battery in a way that keeps the battery alive long enough to pay for its initial cost.

Lead acid batteries are easily recharged by connecting it to a DC voltage that is about 125% of its terminal voltage. Overcharging a lead acid battery is not prohibited, since the battery can withstand some level of overcharge, hence a typical 12V lead acid battery is usually rate at 14-14.9V cycle use. Lead acid battery manufacturers usually allow up to 25% of the battery's Ampere Hour Capacity rating for charging current. Constant Voltage mode of charging is the only one recommended for Lead acid batteries usually with an initial current of not more than 1.75A, which 25% of the 7AH capacity.

The demand for CV mode makes direct connection of PV panels to lead acid batteries for charging improper. This is because the solar energy from the sun varies constantly, and PV panels terminal voltage are normally 17V which will if unguarded, overcharge and damage the lead acid battery.

Li-ion batteries on the other hand have stringent charging requirements like not charging them beyond 4.2V, and with not more than one ampere of current [3]. The terminal voltage of a Li-ion battery is about 3.7V, but they have high capacity to weight ratio, see Figure 1, hence are the love of

portable device designers [5], when it comes

to selecting power sources.



Figure 1: a 2600mAh 18650 Li-ion battery, measuring only 65.57mm in length

Although Li-Ion batteries are initially more expensive than lead acid batteries, they do not strictly require constant voltage or current for charging [5] as demanded for lead acid batteries. Overcharging a Li-ion is strictly forbidden, as the battery may explode if overcharged.

Being unaffected by variations in charge voltage, Li-ion batteries are better candidates for solar based charging system. However, there must be a charge controller employed to properly manage the charging voltage and current of the Li-ion cell under charge.

In this work, an inexpensive PWM based solar charge controller is designed and used to

charge Li-ion batteries (LIR-18650, 3.7V) one at a time.

PWM charge controller.

The block diagram of the PWM charge controller is shown in Figure 2. The DC source (in this work, an 8 watts PV panel) provides power to charge the Li-ion cell, as well as power the PWM generator circuit. The power switch is a power transistor switched by the high frequency PWM pulses from the PWM Generator. The Voltage Monitor monitors the terminal voltage of the Li-Ion cell, when the terminal voltage gets to 4.2V (Full Charge voltage of the Li-Ion cell), it sends a short-off signal to the PWM generator, stopping the charging process.

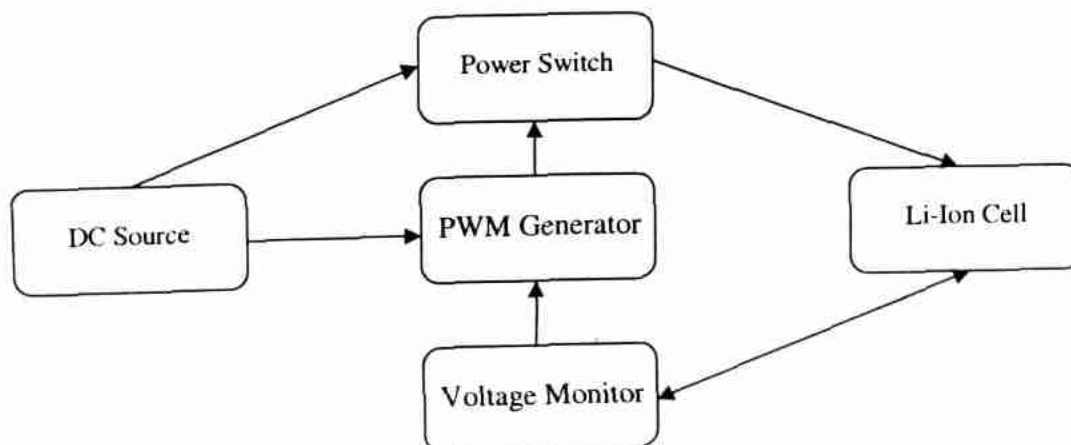


Figure 2: The block diagram of the charge controller, showing the sub units.

Empirical studies has shown that the Li-Ion battery is only charged to about 80% of its capacity the first time its terminal voltage hits 4.2V [5], but when the battery relaxes after this initial charge up, terminal voltage drops to

about 3.8-3.9V. If the battery is still in the Charger when this happens, charging will resume and continue until the terminal voltage attain 4.2V again.

2.0 System Design

Labcenter Electronics Protus 8 was used to design and simulate the entire charge controller to ascertain its workability, before actual construction. The design of the system is detailed next.

2.1 DC Source

The direct current (DC) source is acquired from a PV panel rated 8 watts, capable of generating Short-Circuit current of 500mA, Maximum-Power output voltage of 17V and Open-Circuit voltage of 21V. Since this PV panel had no protection diode, the controller includes a reverse voltage protection diode in the power switching section. Figure 3, shows the representation of the PV panel in Protus 8 environment for the purpose of simulation.

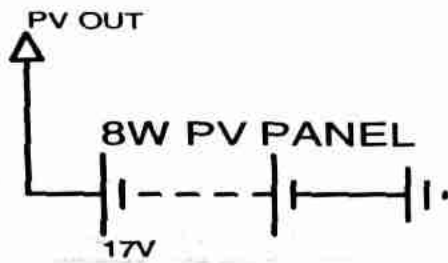


Figure 3: A representation of the 8watts PV panel in Protus 8

2.2 Power Switch

Since the maximum battery charge current cannot exceed 500mA in this application, it is delivered through a bipolar junction transistor (BJT) in common emitter configuration.

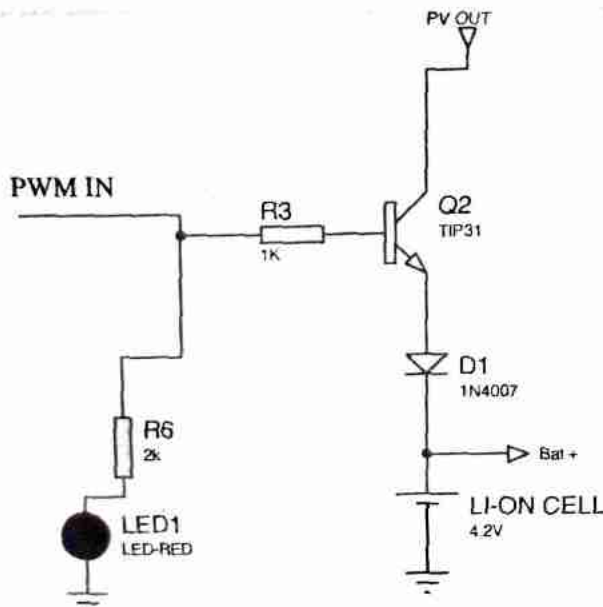


Figure 4: The Power switching BJT (Q2) and reverse voltage protection Diode D1

In the worst case scenario, the Li-Ion battery is a short to ground, and the input pulse to the switch is at its maximum value of 17.3V (i.e. 21V – 3.7V).

To calculate the value of the base resistor R3, a base drive current of 15mA is assumed and proceed as follows;

$$R3 = \frac{V_{PWM} - V_{BEQ2} - V_{D1}}{I_{BEQ2}} \quad (1)$$

$$\therefore R3 = \frac{17.3 - 0.7 - 0.7}{15 \times 10^{-3}} \cong 1000\Omega$$

When the battery is fully charged equation (1) is adjusted to take into account the terminal voltage of the Li-Ion battery.

$$I_{BEQ2} = \frac{V_{PWM} - V_{BEQ2} - V_{D1} - V_{Li.on}}{R3} \quad (2)$$

$$I_{BEQ2} = \frac{17.3 - 0.7 - 0.7 - 4.2}{1000} = 11.7mA$$

This transistor base current, I_{BEQ2} should be large enough to still maintain the operation of Q2 in saturation region, so that Q2 will continue to act as a switch even when battery is fully charged.

Since maximum I_{CEQ2} is 500mA, and minimum I_{BEQ2} is 11.7mA, h_{feQ2} can be determined as follows:

$$h_{feQ2} = \frac{I_{CEQ2}}{I_{BEQ2}} \quad (3)$$

$$\therefore h_{feQ2} = \frac{500mA}{11.7mA} \cong 43$$

Therefore Q2 is selected to offer a gain of 43 at least.

The signal LED (LED1) is used to indicate when charging operation is on, and is driven directly by the PWM circuit, the current drawn by LED1 does not contribute to charging of the battery and hence it is set to a lower value of about 7mA by using 2k Ω for R6.

2.3 PWM Generator

The PWM generator is an NE555 timer integrated circuit (IC) configured in a stable mode, with switching diodes D3 and D4

included to allow the variation of the duty cycle from 0% to near 100%.

Figure 5 below shows the circuit configuration used to achieve a PWM signal that ensures the

charging voltage of the Li-Ion battery stays at about 5V.

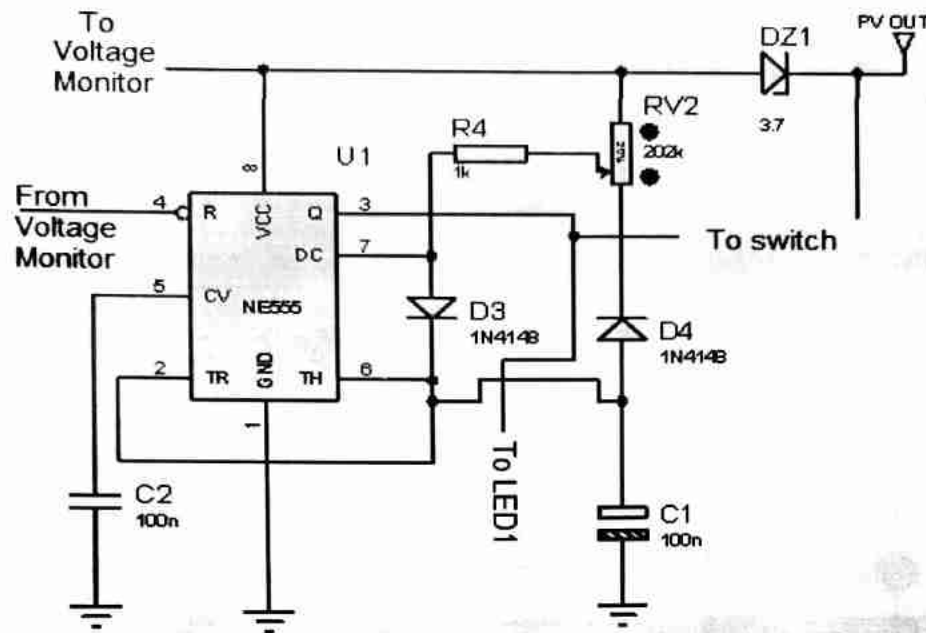


Figure 5: NE555 timer circuit used to generate the PWM signal

The charging voltage is determined by the following steps;

- Replace the Li-Ion battery with a 1KΩ resistor,
- Connect a volt meter across the terminal of the 1KΩ resistor,
- Vary RV2 until the volt meter registers 5V.

One benefit derivable from using this empirical method in setting the charge voltage is that it will allow easy re-tasking of the charge controller to charging of other type of batteries like the lead acid battery.

The zener diode – DZ1 is used as a voltage limiter, it ensures that the supply to the NE555 circuit does not exceed 18V, without restricting the current supply to the circuit.

2.4 Voltage Monitor

The circuit shown in Figure 6 is used to monitor the battery terminal voltage. When the battery terminal voltage attains 4.2V, the zener diode, ZD2 is turned on, which then switches on the BJT Q1, grounding the reset pin of NE555 IC. Pin 4 of NE555 IC is an active low reset; therefore the output PWM signal is automatically turned off.

Once transistor Q1 is turned on, LED2 glows, indicating that the battery is fully charged.

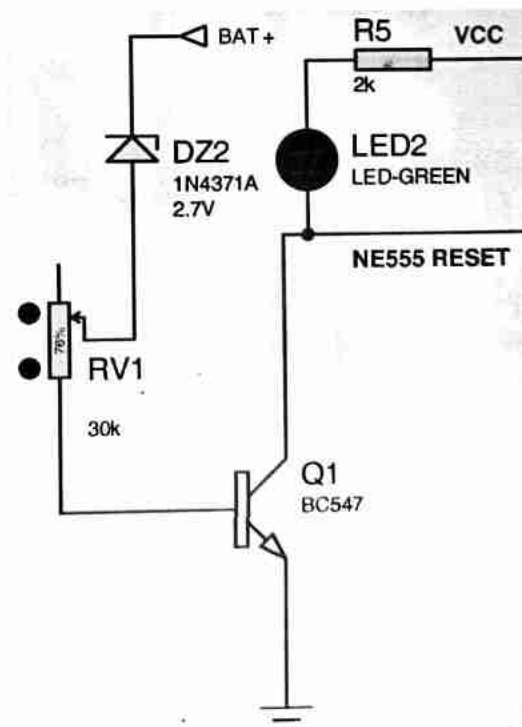


Figure 6: The Voltage Monitoring circuit and Full charge indicator LED

The base of transistor Q1 is driven by the battery in the absence of voltage from the PV panel. Resistor R1 is therefore sized to limit transistor Q1's base current to a value just enough to maintain zener diode DZ2 in reverse breakdown state. This will prevent the battery from discharging into the charge controller.

If the zener diode DZ2 is conducting, the RV1 is given by:

$$RV1 = \frac{V_{LiOn} - V_{DZ1} - V_{BEQ1}}{I_{BEQ1}} \quad (4)$$

For a low current of about $40\mu A$, RV1 is therefore

$$RV1 = \frac{4.2 - 2.7 - 0.7}{40 \times 10^{-6}} = 20k\Omega$$

Q1 is selected to drive a current of about 10mA through the full charge indicator LED1, LED2. Using equation (3);

$$\therefore h_{feQ1} = \frac{I_{CEQ1}}{I_{BEQ1}} = \frac{10mA}{40\mu A} \cong 250$$

3.0 System Implementation and Results

Figure 7 shows the entire circuit as captured in Protus 8 simulator. The following tests were carried out: the voltage of the battery BAT⁺ was monitored alongside CHARGING voltage and the charge controller RESET voltage. Oscilloscope screen print for the charge operation is shown in Figure 8.

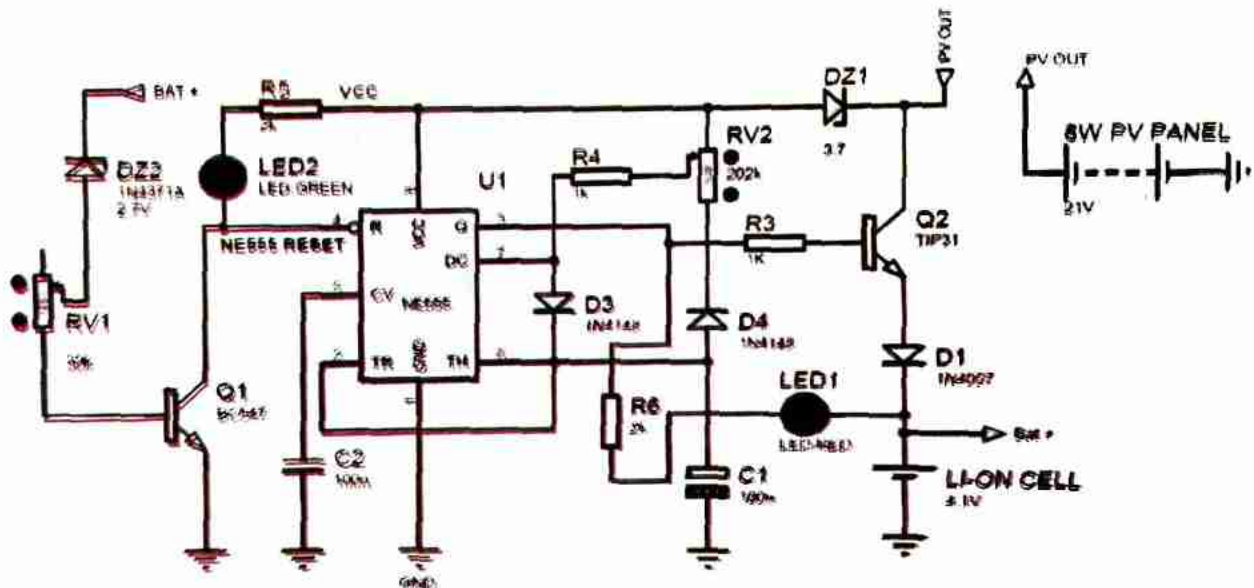


Figure 7: System circuit of the Charge controller.

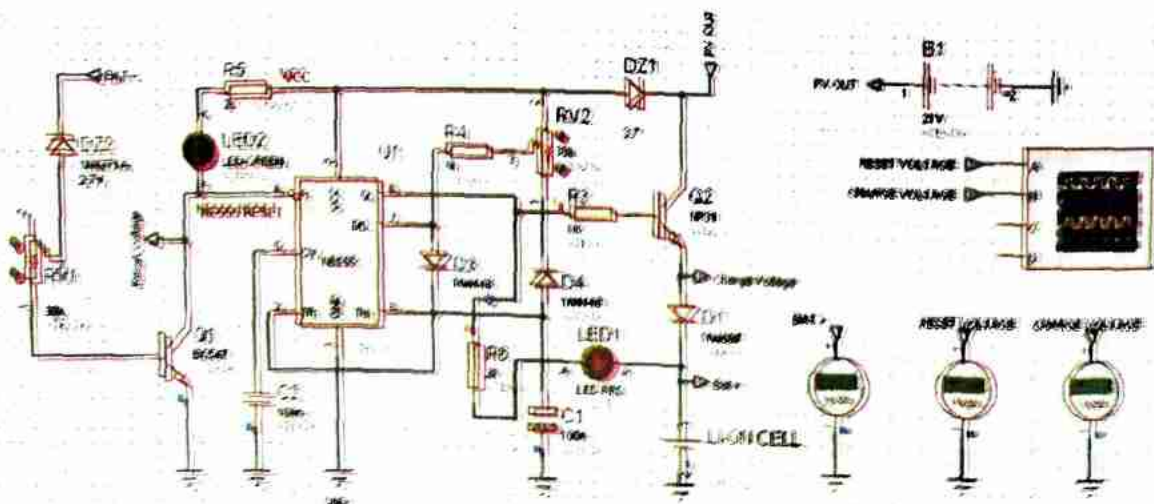


Figure 8: Oscilloscope screen print for the charge operation

On satisfactory simulation of the design, the schematic was transferred to printed circuit board (PCB) using Protus Ares application.

Shown in Figure 9 and 10 are the PCB board and the 3D rendering of the entire circuit.

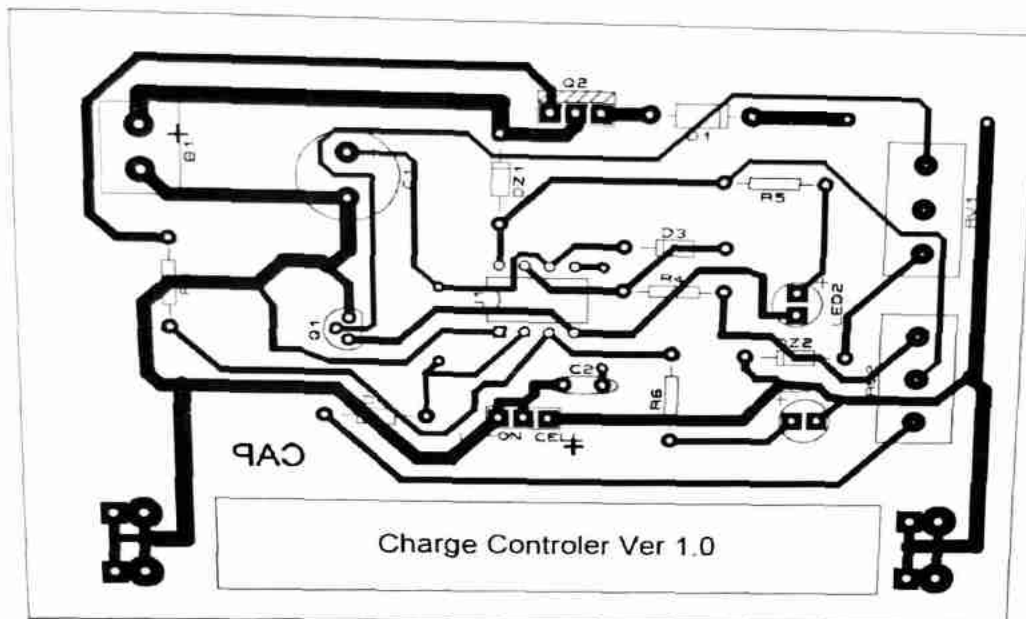


Figure 9: PCB of the charge controller, showing all the layers

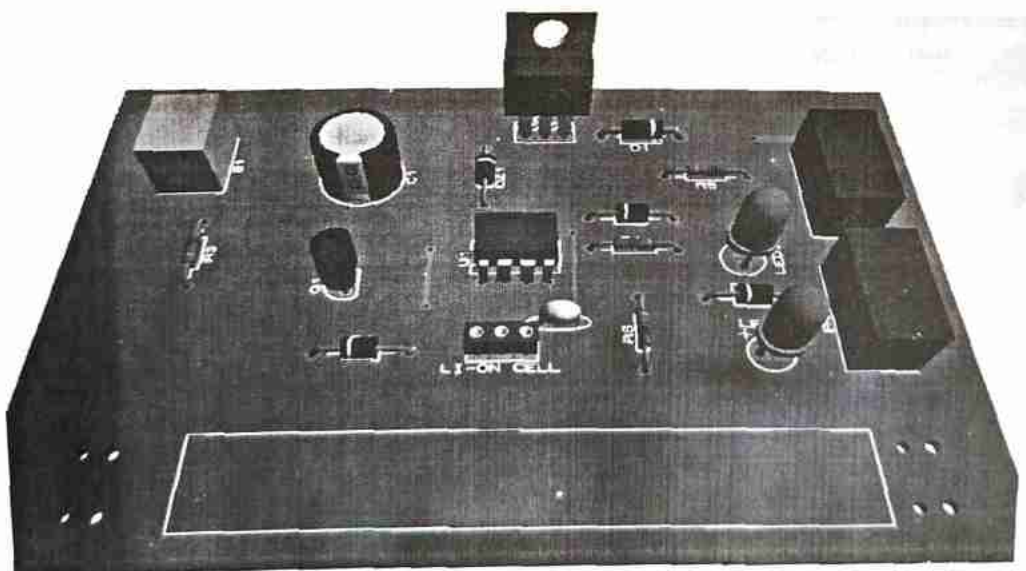


Figure 10: PCB of the charge controller, showing all the layers

4.0 Conclusions

Using the charge controller designed in this work, it was possible to charge a Li-Ion battery from fully discharged to fully charged in just under 5 hours from an 8 watts PV panel. Although the system is simple, it is accurate and performed reliably well during the test. A possible shortcoming of the controller is its inability to charge more than one lithium battery at a time.

Being a standalone system, a user is required to connect the battery to be charge to the controller, and disconnect it when fully charged. This mode of usage is only suitable for portable systems where the batteries are removable, like lithium ion battery powered portable LED lighting systems.

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