Designing of Lithium - Ion Battery Pack Rechargeable on a Hybrid System with Battery Management System (BMS) for DC Loads of Low Power Applications – A Prototype Model

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Abstract. Now a days, Li-ion batteries are quite possibly the most exceptional battery-powered batteries; these are drawing in much consideration from recent many years. M Whittingham first proposed lithium-ion battery technology in the 1970s, using titanium sulphide for the cathode and lithium metal for the anode. Li-ion batteries are the force to be reckoned with for the advanced electronic upset in this cutting-edge versatile society, solely utilized in cell phones and PC computers. A battery is a Pack of cells organized in an arrangement/equal association so the voltage can be raised to the craving levels. Lithium-ion batteries, which are completely utilised in portable gadgets & electric vehicles, are the driving force behind the digital technological revolution in today's mobile societies. In order to protect and maintain voltage and current of the battery within safe limit Battery Management System (BMS) should be used. BMS provides thermal management to the battery, safeguarding it against over and under temperature and also during short circuit conditions. The battery pack is designed with series and parallel connected cells of 3.7v to produce 12v. The charging and releasing levels of the battery pack is indicated by interfacing the Arduino microcontroller. The entire equipment is placed in a fiber glass case (looks like aquarium) in order to protect the battery from external hazards to design an efficient Lithium-ion battery by using Battery Management System (BMS). We give the supply to the battery from solar panel and in the absence of this, from a regular AC supply.

Keywords: Li-ion (Lithium-ion), BMS (Battery Management System), MPPT (Maximum Power Point tracker)

1. Introduction
In these days, the electricity usage and based on this energy working/operating appliances are rapidly increasing. To fulfil the demand the generation of electricity through non-renewable sources at a point of time they may be exhausted and also, generation of electricity these sources cause pollution which leads to global warming. So, electrical energy generation needs alternate way to clean form of energy which gives more life span for environment. However, renewable energies produce harmless, clean and fine electrical energy to meet the needs of society. In rural areas and undeveloped corners, availability of continuous electrical energy is a big task during rainy session, bad weather situations in the absence of regular power supply, any common person needs a light for some number of hours up to restore the regular power supply and now a days, usage of mobiles and laptops for communication purpose/exchange of information is become part and partial of human lives from an utter most level to
upper most person. To meet/overcome this emergency situation, we preferably use an alternate device which fulfill this need. For this purpose, the Lithium-ion battery pack/set based portable, reliable and durable device is essential. However, with this idea/concept we design a prototype model stand by rechargeable portable device for lighting (dc loads i.e., LEDs) purpose, charging of mobiles, supply to laptops, footpath/street business person during nights need light more time etc., will meet with this device. Li-ion batteries provide a variety of benefits over other superior rechargeable battery technologies. Furthermore, Lithium-ion battery cells can deliver up to 3.6 volts, which is 3 times greater than Ni-Cd or Ni-MH technology. Lithium-ion batteries need low-maintenance, as they don't need to be cycled on a regular basis to keep their life. This gives it an edge over Ni-Cd and Ni-MH batteries, both exhibit this effect. Li-particle batteries require wellbeing components to restrict voltage and interior pressing factors, which can expand weight and cut-off execution. In [1], the imbalance marvel of Li-ion batteries goes undercharging & the discharging state is discussed and also, continuous current & continuous voltage controllers while the charging time for a series connected Li-ion batteries through simulation. In [2], the Li-ion battery modelling is helpful to know the state of health, state of charge and the rest of charge period for doing useful works of an electric circuit model to a non-linear equation-based half-cell. The battery performance is characterized by genetic algorithm has been discussed. In [3], the various patterns of ECM (equivalent circuit model) parameters with different SoH (state of health) and ECM are characterize by the aging factor of battery is discussed. In [4] about electric vehicles play a vital role in transportation system in overcome the issues related with environment. A battery monitoring system in real time is used through Android smart phone system to observe the parameters such as current, voltage, temperature information collected and send to the smart phone with the help of an on-board monitoring device has been explained. To fulfill the demand of large capacity of battery systems and high voltages for electric vehicles, large number of battery cells supposed to connected them in a series and parallel combination. Detecting faults in sensors of a complex battery pack system is complex. For this, an innovative diagnoses methodology based on hybrid system and UPF approaches [5] discussed. To store electrochemical energy, need a rechargeable electric battery is quite frequently adapted in power system networks. Basically, battery is consisting of an electrode soaked in an electrolyte material that gives an ion exchange to produce electricity. A continuous improvement in battery performance, safety, reliability, cost, efficiency and with standing capacity [6]. At present in automotive industry electric vehicles plays a key role with zero emission as an alternate way to reduce the pollution and usage of fossil fuels which leads to increase in global warming. To meet this, an electric energy storage device such as a battery need with durability & a state of charge monitoring system (virtual) is essential in view of safety of vehicle and passenger [7]. In power system networks, with the large expansion of integrated power supply applications needs battery backup packs usage increased rapidly. The battery performance operation is very crucial in power grid in of security of the system monitoring. There are many issues associated with the battery operation such usage of material for manufacturing process, construction of quality, improper manage system and also overcharge, undercharge [8]. In [9], the basic device used in EVs is battery will behave as the main source to supply the electrical energy to the rest of the components to function and the selection of material for cell manufacturing is the crucial role is explained. In [10], With the advancement in remote correspondence advancements, it is feasible to kill the complex associations and the framework can beat the wired partner. Despite the fact that a large number of bands are available over the whole electromagnetic spectrum, the selection for use in the automobile context will be constrained by power consumption and interference immunity. The wireless technology-based system should not interfere with the normal operation of other modules within the vehicle (Electromagnetic Compatibility). In [11] these days, for EVs Li-ion batteries are extensively used for their operation due to zero emission of CO2, noise free but more costly than IC (Internal Combustion) engine vehicles. In EVs refuelable technology is used to obtain the desired performance and an effective battery monitoring system is needed to increase the performance and also to get extended life of the batteries. In [12], the constant depletion of fossil fuels, along with growing environmental concerns, has resulted in an exponential increase in technological advancement in the
field of EVs (Electric Vehicles). Because of this developing interest for clean energy, EVs producers have definitely moved from traditional petroleum product to electrified vehicles. As a result, battery storage is an important aspect of renewable energy since it mitigates unpredictability and stabilises frequency and voltage. In [13], nowadays there are any types of rechargeable Li-ion batteries are available among all LiFePo4 is recent one and economically low cost and safe in operation. Li-ion batteries need a strict monitoring system to prevent any dangerous situation from the abnormal condition such as temperature management due to variation of cells behaviour may cause burst of the battery. In [14], the need of storage of electrical energy for the purpose of illumination where ever and whenever for portable application and also, for non-electrified rural areas a renewable energy based operating device need. In [15] E-bike the main component to supply the required/necessary electrical energy for its operation supplied through Li-ion battery and its performance/behaviour observed through BMS (battery management system).

2. Design of a Prototype Model
In the absence of regular power supply, we need to depend upon alternate source of energy to fulfil our needs especially during emergency period such as night times for lighting purpose. For this need, we use a renewable energy i.e., solar energy, wind, tidal and geothermal out of this, solar energy based electrical device is used to overcome this situation. So, we design a prototype model in this paper to achieve the requirement with Lithium-ion battery pack/set for a low power applications of dc load i.e., LEDs. In this model, we used solar energy to charge the battery with the electrical energy. We know a solar energy is collected through a solar panel with the need of a Maximum Power Point Tracker (MPPT) to get more energy by placing an intermediate device as a charge controller. The energy collected by solar panels is varies due to the variation in the intensity of sun light. So, the output voltage also changes which may leads to fluctuating in temperature, current values under abnormal condition. This behaviour is harmful to the performance of the battery. So that, to avoid/overcome this instant with the placement of a battery management instrument during charging period and also during discharging period of time protects under thermalrunaway problem. A display device is connected to the Arduino which is interfaced with the battery pack/set to indicate the level of voltage and percentage of voltage charged/discharged. A dc load such as LEDs for lighting purpose (or) a mobile charger is connected to the output of the battery pack/set. For this prototype model, in the absence of solar energy due to cloudy atmosphere, we made an alternate way to recharge the battery pack with the regular power supply.

2.1. Hardware Components Required:
(i). Lithium-ion cell:
Batteries of Lithium-ion are generally possessing more density of energy, small (or) the memory does not effect & a small discharge of itself when associated with different types of batteries. They are widely used to provide power to the electric tools and medical equipment where DC supply is used.
Properties:
Nominal cell voltage: 3.7V; Cell Capacity: 2.5Ah; Current rating: 50mA; Specific energy: 9.25wh
(ii). Solar Panel:
The term Sun based Panel is used casually for a photo voltaic (PV) module. A photovoltaic module is a collection of PV cells which are set in a framework. Photovoltaic cells produces DC potential as an electricity energy using sunlight as a source of energy.
Specifications:
Power at maximum peak : 5Wp; Voltage at maximum peak : 9.8V
Current at maximum peak : 0.51A; Open Circuit Voltage : 12V
Short Circuit Current : 0.54A; Power : 36W
Tolerance : +3%
(iii). Charger:
A charger is an electrical gadget that is made of at least one than one diode that believers the rotating flow (AC) into direct flow (DC). It's utilised for rectification, as shown in the method below, which transforms AC into DC, which only flows in one direction.

**Specifications:**
- Current: 5A
- Voltage: 12V

(iv). MPPT:
Maximum Power Point Tracker is an electronic device which converters direct current to direct current converter that advances the match between the sunlight-based exhibit (PV boards), and the battery bank or utility framework. The MPPT solar charge controller decreases system complexity while increasing system efficiency.

**Arduino:**
Arduino is a micro controller device which refers to an open-source electronics platform and it depends on simple to-utilize equipment and programming. Arduino program can be programmed by using Arduino IDE.

**Specifications:**
- Operating Voltage: 5V
- Input Voltage: 7 to 20V
- DC Current per I/O Pin: 20 mA
- DC Current for 3.3V Pin: 50 mA
- Clock Speed: 16 MHz

(v). Display monitor:
LCD (Liquid Crystal Display) is a type of display that runs on liquid crystals. Because LCDs block rather than transmit light, they require far less energy than LED and gas-display displays. The nature of a presentation regularly alludes to the quantity of pixels.

2.2. The BMS may forestall activity outside the battery's protected working region by:

**Under Voltage:**
When a condition where the battery voltage drops below a set parameter. Most BMS's will be default set around 3.0V/cell (for standard lithium cobalt cells).
- Most BMS system disconnects the load. Some BMS systems has both a load and charge port and on those, they only disconnect the load port to let the system charge back up.

**Overvoltage:**
When a condition where the battery voltage goes above a set parameter. Most BMS's will be default set around 4.2V/cell (for standard lithium cobalt cells) same as under voltage action but if charge port exist that port is only disconnected.

**Over-Discharge:**
When a condition similar to Under Voltage, however some batteries will bounce back enough to allow the BMS to turn the power back on. If Over Discharge is a function of the BMS, then it will monitor the number of times of bounce back, and keep track of what's happening. If it records the voltage is getting progressively lower, it will completely disconnect the battery and only when applying a charger will it reconnect. Generally, only exist on more expensive BMS systems where you generally keep track of the SOC by counting energy going in and out of the system.

**Over-Current:**
When a condition where the battery current goes above a set parameter. Depending on the BMS rating, this can be 20A, 30A, 50A, 100A. This rating is usually included in the advertisement title of the BMS “3S/4S 100A 12V BMS Li-ion Lithium Protection Module”. It is measured by a shunt disconnects either the load or charge port or both.

**Short-Circuit:**
When a condition kind of similar to Over Current, but is much more specialized. If a BMS does not have SC protection, it is possible to take the Pos/ Neg outputs of the BMS and connect them together, and destroy the BMS. With SC protection, the BMS detects a direct short and disconnects the power before anything has a chance to be fried. This is a feature that is not common, especially on cheap BMS units.
Temperature:
When both E-bike BMS systems and BMS systems made for larger installs tend to have temperature sensors. It’s important to have them installed on the battery pack. The main function is to sense how the battery pack is stressed or when it is in bad health. A battery tends to heat up when too large current is drawn or sent to a cell and this will in conjunction with its internal IR result in heat being dissipated. A cell or battery that gets hot can result in a nonstopable battery fire.

2.3. Steps to be followed for designing a prototype model:
Step. 1 Let us first take a Lithium-ion cell of 3.7V

![Fig. 1 Lithium-ion Cell](image1)

*Fig. 1 Lithium-ion Cell*

*Step. 2 Arrange all 24 cells of Lithium-ion cells in a parallel & series combination.*

![Fig. 2 after cells arrangement top view](image2)

*Fig. 2 after cells arrangement top view*

*Step. 3 Connect 3 Li-ion Cells in series (3S) connection in order to increase the voltage level and 8 Lithium-ion Cells (8P) connected in parallel to increase the current level.*

![Fig. 3 3S, 8P Battery Pack side view](image3)

*Fig. 3 3S, 8P Battery Pack side view*

Where 3S → 3 series set of cells connected

*Step. 4 Then, connecting a Two Battery Management Systems to protect the lithium-ion battery from the abnormal conditions in either side.*
Step 5 Arduino Connections in order to display the voltage level and percentage of charging.

Step 6 Displaying the voltage and battery percentage.

Step 7 Two Solar Panels and Charge Controller is connected to provide supply to the battery pack.
Fig. 7 Lithium-ion battery with BMS and Supply

Step.8 A MPPT is connected between solar panel set and charge controller to track the maximum power.

Fig. 8 MPPT connection
Step 9: Final Design of the prototype model.

Fig 9: Final Connections of the battery pack

2.4. Battery Calculations:
Each cell voltage = 3.7V
No. of cells connected in series = 3
= 3.7V + 3.7V + 3.7V + 3.7V
= 11.1V (nominal voltage)
The total voltage of the battery pack = 12V (peak voltage)
Case: 1: Full load: \( I = I_L = 3\,A \); \( V = 12\,V \); \( P = V \times I = 12 \times 3 = 36\,W \)

(i). Charging: \( \text{Charging Time} (t) = \frac{\text{Capacity (Ah or mAh)}}{\text{Load (A)}} \)
Each cell Ah for Lithium-ion battery = 2.5 Ah
For one battery pack = \( 2500 \times 10^{-3} \times 8 = 20\,Ah \)
\[ t = \frac{20\,Ah}{3\,A} = 6.666\,hrs \approx 7\,hrs \]

(ii). Discharging: \( \text{Charging Time} (t) = \frac{\text{Capacity(Ah(or)mAh)}}{\text{Applied Current (A)}} \)
Each cell Ah for Lithium-ion battery = 2.5 Ah
For one battery pack = \( 2500 \times 10^{-3} \times 8 = 20\,Ah \)
\[ t = \frac{20\,Ah}{5\,A} = 4\,hrs \]

Case: 2: Half load: \( I = I_L/2 = 1.5\,A \); \( V = 12\,V \); \( P = V \times I = 12 \times 1.5 = 18\,W \)

(i). Charging: \( \text{Charging Time} (t) = \frac{\text{Capacity (Ah or mAh)}}{\text{Load (A)}} \)
Each cell Ah for Lithium-ion battery = 2.5 Ah
For one battery pack = \( 2500 \times 10^{-3} \times 8 = 20\,Ah \)
\[ t = \frac{20\,Ah}{1.5\,A} = 13.33\,hrs = 14\,hrs \]
\[ t = 800\text{ minutes} \]

(ii). Discharging: 
\[ \text{Charging Time} = \frac{\text{Capacity (Ah or mAh)}}{\text{Applied Current (A)}} \]

Each cell Ah for Lithium-ion battery = 2.5 Ah
For one battery pack = \(2500 \times 10^{-3} \times 8 = 20 \text{Ah} \)
\[ \therefore t = \frac{20 \text{Ah}}{5 \text{A}} = 4 \text{hrs} \]

\[ t = 240 \text{ minutes} \]

2.5. Benefits of Lithium-ion battery over Lead acid battery:

| Specifications               | Lithium-ion battery | Lead acid battery |
|------------------------------|---------------------|-------------------|
| Power density                | high (12wh/kg)      | low (7wh/kg)      |
| Nominal voltage              | 3.6v/cell           | 2v/cell           |
| Efficiency                   | High                | Low               |
| Maintenance                  | Not required        | Required          |
| Charge/discharge cycles      | >3000 cycles        | 1200 cycles       |
| Replacement                  | 7 to 8 cycles       | 2 to 3 cycles     |
| Memory effect                | Absent              | Present           |

Table 1

**Buck Converter**

Fig. 10 buck converter circuit diagram
3. Experimental Results:

![Experimental setup with LED lights and solar panels](image)

**Fig. 12** DC Light load-LEDs
4. Conclusion
An improved battery model is proposed in this work by considering the self-discharge effect, the temperature effect observed in all batteries. The model was stimulated using Matlab/Simulink, and under simulation results were discussed. In order to protect and maintain voltage and current of the battery within safe limits, Battery Management System (BMS) should be used. BMS provides thermal management to the battery, safeguarding it against over and under temperature and also during short circuit conditions.
Finally, a 24 lithium-ion cells are connected in a series & parallel combination to increase the potential (voltage) level up to 12V, which is produced by connecting 3.7V lithium-ion cells in series and to improve/increase the current level up to 20A through the Li-ion cells are arranged in parallel and the output from the battery is given to different loads like mobile charging, DC lights such as LEDs.

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