Portable Power Station and UPS Embedded with MPPT PV Charger and BMS

By

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Dedication

This thesis is dedicated to my beloved parents, teachers and friends, who have been the source of inspiration, guide and strength, who continually provide their moral, spiritual, emotional and financial support.

Certificate of Originality

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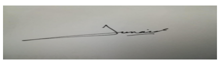
Student Signature: 

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Glory be to Allah (S.W.A), the Creator, the Sustainer of the Universe. Who only has the power to honour whom He please, and to abase whom He please. Verily no one can do anything without His will. From the day, I came to NUST till the day of my departure, He was the only one Who blessed me and opened ways for me, and showed me the path of success. Their is nothing which can payback for His bounties throughout my research period to complete it successfully.

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Contents

List of Figures

List of Tables

Abstract

Electric energy is the basic demand in the era of electronic gadgets. Energy access is a significant challenge for the people who are lovers of camping and travelling. Our Portable Power station is a best product not only as the standalone power source but our product will also work as a UPS when installed at home with the mains. It allows you to get rid of the noise and exhaust of the portable generators. It can keep electric gears running for hours. It will be small in size, easily portable and equipped with latest technologies.

This thesis tends to develop a portable power station that can be charged with PV (Photovoltaic) panel through MPPT (Maximum Power Point Tracking) charge controller to charge Lithium Iron Phosphate batteries (4 * 3.2 V, 25 Ah), those can also be charged through mains with a dedicated $LiFePO_4$ charger. Battery Management System will be added to regularize and monitor $LiFePO_4$ (Lithium Iron Phosphate) batteries. Portable power station tends to have 220 volts AC and other charging outlets like 12V DC and 5V USB interface.

Chapter 1

Introduction and Motivation

1.1 Introduction

Electronic gadgets in these days are of immense importance in our lives. All the businesses, research, recreation and studies are directly dependent on these gadgets. Meanwhile all the daily routine chores are dependent on the electric supply. In the era of machine age, all our tasks are done with the help of electric machines in one or the other way. All these gadgets and machines require electricity or you can say electric energy for their operation.

Electric energy is needed for lightening, communication and cooking. For the houses in areas far from infrastructure and electric supply, we aims to develop a stand alone system that can meet the daily demands of the house. This will enable them to get connected to the world.

Travelling is a major hobby for some enthusiastic people. These travelers frequently need the electric supply during camping and travelling, to power up their laptops, mobile phones, photographic cameras and other gadgets. Also huge systems are not feasible for travelling. Our portable power station is a feasible solution for these enthusiasts.

Portable Power station is a reliable solution for off grid electricity through its integrated lithium iron phosphate batteries, inverter and outlet sockets. Its renewable recharging facility and good backup time gives an amazing experience of outdoor

Figure 1.1: Use of Portable Power Station in camping

recreation and peace of mind during emergency scenarios. Recharging of mobile phones and laptops, getting photographic cameras powered up is not an issue now during camping.

When we look into the history, since the invention of electricity and its use in daily life, there always been the need of standalone power sources. The grid power is expanding, but due to the cost and infrastructure requirement, it is impossible to get the grid to every man's life. On the other hand electrification is very important to increase the standard of living.[3]The areas with no electricity supply may be due to the reasons

1. High proportion of cost is required for civil work.
2. Lack of trained staff to maintain that systems.
3. The availability of spare parts and technical help is weeks away.
4. There might be too much line loses due to long distances.

One of the most important use of the advancement in renewable energy is its installation in remote areas. Solar energy is a reliable alternative to diesel operated energy generators. With the increasing prices of fossil fuels, the renewable energies are getting importance day by day. The hybrid energy systems, also known as stand alone energy systems [4]that merge the renewable energy with the conventional grid electricity and using batteries for storage are getting advanced with every day passed.

More than two billion people globally, live without electricity. Renewable energy and its storage for overnight use is the only alternative to traditional means of cooking by using wood and biomass. The significant improvements can be carried out in rural living by just supplying them with electricity. With the recent decline in prices of photovoltaic panels has increased the utilisation of solar energy in remote areas power generation. As the solar energy is only available during day time, so energy storage devices are also kept in loop to save the extra energy for powering lights during night time. So, a complete and off grid system is required in these situations.

Moreover, in our country, the load shedding is a big issue during the high load demand months. Government has to shut down power supply of some areas alternatively to keep the industries running. In those situations, everyone wants to have their own small backups to keep their gadgets running and homes lightened up. That individual systems require batteries to store energy either from the renewable source or the electricity supply. [6]

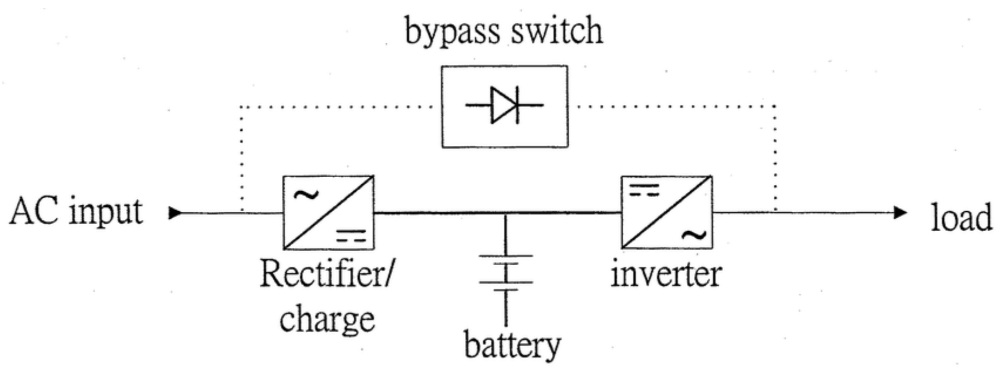

Figure 1.2: Diagram of Off line UPS

It is a well documented fact that the repeated electricity outage causes economic loses. To avoid these power cuts, people try to manage their self owned power sources, these might include the diesel generators, inverters with batteries and renewable energy sources. The ultimate cost however has to pay by the nation. In Pakistan, people tends to buy small portable power sources with one or two hour of backup time. These backup system, most of the time have large operating costs that are not clear to the users and their less information results into uninformed decisions that do not have economic sense.[11] The battery inverter system have its efficiency far below 100 percent, its use not only affect the owner but the economy on the country. These back up systems are generally known as Uninterrupted Power supply(UPS) and use lead acid batteries for energy storage.

1.2 Problem Statement and Contribution

Solar panels are the backup source of energy while in remote areas these are also used as a main power source. These are used to power up equipment at day time but the excess energy has to be stored in one or the other way to use at night. Batteries are used to store energy. The batteries in use are of various types, including lead acid batteries and lithium batteries. System is required to store the excess power from solar or from other sources to get them stored in batteries efficiently.[1]

The lead acid batteries are commonly used as energy storage. These conventional batteries are less efficient. The process of charging the batteries is the conversion of the electrical energy to the chemical energy and this conversion of energy has some energy loss as well. This loss has a considerable amount approximately up-to 20 percent. These lead acid batteries has another drawback of charging time. These require 2 to 4 hours for charging depending on the depth of discharge.

A new technique or you can say the newer version of batteries are the lithium ion batteries. These lithium batteries are much smaller in size, more efficient and require less time for charging. These require only 1 to 2 hours for charging and energy loss is approximately 2 - 8 percent. These lithium batteries can tolerate Partial State of Charge (POS) for longer periods unlike lead acid batteries.

The battery capacity is measured in Ampere-hour or kilowatt-hour. The battery percentage available for use is called the depth of discharge. The lead acid batteries can only be used up to 40 percent on daily basis, while lithium batteries are deigned for 90% depth of discharge(DOD).

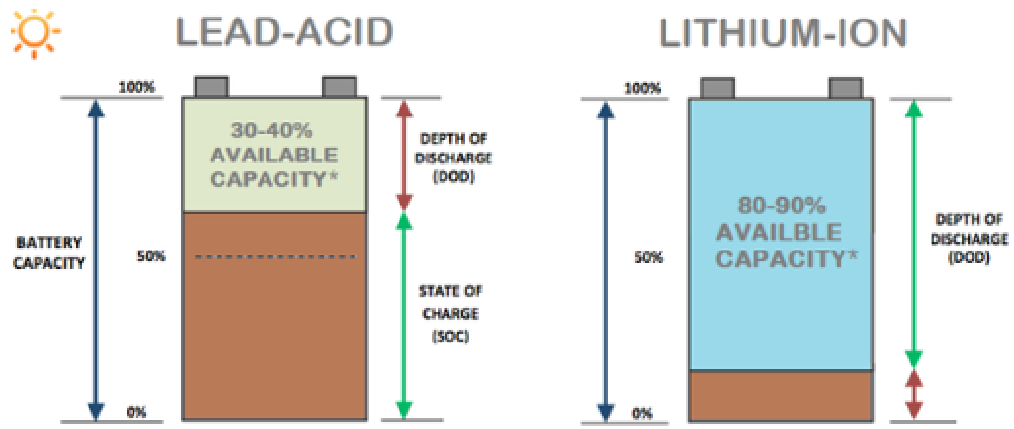

Figure 1.3: Depth of Discharge

The most obvious advantage of lithium batteries is their compact size, greater depth of discharge and high energy density. The off grid power systems available in Pakistan market are designed for lead acid batteries. These solutions are such that either they can be used as off grid solar power source or the others are only UPS. The main problem for the Pakistanis are to buy and maintain both of them separately. Also the available solar inverters of smaller capacity are large in size and are without batteries. Batteries has to be attached separately and as they can handle only lead acid batteries, so the overall package becomes too bulky that it cannot serve the purpose of the Portable Power System.

The system or the product we are going to introduce in our research is a small Portable Power Station that has its own embedded lithium battery and it can be charges with solar power and the grid power. Our solution can also be used as a Uninterruptible Power Supply (UPS) at homes and that same unit can be taken with oneself on travelling and camping.

The one pack solution we are offering comprises of Maximum Power Point Tracking (MPPT) solar charger, Lithium Iron Phosphate(LiFePo4) batteries, lithium battery charger from wapda, Battery Management System (BMS) for LiFePO4 battery and the circuitry for UPS. This one package solution is being offered first time in Pakistan and in a very reasonable price as compared to international market.

Chapter 2

Literature Review

2.1 Portable Power Station

Renewable energy from solar radiations are of immense importance in the era of green energy. The portable power stations have the feature of charging from solar panels. In the international market, Portable Power stations of different capacities are available. These power stations are of two types. One of them are those which are only used for power storage for travelling and camping or to power up gadgets in absence of electricity. The other are of advanced form that are also used as UPS in homes. Those which only store energy for later use are of more importance for the people of areas far from electricity.[13]

The market overview of the Portable Power Station shows an immense increase in their demand in recent years. Portable Power Stations are compact and versatile devices to give power through different ports. The expansion witnessed in their market is propelled by the demand of off-grid power stations that are important for outdoor adventures, emergencies and remote localities.

The market size of the Portable Power Station is increasing day by day. The market size refers to the industry related to manufacturing, development, and sale of Portable Power stations. The international markets size in 2023 was USD 4.34 Billion and is expected to be USD 6.13 Billion by the year 2032. The Portable Power Station market is experiencing notable expansion due to increased trend towards the outdoor recreations and outdoor sports. Along with these activities, the ease of use to charge electronic gadgets is an important feature. The limited energy storage is still a constraint in the expansion of market size.

The main factors that are responsible for this growth are as follows:

1. The increasing demand for electricity in areas that are away from conventional electricity.
2. The demand for reliable power backup in case of natural disasters.
3. A large trend for outdoor adventures, recreation, camping and travelling.
4. Increased use of electronic gadgets as a source of recreation.
5. The proliferation of smartphones, tablets and laptops.
6. People shifting towards remote work and work from home, necessitating the requirement for reliable power source.

The users of Portable Power Stations with power-hungry devices reports the less storage capacity as its drawback. This is only due to its compact size designed to transport easily. This limitation of energy capacity influences its suitability in long power outages and in remote areas. This drawback can be resolved by integrating the renewable energy to charge the batteries of Portable Power Station. This will also lead to a new window in its market. The users in areas far from conventional energy sources can harness solar energy during daytime and can use it during night.

2.2 Types of Batteries

2.2.1 Lead Acid Batteries

Lead Acid batteries technology has been in use for more than 100 years. This is still reliable and safe technology when installed correctly. Especially in large off-grid systems this is a reliable solution and lasts more than 15 to 20 years. Lead-acid batteries do not have a specific cut off at lower voltages and can be discharged to provide power in emergency situations until the cut-off voltage of inverter is reached. This excessive discharge may effect the life of battery to some extent. If we talk about the round trip efficiency of the lead-acid batteries then the loses is around 20%. This loss is due to the physics rule that energy is lost when converted from one form to another. Besides other factors the recycling of batteries are also important. In this regard the lead-acid batteries are more feasible and easily recycled.

The charging time is important when selecting a battery. The charging time off lead-acid batteries is longer ranging from 2-4 hours depending on Depth of discharge(DOD). This is feasible in longer daylights, but in bad weathers and cloudy days the charging will be low and that long low charging results in decreasing the life of lead-acid batteries.

If we consider the working efficiency of these batteries under load, we come to know that these lead-acid batteries can be discharged 30% to 40% on daily basis. So, these cannot be discharged more that 40% DOD as more discharge on daily basis results in decreased battery life. In backup situations we can use 70% of these batteries but that should not happen on regular basis. This DOD comparison also showed in 1.3.

The basic principle on which the lead-acid batteries work is that the electrical energy is stored as chemical energy in the battery. At the cathode the lead dioxide reacts with sulphuric acid to form lead sulphate and water. While at anode lead reacts with sulphate ion to form lead sulphate. [2]

2.2.2 Lithium Ion Batteries

In recent years, the lithium ion batteries are overtaking the lead-acid batteries in home solar systems. Lithium batteries are smaller in size with high charge density. Generally speaking, Lithium batteries are 30% of the size and weight of their equivalent lead-acid batteries. These lithium batteries are more efficient that traditional lead acid batteries. Their efficiency is about 92% to 98% as the energy loss in them is around 2% - 8%. The charging duration required for lithium batteries is short ranging from 1-2 hours. Unlike the lead-acid batteries, the lithium batteries can tolerate the Partial State of charge(PSOC) for longer periods and does not effect the battery health.

Lithium ion batteries are designed to discharge from 90% to 100%. So, normally these batteries are discharged up to 20% of their SOC. This comparison of Depth of discharge of both batteries is shown in 1.3. Under load conditions, the voltage of lithium batteries is constant and does not fluctuate more than 1-2 volts. This is due to the much lower internal resistance as compared to the lead-acid batteries. This lower internal resistance also helps in less loss in charging and discharging and hence increased round trip efficiency of lithium ion batteries.

Unlike lead-acid batteries, these batteries do not require a proper ventilation and air flow for trace gases to escape. Also when space is an issue, lithium batteries are not problematic unlike other large sized batteries. Lithium batteries have an extra circuit with them called the Battery Monitoring System (BMS). This BMS regulates the battery voltages and monitors cell temperature to avoid unnecessary increased temperatures, avoids overcharging and divides the voltages among cells equally. This increases the battery life to large extent.

There are many types of lithium ion batteries. The one of the most important are lithium iron phosphate(LiFePO4). The cycle life of LiFePO4 batteries is four times more than other lithium ion batteries. It is also the safest of the available lithium ion batteries as they do not catch fire even ruptured. While using these iron phosphate batteries, one has not to worry about over discharging as these can be discharged to 100% DOD. Due to their enhanced number of cycles, their cost over time is much better. The upfront cost, which is the basic issue for users, is large for the lithium batteries as the material required for them is expensive. Although the cost is much lower as they last longer than lead-acid batteries. [15]

2.2.3 Sand Battery

Sand battery is the latest type of battery that is going to be established soon. The researches are under process to make it functional. The basic technique is to store excess energy as a form of heat in the sand or some other material. It is claiming to be with high efficiency, low cost and long lifespan. Energy is stored in sand as thermal energy, sand is heated using renewable energy like solar and wind in the excess production hours. Sand can store large amount of energy and it has low maintenance cost. The technology is in research phase for the time being. Overall, this technique has the potential to revolutionize the way we store energy by providing cost effective way of storing excess energy. Research and development is required to make it commercial.[19]

2.3 Battery Management System (BMS)

Battery Management System is an integral part of the lithium ion batteries. This system keeps track of the batteries cell voltages, currents and battery temperature. In order to maintain the state of battery, different sensors and micro-controllers are used. Battery Management System is the crucial system for lithium batteries, wherever these are used. This is used to avoid over charging and over discharging because that decreases the life span of batteries.

Battery Management System is essential for following reasons:

1. To maintain safety and reliability of battery.
2. Monitoring battery parameters.
3. Balancing cell voltages.
4. Keep track of SOC.
5. Avoiding overheating of battery.

The cell voltage sampling, battery temperature sampling and current sampling is done with the special Integrated circuits(IC). The block diagram of the Battery Management System is as shown below. [12]

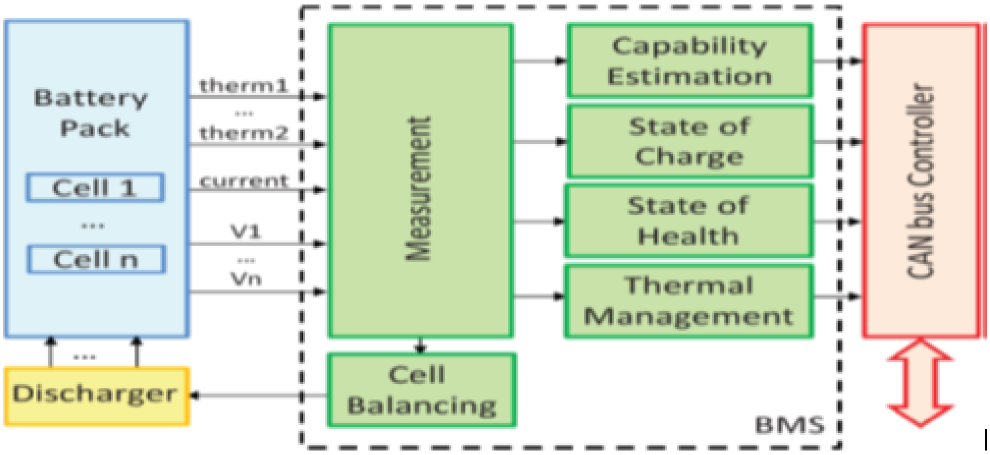

Figure 2.1: BMS Block Diagram

2.3.1 State of Charge Estimation

State of Charge (SOC) is actually the state of the remaining battery with respect to the full capacity of battery. State of Charge gives crucial information to BMS for the safe operation of battery by controlling charging and discharging. State of Charge is not measured directly. It is estimated by using the equation:

$$SOC = 1 - \frac{\int idt}{C_n}$$

where i is the current flowing out of the battery while its discharging and flowing in during charging, and C_n is the maximum capacity of current that battery can hold. The SOC estimation is necessary to keep track of the total available current to keep the battery operating safely. There are various methods of State of charge estimation. Some of them are:

1. Coulomb Counting

2. Fuzzy Logic

3. Kalman Filtering

4. Open Circuit Voltage Method

2.3.2 State of Health Estimation

State of Health Estimation describes the battery health with respect to the new battery. It gives the available discharge capacity of battery during its lifetime. It tells that how much load can be operated for what duration. State of Health is defined as the ratio of maximum charge of battery to its rated value.

The percentage of SOH in equation form is:

$$SOH\% = \frac{Q_{max}}{C_r}100$$

where Q_{max} is the maximum charge of battery and C_r is its rated capacity. [12]

2.4 Maximum Power Point Tracking

Global warming and severe energy crisis are the main reasons due to which the world is shifting to photovoltaic energy systems. Solar energy is the unlimited reserve and beyond and geographical boundaries. The different ways are being developed to get maximum energy from photovoltaic cells. Maximum Power Point Tracking is one of them. As the sunlight is available for some duration of the day and also affected by different weather conditions, so it is necessary to have some algorithm to get maximum from the solar panels. Maximum Power Point Tracking (MPPT) enables us to use solar energy more efficiently.

The basic methods used to get maximum efficiency of solar energy includes **Voltage Feedback Method**, that obtains voltage of solar cells in a fixed environment, this method is not usable for different climates automatically. Other technique used is **Perturbation and Observation**, this P&O method increases and decreases terminal voltage of solar cells in a fixed duty cycle, if the perturbation causes the output of solar panel to increase then it keep moving, if the output decrease then it moves in opposite direction to decrease the voltage hence increasing the output power of solar panels. The drawback is that there is an oscillation effect while reaching MPPT point.[5] **Incremental Conductance method** searches for dP/dV = 0 is also based on P&O; when its step size is large, the tracking speed is high but when near to the MPPT point its step size is decreased and hence the steady state oscillation is reduced relatively. This is also called the Variable Step size Incremental Conductance Method. [9]

The mathematical model of a solar cell is expresses in an equation as:

$$I_{PV} = I_{ph} - I_{sat}(exp\frac{q}{BkT}V_{PV} - 1)$$

I_{PV}: Output Current of Solar Cell	I_{ph}: Current generated by solar cell
V_{PV}: Output Voltage of Solar Cell	I_{sat}: Reverse Saturation current of solar cell
k : Boltzmann constant	T : Solar cell surface absolute Temperature
q : Quantity of electronic charge	
B : Ideal factor of solar cell	

The variable step size increment conductance method also described in [16] as improved conductance increment method is applied in two steps.**Step 1** When PV system is started, the algorithm uses initial voltage of 0.8 times of MPP voltage to reach vicinity of MPP point fast. This is done based on fixed voltage method to reach desired point fast.**Step 2** Near the MPP point if dV is not zero but dI is zero it means that MPP has been reached. If dI is greater than or less than zero, it means that output power is to the left or right of MPP. It means that we have to change the tracking step to precisely find the MPP point.

2.5 Charging Lithium Batteries

The lithium batteries are the main concern for energy storage nowadays. The energy storage depends on effective charging techniques. There are various techniques including constant current - constant voltage, constant power - constant voltage and constant loss - constant voltage methods are discussed in [14]

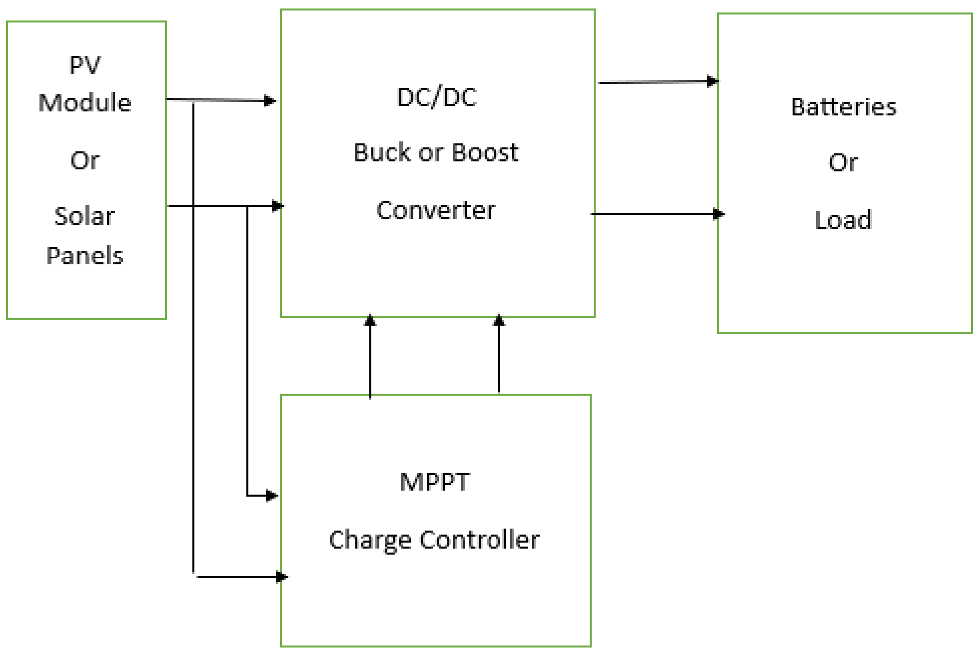

Figure 2.2: MPPT with PV modules

2.5.1 Constant Current - Constant Voltage(CC-CV)

This is the most common method, the process is divided into two stages. In first part, the battery is charged with constant current until it reaches the said terminal voltage. This first step allows fast charging. The second stage of constant voltage helps to prevent battery overcharging. Thus this technique is fast as well as safe for the batteries. This is the traditional method and most frequently used.

2.5.2 Constant Loss - Constant Voltage(CL-CV)

This method uses constant loss charging in the first stage until the battery terminal voltage reaches the upper limit. The loss is defined as the square of the current multiplied by the battery's equivalent impedance. This equivalent impedance varies with the battery's remaining capacity. The calculation of charging loss is defined by equation:

$$P_{chg-loss} = I^2 \times R$$

The $P_{chg-loss}$ is determined from the predefined current value and the equivalent resistance is found depending on the SOC of the battery.In second stage, constant voltage charging is done until the current drops below 0.05C.

2.5.3 Constant Power - Constant Voltage(CP-CV)

The battery charging is initiated with the constant power method and shifted to constant voltage method when the terminal voltage equal to rated voltages is achieved. In second phase the charging is done under constant voltage mechanism until current decreases below 0.05C. In first stage, the constant power is calculated using the rated current value of the battery.

Chapter 3

Design and Methodology

3.1 Proposed Architecture

In this section we present our novel methodology of using the state of the art equipment in designing the Portable Power Station and UPS that can be used in situations described in 1.2. The design that we are going to implement in our product is an efficient and with dual functionality of portable power station and UPS. This proposed design uses both solar power and utility supply to charge the batteries. This system is easily handle-able and can be used by travelers and adventurers on expeditions to power up their electronic gadgets. This novel system can also be installed in remote areas with no power supply to run electronics gadgets from solar power at day time and from stored batteries during night. One can also install it at home to get uninterrupted power supply for sensitive gadgets in case of blackout and the same can be taken with oneself during travelling and camping.

The designed product can power lights, fan, laptops and with USB outlets mobile phones can also be charged safely. This power station uses Lithium Iron Phosphate batteries as a energy storage medium, solar power from PV panels is extracted using MPPT module to get maximum efficiency. Battery Management System is added to monitor proper functionality of LiFePO4 batteries.

3.1.1 Equipment Used

As the name **Portable Power Station and UPS** suggests that it will have its own batteries, inverter and charging system. As the product is solar powered as well, so it also has MPPT charger. Lithium Iron Phosphate batteries with Battery Management System are installed.

3.1.1.1 Lithium Iron Phosphate Batteries

The batteries are the main component of any charge storage device. We have used Lithium Iron Phosphate (LiFePO4) batteries for this purpose. Four cells of each 3.2 volts and 25 Ah capacity are being added in series to provide total of 12.8 volts and 25Ah. The reason to select these lithium batteries is their compact size and high charge density, with maximum of 100% depth of discharge. Moreover their comparison with other types of lead-acid and lithium batteries is described in section 2.2. The batteries with their series connection is shown in figure 3.1.

Figure 3.1: LiFePO4 batteries with BMS

The crystalline structure of LiFePO4 enhances overall safety of the battery pack. It does not catch fire even at high temperatures or a hole is made in their body. At the cathode terminal, the lithium undergoes oxidation to provide energy. During charging, the lithium ions moves from cathode to anode where they are absorbed by the carbon or graphite structures. The equations for charging[7] are as under:

- $LiFePO_4 \xrightarrow{Charging} yLi^+ + ye^- + Li_{1-y}FePO_4$ At positive electrode
- $xLi^+ + xe^- + Li_{1-x}C_6 \xrightarrow{Charging} LiC_6$ At negative electrode

The reverse of the above occurs during discharge. The chemical reactions emit energy in the form of flowing electrons resulting into the flow of current. These batteries are usable for 3000 to 4000 cycles hence having a long life span resulting into the low cost of operation.

3.1.1.2 MPPT Solar Charger

The Portable Power Station that we have proposed is embedded with **Maximum Power Point Tracking** solar charger. The basic function of the MPPT is to get maximum power out of the solar panels under varying weather conditions. It tracks the voltage and current point at which the power is maximum. The different MPPT charge controllers have different working mechanisms as described in 2.4. MPPT charge controllers operate at V_mp, which is the maximum power voltage and it is the point where the product of voltage and current is maximum. MPPT controllers sweeps over the solar array voltage to find out the point at which the array is delivering the maximum power.

The Maximum Power Point Tracking charger, after tracking the V_mp, works as boost or buck converter in order to match with the nominal battery voltage. One thing is obvious that the Power Input to Charger is equal to Power Output with ignoring small inner losses. Now if the V_mp is higher than battery voltage, which normally is the case, so it increases or boosts the output current and drops voltage to keep the product of the V_mp and current equal to the input power[17]. The module 's photograph is shown in fig 3.2.

Figure 3.2: MPPT Solar Charger

3.1.1.3 Power Inverter

The power inverter is used in our product to change the Direct Current (DC) from the battery to the Alternating Current (AC) that is used by the household equipment. All the gadgets in our use is mostly designed for the consumption of the Alternating Current. Batteries store current in the form of direct current only, so inverters are very essential for the working of gadgets and powering up lights and fans.

There are two topologies that are mainly used in inverters. One is Push-Pull and the second one is H-Bridge. The Push-Pull technology produces the square wave and modified square wave with little modifications. H-Bridge is the complicated circuitry that is suitable for sine-wave AC current. The Push-Pull technology is the most basic of the inverter technology. It is very cost effective and easy to manufacture and use. Its advantage is in its simplicity and cheap form of inverter technology. The disadvantage is the power loss in square wave design. The modified square wave design of the Push-Pull topology has very good voltage regulation, less total harmonic distortion and much better efficiency. Most of the electronic components work effectively with modified square wave output. H-Bridge topology has much better sine wave output, but is much complex in manufacturing and use. The loses are in the transistor switches and it is costly compared to Push-Pull. [8]

Most inverters used with Photovoltaic modules have the Push-Pull topology used with modifications for the resulting wave form to be modified square wave. The inverters that are used in solar systems that are grid connected require more complicated circuits. As we are concerned for the off grid PV system for the time being, so we have used the inverter technique of modified Push-Pull topology. The circuitry for this inverter is shown in fig 3.3

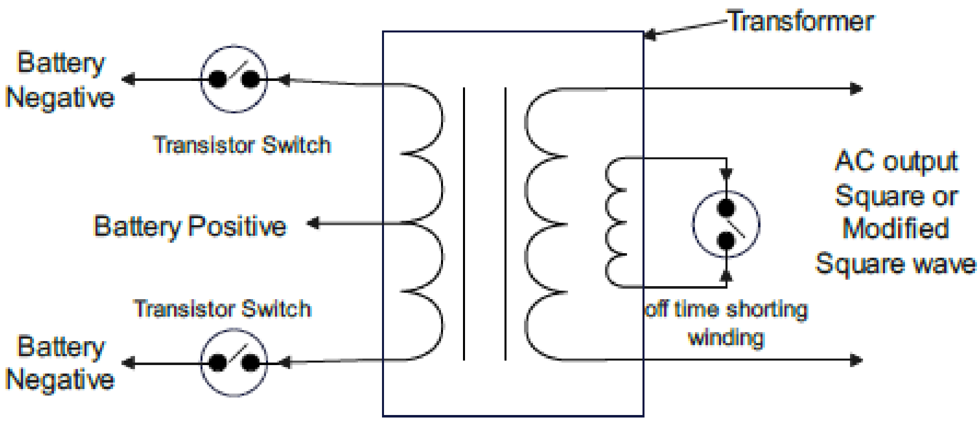

Figure 3.3: Inverter's Circuit

3.1.1.4 Battery Management System

The Battery Management System(BMS) is most vital part of any battery operated system using lithium batteries as a power storage. The basic criteria for BMS selection includes the maximum battery operating current, the battery voltage, operating temperatures and the number of cells that we are going to connect in series and in parallel. There are different topologies used in BMS. The BMS with centralized topology that we have used has one central control unit, this control unit is connected to each cell with separate wires. The connections of BMS with cells are shown in figure 3.4. All the sensors are also attached to this central unit. This is the most simple yet robust technique used in monitoring the batteries. Some advanced BMS also has the functions of State of Charge and

State of Health estimations. The BMS ensures safety of the battery by carefully monitoring the charging and discharging of the batteries and specified voltages. The equalization among the battery cells keeps the battery operating in safe conditions and hence increasing its lifespan. It ensures correct communication of results including voltages, currents, temperatures and SOC to the user. [18] The BMS we are using is 12V 4S LiFePO4, this implies that it can be used with a 12 volts of lithium iron phosphate battery that has four cells connected in series. The connection diagram of BMS with battery is shown in figure 3.4. It is clearly mentioning the connections of each and every cell of battery pack with sampling cable of BMS. This sampling cable then connects the cell to BMS input port. At the end we get two open poles that are the positive and negative of battery, and those are used to connect the load and the charger. Also the physical connections and the hardware component is shown in 3.1.

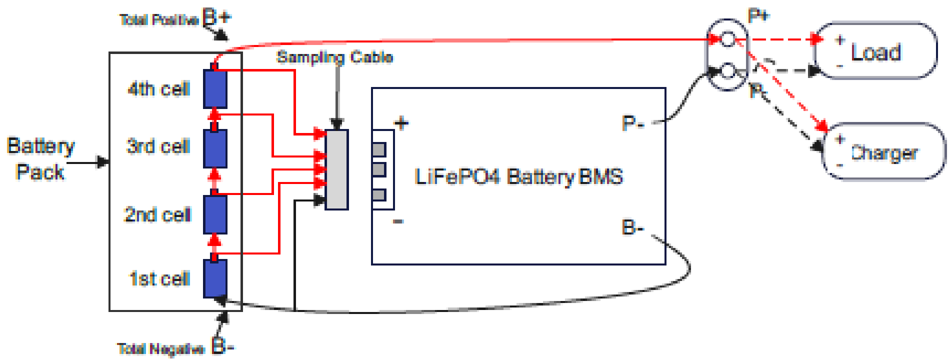

Figure 3.4: BMS Wiring Diagram

3.1.2 Circuit Layout

The main circuit layout for the Portable Power Station and UPS embedded with MPPT PV charger and BMS is shown in figure 3.5. It shows how the entire above discussion results into a usable module. This layout describes the symmetry of the components inside the module and somehow describes the working principle.

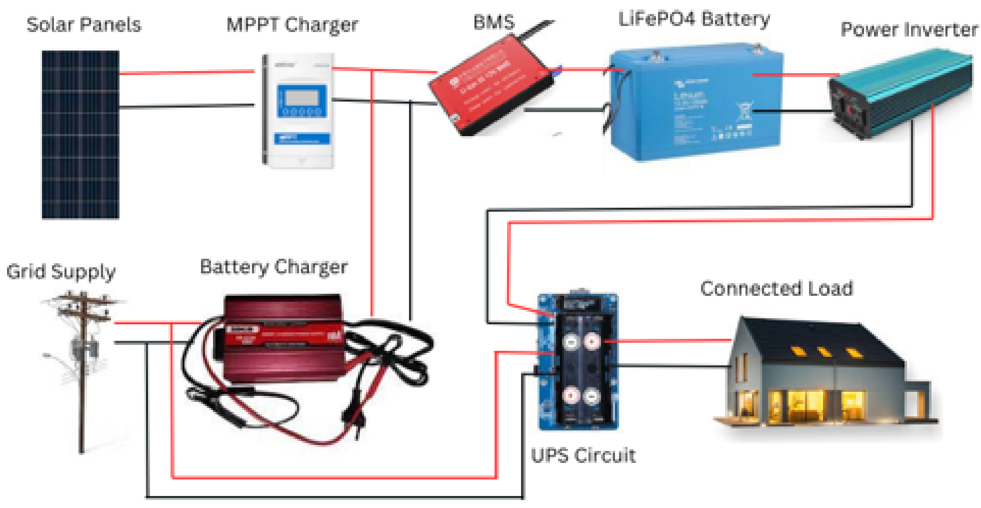

Figure 3.5: Circuit Layout

3.2 Evaluation

The methodology and the equipment proposed in the report are the best way to design a Portable Power Station. The available products in the market are much expensive as compared to the proposed design. The Portable Power Stations available in online stores of the same capacity as of ours are approximately costs Rs.150000. This cost is too much due to the shipping costs and the taxes. The same features are being offered in our product for the sale price half of the above mentioned cost.

This product is within the costs of a normal UPS available in market but having much better and advanced features including the Solar Charging and usage of Lithium batteries. The comparison of Portable Power Station and UPS embedded with MPPT PV charger and BMS with the traditional UPS is given in table 3.1

The facts described in table 3.1 clearly defines the superiority of our design over the traditional UPS being used. The Portable Power Station and UPS embedded with MPPT PV Charger and BMS has its own battery pack and solar charger. This is a one pack complete solution for the energy reservoir and its harnessing during requirement. This is solution for emergency situations and in case of far off areas it works as a electricity producer from the solar radiations and its storage for night time. The similar product available internationally is too expensive as compared to our product cost. This design is also an achievement of locally manufacturing Portable Power Stations that are only being imported for the time being. This saves the foreign reserves and emerges new opportunities in the country.

The international trends towards the Portable Power Station as described by the Precedence research shows that the demand for such gadgets is increasing day by day. The load shedding issues described in [11] also shows an immense demand and requirement for such energy storage devices. People in the modern era are more focused towards the recreational activities in natural places, such places do not have infrastructure and Portable Power Station is helpful for enjoying in such areas and keeps them connected to the world during long voyage.

Specification	Portable Power Station (Our Design)	Normal UPS
Movability	Portable	Fixed
Main Functionality	For Off Grid, Travelling & as UPS	For Uninterrupted Power Supply at homes
Solar Panel Charging	MPPT Charger	NO
Turning ON & OFF	Supports UPS mode and Portable Power Station mode	Only works as Uninterrupted Power Supply
SOC & SOH	Yes	No
Power Rating	300 watt	300 watt
Sine Wave Type	Modified Sine Wave	Square wave
Weight	8-10 kg	UPS+battery= 25 kg
Price	Rs.50,000	UPS+battery = Rs.33,000
Battery Replacement	After 3000+ cycles	After 400-600 cycles
Battery Type	LiFePO4 battery	Lead Oxide(Does not support Lithium battery)
Battery Maintenance	Not Required	Required
USB Charging Port	Yes	No
Runtime	Preferred for long duration	Good backup for short period of time
Use during Plugin	Can be used Normally	All attached equipment works during plugin
Charging Technique	Solar and Grid charging	Only Grid Charging

Table 3.1: Comparison of Normal UPS with our Design

Chapter 4

Results and Discussions

4.1 Practical Testing with PV

In the testing phase of the product with the solar power, the photovoltaic panel is connected to the Maximum Power Point Tracking (MPPT) charge controller through a voltage and ampere meter. The data was collected for a time duration of 45 minutes with an interval of 2 minutes. This data is shown in table 4.1. Also the same data was collected by connecting the PV panel directly to the battery without the MPPT and the reading were taken for the same duration of time. The data is available in table 4.2. The comparison of both data using the power column of both tables is done in table 4.3. The percentage difference in powers shows the difference in power generated from PV panel during two different techniques. The one other test was also made by connecting 12V DC load directly to PV but that resulted into 7 volts with 4 Ampere current hence 28 watts from PV. The results in table 4.3 clearly shows the superiority of using MPPT for harvesting energy from solar panels as more power can be generated from solar cells by using MPPT charge controller. Hence our product in terms of use as a stand alone power generator in far off areas is best in terms of efficiency and cost.

The results of the power comparison from table 4.3 are shown graphically in the figure 4.1. The percentage increase in power generation from Photovoltaic panels due to MPPT charge controller is about 9.25%. Generally in literature, the

V_{in} (volts "V")	I_{in} (Ampere "A")	P_{in} (watts "W")
13.6	2.2	29.92
13.6	2.24	30.46
13.8	2.2	30.36
13.7	2.24	30.68
13.7	2.26	30.96
13.7	2.3	31.5
13.7	2.3	31.51
13.7	2.32	31.78
13.8	2.33	32.15
13.8	2.35	32.43
13.8	2.38	32.84
13.8	2.4	33.12
13.8	2.42	33.39
13.8	2.45	33.81
13.8	2.45	33.81
13.8	2.48	34.22
13.9	2.46	34.25
13.8	2.48	34.28
13.9	2.46	34.24
13.9	2.467	34.3
13.8	2.48	34.32
13.9	2.466	34.28

Table 4.1: Test results with MPPT

mentioned power gain with MPPT is about 10% to 15%. The MPPT method basically computes the maximum power and controls the generated power from the PV cells. MPPT tracks the maximum power under the varying weather conditions and adjusts the voltage and output current to extract maximum power from PV panels. Keeping in view the reference results and obtained efficiency, our product

V_{in} **(volts "V")**	I_{in} **(Ampere "A")**	P_{in} **(watts "W")**
14	1.93	27.00
14.1	1.98	28
14.1	2.02	28.5
14.0	2.04	28.58
14.0	2.08	29.2
14.0	2.07	29.1
13.9	2.11	29.4
13.9	2.14	29.8
13.9	2.166	30.1
13.8	2.16	29.9
13.8	2.15	29.8
13.8	2.16	29.9
13.8	2.17	30
13.8	2.16	29.9
13.9	2.17	30.2
13.9	2.16	30.1
13.8	2.19	30.3
13.8	2.18	30.2
13.8	2.2	30.38
13.8	2.21	30.4
13.9	2.18	30.38
13.9	2.187	30.4

Table 4.2: Test results without MPPT

is very close to the ideal case. This shows the good working of the product.

Power generation with MPPT Watts	Power generation without MPPT Watts	Increased Power Percentage %
29.92	27.0	9.75
30.46	28.0	8.08
30.36	28.5	6.13
30.68	28.58	6.84
30.96	29.2	5.68
31.5	29.1	7.62
31.51	29.4	6.69
31.78	29.8	6.23
32.15	30.1	6.37
32.43	29.9	7.8
32.84	29.8	9.25
33.12	29.9	9.72
33.39	30.0	10.15
33.81	29.9	11.56
33.81	30.2	10.67
34.22	30.1	12.04
34.25	30.3	11.53
34.28	30.2	11.9
34.24	30.38	11.27
34.3	30.4	11.37
34.32	30.38	11.48
34.28	30.4	11.31
Average percentage increase		**9.25**

Table 4.3: Comparison of Power with and without MPPT

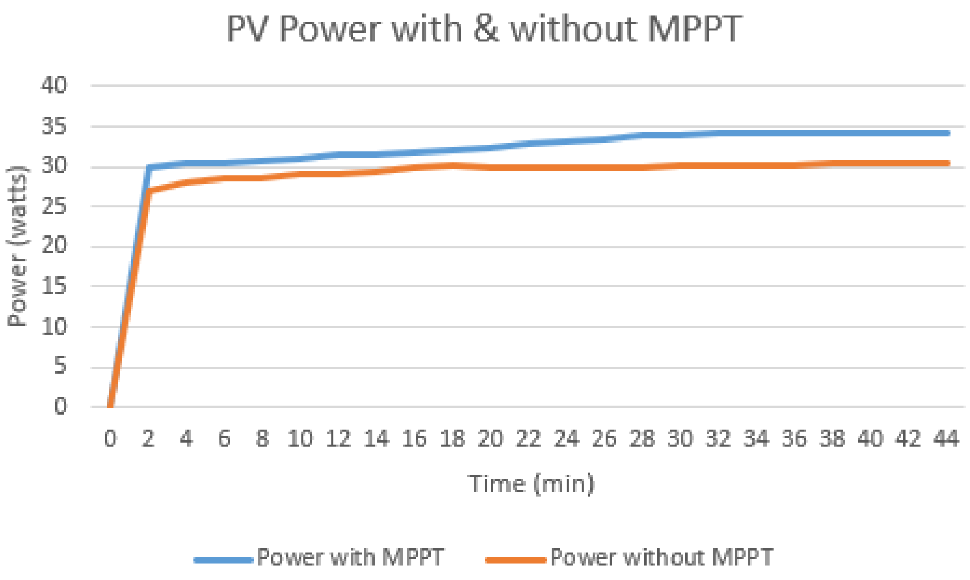

Figure 4.1: PV module Power Generation

4.2 Discharging Curve Comparison

The Lithium Iron Phosphate (LiFePO4) batteries have a flat discharge curve. The voltage remains almost constant from 99% SOC to 20% SOC. After that the voltage drops drastically. During the testing and plotting of the discharging curve with respect to time, a constant load of 165 watts was applied on the inverter output. A table containing the battery voltage with respect to time was filled. The battery voltage and current was measured using a DC volt and ampere meter in the circuit. The procedure was continued for almost two hours until the batteries died. The capacity of batteries was found using the time and the constant load run by batteries for that time. The whole data was then plotted as shown in fig 4.2. The figure clearly proves the concept explained above regarding voltage verses SOC.

The discharging curve data is already available in literature that has been published and being followed for years. The practical testing of our product proves the literature data and also confirms the practicality of our product. The graph shown in fig 4.3 is taken from the research paper [10]. This graph compares cell voltage for charging and discharging. The discharge curve of LiFePO4 is similar

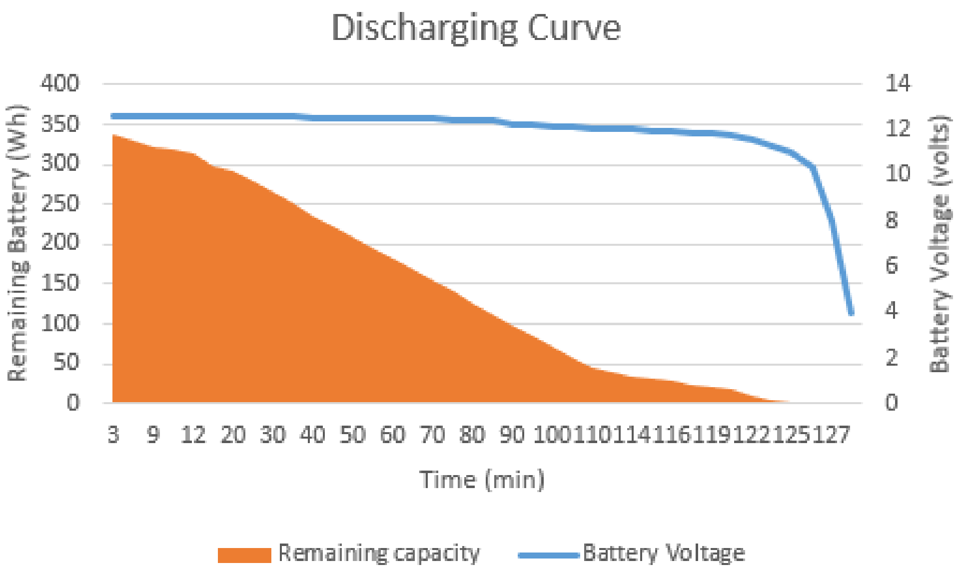

Figure 4.2: Discharging Curve and Battery Capacity

to the one plotted by our product in 4.2. This proves the good functionality and working of our design.

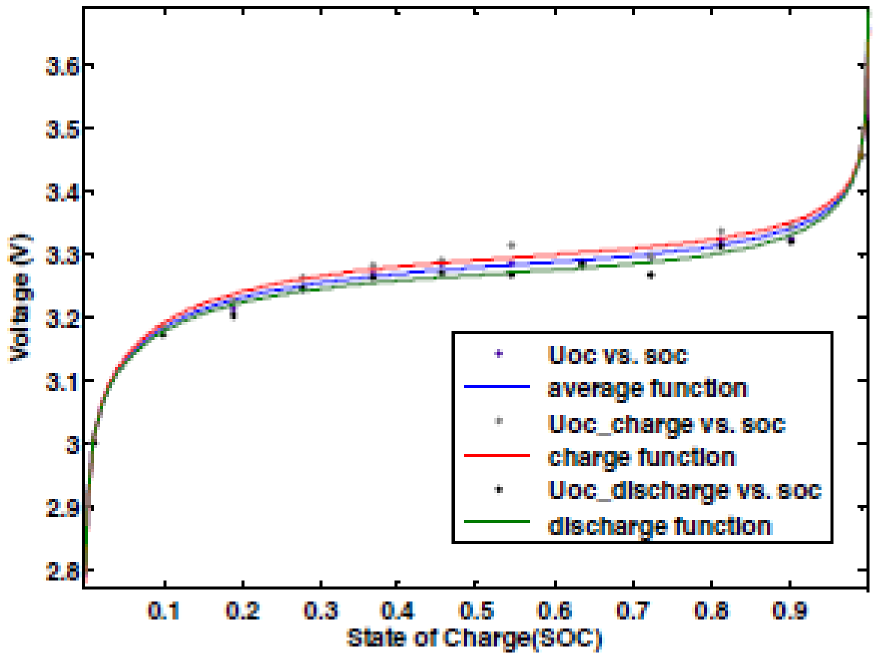

Figure 4.3: Reference Discharge Curve

4.3 Comparison of Cost and Features

The products similar to the one we have designed are available in international market. Pakistani market does not has such product available. The one with its requirement has to buy online, this not only costs him too much but also the shipping charges adds to the cost to make it too expensive. Our aim is to produce it locally so that the people of Pakistan have easy access to it, as it is the most required gadget nowadays. The features and working of our product is similar to the ones available internationally but available in very cheap price. The comparison of features, battery types and capacities is done in table 4.4.

The comparison table shows that the two products are almost similar in available features but a large difference is present in the cost of two products. The already available product costs almost three times to the proposed product.

Feature	Available Product	Proposed Product
Main Functionality	Portable Power Station & UPS	Portable Power Station & UPS
Battery Type	LiFePO4	LiFePO4
Battery Capacity	595 Wh	320 Wh
Max AC Output	600 Watts	400 Watts
Output Sockets	Three 220 V sockets	Two 220 V sockets
Modes of Charging	Solar and Utility	Solar and Utility
Other Output Types	USB Type A, USB Type C, 12V DC	USB Type A & 12V DC socket
Output Waveform	Pure Sine Wave	Modified Square Wave
BMS	Simple BMS	BMS with mobile app
Overload Protection	Yes	Yes
Product Weight	10 Kg	8 Kg
Cost	Pkr. 170000	Pkr. 50000

Table 4.4: Cost and Features Comparison

Chapter 5

Conclusion

This thesis proposes a Portable Power Station that can also be used as UPS (Uninterrupted Power Supply). The proposed product can be used during camping and travelling to power up electronic gadgets, and as a stand alone power source in far off areas. It uses MPPT Charge controller to charge the LiFePO4 batteries from the PV module. The house's electric supply can also be used to charge batteries. The product can also works as UPS for sensitive equipment at homes or offices in case of power failure. The power storage LiFePO4 batteries have a Battery Management System(BMS) for the safe operation of batteries. The power inverter inverts DC current to 220 volts AC to be used normally. The output of the power station has a USB port power socket and a 12 volts DC socket in addition to normal 220 volts AC output.

Bibliography

[1] A.G. Bakirtzis and E.S. Gavanidou. "Optimum operation of a small autonomous system with unconventional energy sources". In: *Electric Power Systems Research* 23.2 (1992), pp. 93–102. ISSN: 0378-7796. DOI: https://doi.org/10.1016/0378-7796(92)90056-7. URL: https://www.sciencedirect.com/science/article/pii/0378779692900567.

[2] Kathryn R. Bullock. "Lead/acid batteries". In: *Journal of Power Sources* 51.1 (1994), pp. 1–17. ISSN: 0378-7753. DOI: https://doi.org/10.1016/0378-7753(94)01952-5. URL: https://www.sciencedirect.com/science/article/pii/0378775394019525.

[3] D. Butler. "Portable power stations". In: *Journal of Power Sources* 48.1 (1994). Proceedings of the Fifth Asian Battery Conference, pp. 247–254. ISSN: 0378-7753. DOI: https://doi.org/10.1016/0378-7753(94)80021-9. URL: https://www.sciencedirect.com/science/article/pii/0378775394800219.

[4] B. Wichert. "PV-diesel hybrid energy systems for remote area power generation — A review of current practice and future developments". In: *Renewable and Sustainable Energy Reviews* 1.3 (1997), pp. 209–228. ISSN: 1364-0321. DOI: https://doi.org/10.1016/S1364-0321(97)00006-3. URL: https://www.sciencedirect.com/science/article/pii/S1364032197000063.

[5] L. Zhang, A. Al-Amoudi, and Yunfei Bai. "Real-time maximum power point tracking for grid-connected photovoltaic systems". In: *2000 Eighth International Conference on Power Electronics and Variable Speed Drives (IEE Conf. Publ. No. 475)*. 2000, pp. 124–129. DOI: 10.1049/cp:20000232.

[6] Ming-Tsung Tsai and Chia Liu. “Design and implementation of a cost-effective quasi line-interactive UPS with novel topology”. In: *Power Electronics, IEEE Transactions on* 18 (Aug. 2003), pp. 1002–1011. DOI: 10.1109/TPEL.2003.813764.

[7] Li-Xia Yuan et al. “Development and challenges of LiFePO4 cathode material for lithium-ion batteries”. In: *Energy & Environmental Science* 4 (July 2010), pp. 269–284. DOI: 10.1039/c0ee00029a.

[8] Saidatul Saad et al. “Study of inverter design and topologies for photovoltaic system”. In: (June 2011). DOI: 10.1109/INECCE.2011.5953934.

[9] Her-Terng Yau, Qin-Cheng Liang, and Chin-Tsung Hsieh. “Maximum power point tracking and optimal Li-ion battery charging control for photovoltaic charging system”. In: *Computers & Mathematics with Applications* 64.5 (2012). Advanced Technologies in Computer, Consumer and Control, pp. 822–832. ISSN: 0898-1221. DOI: https://doi.org/10.1016/j.camwa.2011.12.048. URL: https://www.sciencedirect.com/science/article/pii/S0898122111011047.

[10] Junbo Jia et al. “Multirate Strong Tracking Extended Kalman Filter and Its Implementation on Lithium Iron Phosphate (LiFePO4) Battery System”. In: June 2015. DOI: 10.1109/PEDS.2015.7203572.

[11] Hussain Kazmi et al. “Electricity load-shedding in Pakistan: Unintended consequences, opportunities and policy recommendations”. In: *Energy Policy* 128 (2019), pp. 411–417. ISSN: 0301-4215. DOI: https://doi.org/10.1016/j.enpol.2019.01.017. URL: https://www.sciencedirect.com/science/article/pii/S0301421519300175.

[12] A. Hariprasad et al. “Battery Management System in Electric Vehicles”. In: *International Journal of Engineering Research and* V9 (May 2020). DOI: 10.17577/IJERTV9IS050458.

[13] Azriyenni Azhari Zakri et al. “Portable power supply design with 100 Watt capacity”. In: *INVOTEK Jurnal Inovasi Vokasional dan Teknologi* 21 (Jan. 2021), pp. 2549–9815. DOI: 10.24036/invotek.v21i1.901.

[14] Guan-Jhu Chen and Wei-Hsin Chung. “Evaluation of Charging Methods for Lithium-Ion Batteries”. In: *Electronics* 12.19 (2023). ISSN: 2079-9292. DOI: 10.3390/electronics12194095. URL: https://www.mdpi.com/2079-9292/12/19/4095.

[15] Jinya He. “Classification and Application Research of Lithium Electronic Batteries”. In: *MATEC Web of Conferences* 386 (Nov. 2023). DOI: 10.1051/matecconf/202338603008.

[16] Rui Ji and Zhihe Wang. “Improved variable-step incremental conductance MPPT algorithm applied to photovoltaic storage systems”. In: *Journal of Physics: Conference Series* 2427.1 (Feb. 2023), p. 012045. DOI: 10.1088/1742-6596/2427/1/012045. URL: https://dx.doi.org/10.1088/1742-6596/2427/1/012045.

[17] Musong L. Katche et al. “A Comprehensive Review of Maximum Power Point Tracking (MPPT) Techniques Used in Solar PV Systems”. In: *Energies* 16.5 (2023). ISSN: 1996-1073. DOI: 10.3390/en16052206. URL: https://www.mdpi.com/1996-1073/16/5/2206.

[18] Munish Manas, Ravish Yadav, and Rajesh Kumar Dubey. “Designing a battery Management system for electric vehicles: A congregated approach”. In: *Journal of Energy Storage* 74 (2023), p. 109439. ISSN: 2352-152X. DOI: https://doi.org/10.1016/j.est.2023.109439. URL: https://www.sciencedirect.com/science/article/pii/S2352152X23028372.

[19] Abhay M Vyas and Gyaneshwar Singh Kushwah. “Sand Battery: An Innovative Solution for Renewable Energy Storage (A Review)”. In: *2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM)*. 2023, pp. 1–5. DOI: 10.1109/RESEM57584.2023.10236319.