SOLAR POWERED BATTERY CHARGER WITH STATE OF CHARGE INDICATOR CIRCUIT

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ABSTRACT

Solar energy is one of the many forms of renewable energy on earth. This energy can be harnessed by using a solar cell or photovoltaic cell which converts sunlight directly into electricity. Solar power can also be used in many small electrical devices such as battery chargers. In this project, a solar powered battery charger with a state of charge indicator circuit is developed to charge AA batteries and to show indication to the user when the batteries reach a fully charged state. The primary benefit of using a solar powered battery charger is that it is one of the cheapest forms of recharging batteries. Apart from this, solar powered battery chargers are fast gaining popularity as they have been proven to be handy in many situations especially in the outdoors, being portable and user friendly. In this project, a constant current source is provided to the batteries in order to recharge it and the state of charge indicator circuit is developed with an adjustable precision Zener shunt regulator. Once the batteries are fully charged, an LED will light up to show the user that the batteries can now be used reused.

ABSTRAK

Tenaga solar adalah antara salah satu sumber tenaga yang boleh di perbaharui di bumi. Tenaga ini boleh diperolehi dengan menggunakan sel solar ataupun sel fotovoltaik yang boleh menukarkan cahaya matahari secara terus kepada kuasa elektrik. Tenaga solar juga boleh digunakan dalam peralatan elektrik yang kecil seperti pengecas bateri. Dalam projek ini, sebuah pengecas bateri di reka yang menggunakan tenaga solar sebagai sumber kuasanya. Litar ini direka untuk mengecas bateri AA dan menunjukkan status pengecasannya kepada pengguna apabila bateri telah dicaskan sepenuhnya. Pengecas batteri yang mengunakan tenaga solar ialah cara termurah untuk mengecas bateri lama dan kini sedang menjadi lebih popular kerana ia mudah alih dan senang digunakan apabila berada di luar. Dalam projek ini, sumber arus yang tetap di salurkan kepada bateri agar pengecasan berlaku. Apabila bateri telah dicaskan dengan sepenuhnya, LED akan bernyala sebagai petunjuk kepada pengguna bahawa batteri yang sedang dicaskan kini boleh digunakan semula.

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LIST OF SYMBOLS

I	-	Current
$k\Omega$	-	kiloOhm
mA	-	mili Ampere
MW	-	Mega Watt
P	-	Power
R	-	Resistance
SOC	-	State of Charge
V	-	Volt
V	-	Voltage
W	-	Watt
W/m^2	-	Watts per square meter
WH/m^2	-	Watt hours per square meter
Ω	-	Ohm

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The introduction to this thesis can be divided into four major parts. Each sub section will discuss the background of the project, problem statement, objectives and scope of the project.

1.2 Project background

There are many forms of renewable energy on earth. Solar energy is one of this many forms. The earth receives about 1×10^{12} MW of energy from the sun every year. This amount is enough to cover the Earth's energy demand for over 1000 times. Capturing sunlight and turning them into electricity for daily usage is a very good way to minimise expenditure and pollution. Solar energy has proven to be a clean and safe form of energy for our daily living and is made available naturally around most parts of the world.

Solar energy can be harnessed by using a solar cell or photovoltaic cell to convert sunlight directly into electricity. Since the development of early photovoltaic cells, the very first photovoltaic system has been applied in Malaysia in early 1980s. The applications of photovoltaic system were mainly concentrated on stand-alone systems, especially for rural electrification program.

However, lately we find that solar power can be used in many devices such as water heaters, home lighting systems and even calculators. Furthermore, smaller electrical appliances such as garden lights and street lights are also powered by solar energy. Due to the introduction of solar energy to power small electrical appliances, we now find that battery chargers can also utilise this source of power. In fact, one of the cheapest forms of recharging batteries is by using a solar cell as it is simple to construct and the energy obtained from the sun is free.

Solar powered battery chargers are fast gaining popularity as they have been proven to be handy in many situations especially in the outdoors. Furthermore, this battery charger is quite portable and user friendly too as it is simple to handle. These attractive features are further enhanced by the fact that this type of battery charger is cheap to construct and has many added advantages.

The solar powered battery charger is environmentally safe too as it purely uses renewable energy and reduces chemical waste because it allows alkaline batteries to be reused for a certain amount of times before being disposed. This type of battery charger also has a longer life cycle as it requires minimal maintenance and can directly convert energy from the sun to produce electricity.

1.3 Problem statement

We tend to use many battery powered electrical devices in our daily lives especially when we are outdoors during hikes, camping, road trips and vacations. These electrical devices such as torch lights, radios and walkie talkies are essential items when we are outdoors. When these electrical devices run out of battery charge, we usually find ourselves in a lurch in locating a suitable power source to recharge the batteries. Hence, in this situation, a solar powered battery charger would be a more practical solution to charge these batteries.

1.4 Objectives

There are two objectives in this project. They are as the following

(i) To develop a solar powered battery charger.

(ii) To develop a state of charge, (SOC) circuit to indicate the charging level of the batteries.

1.5 Scope of project

Scope of this project can be narrowed down into two main areas. They are as the following

(i) To use supply purely from a solar cell.

The battery charger is expected to be powered using a 20 V 10 W solar panel. This solar panel will function as the power supply to the entire circuit with a supply current of around 0.5A when the solar panel is able to perform at its maximum level.

(ii) Battery charger has an output of 1.5-3 V.

The battery charger is expected to have an output of 1.5 – 3 V of charging voltage. The charging unit is expected to be able to produce a charging current of around 83 mA. This current will then be capable of charging one or two alkaline batteries each with the output voltage of 1.5 V.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review of this thesis is divided into three parts. The first part of the literature review begins with an introduction to solar power as a form of renewable energy. It also concentrates on the benefits that can be obtained from using solar energy as a power source. The second part of the literature review gives a history of the solar cell and its chemical composition. This part also dwells on how a solar cell works. The third part is a summary of the benefits of a battery charger in particular the solar battery charger. It also explains how solar powered battery charger can be developed.

2.2 Solar Energy

Solar energy is be categorised as energy in the form of heat and light from the sun. Energy from the sun travels to the earth in the form of electromagnetic radiation with a wide spectrum of frequency range. Available solar energy is often expressed in units of energy per time per unit area, such as watts per square meter (W/m^2) or watt hours per square meter (WH/m^2). The amount of energy available from the sun outside the Earth's atmosphere is approximately 1367 W/m^2 [1].

At any particular time, the available solar energy is primarily dependent upon how high the sun is in the sky and current cloud conditions. On a monthly or annual basis, the amount of solar energy available also depends upon the location. In general, useable solar energy is depends upon available solar energy, other weather conditions, the technology used, pollution or geographical position and the application involved [2,3].

2.2.1 Solar Energy as a Power Source

Electricity generation using solar cells has been of particular interest for a long time and is fast gaining popularity among countries that lie across the Equator. Malaysia, as a country close to the Equator, possesses a daily peak solar hours more than 4 hours. This is higher than those in Japan, Germany and USA where solar energy, as an alternative energy, has been strongly supported by their governments. The availability of solar energy in Malaysia makes it an ideal source for power generation.

Energy substitution is not a recent innovation as many forms of renewable or alternative energy have been explored to date [4]. Solar energy demand has grown at about 25% per annum over the past 15 years. This form of energy has been accepted worldwide as a high potential alternative energy as current research and markets have shown that solar photovoltaics (PV) is amongst the fastest growing and most promising forms of renewable energy for electricity generation [2].

To understand how solar energy can be fully utilized, we first need to understand and useful way by utilizing an old, well-known physical phenomenon, the photovoltaic effect, whereby some of the sun's light is transformed directly into electicity [4].

A photovoltaic solar cell is essentially a semiconductor which can generate as electric potential when ionized by radiation. In other words, a solar cell can convert the radiant energy of sunlight directly into electricity with high reliability and long life cycle.

2.2.2 Benefits of Solar Energy

Photovoltaic systems or solar cells can be utilised in many ways. Solar cells have been used to charge various solar batteries for applications in aerospace industry, electric vehicles, communication equipment and remote motor supplies [5]. Many different applications of PV systems are possible and vary from water pumps to total electrification of remote villages, serving multiple loads [4, 6] and satellite power systems [7]. In Malaysia, the potential of solar energy has begun to be utilised in a wide range of applications such as heating, lighting and other forms of agricultural uses as well a wide range of applications in remote and urban areas [8].

There are many benefits to be gained from using solar energy as a power source. Photovoltaic technology has been proven to be a new and exciting energy source as its conversion method is both novel and unique. Photovoltaic power systems do not contain any moving parts which may wear out, do not contain any fluids or gasses which could leak and can operate at moderate temperatures. Furthermore, no fuel is needed to activate this system, making it a non-polluting and quick responding as well as almost maintenance free power source [1]. Solar energy does not give rise for environmental concern as some other conventional energy sources which contribute dangerous chemical emissions [8].

On the plus side, photovoltaic array can be made from silicon, a common element found on earth. Recent technological developments in thin-film photovoltaic, such as amorphous silicon and hybrid die sensitized/photovoltaic (PV) cells, are leading to new generations of consumer portable solar arrays. These new arrays are lightweight, durable, and flexible and have been reported to achieve power efficiencies of up to 10%.

Commercial-off-the-shelf arrays already exist, that have panels embedded in fabric that can be folded to dimensions of less than 12" x 12", yet are able to produce up to 50 Watts of power at 12 V. These new products make solar power available to hikers, campers, soldiers-on-the-move, etc., since the arrays can now be easily carried in backpacks [9].

2.3 Solar Cell

The solar panel, sometimes called solar cell or photovoltaic cell is a device that converts light directly into electricity by the photovoltaic effect. Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight, while the term photovoltaic cell is used when the light source is unspecified. Assemblies of cells are used to make solar panels, solar modules, or photovoltaic arrays. These arrays are then used during energy conversion.

2.3.1 History of the Solar Cell

The photovoltaic was first reported in 1839 by Edmund Bequerel who observed that the action of shining light on an electrode submerged in a conductive solution would create an electric current. Forty years later the first solid state photovoltaic device was created as the photoconductivity of selenium was discovered. In 1894, Charles Fritts prepared the first large area solar cell by pressing a layer of selenium between gold and another metal. This paved the way for observing early cells which were thin film Schottky barrier devices where a semitransparent layer of metal deposited on top of the semiconductor top provides photovoltaic action [10].

However, it was not the photovoltaic properties of materials like selenium that was further researched on but its photoconductivity was given importance. The fact that the current produced was proportional to the intensity of the incident light and related to the wavelength of light in a definite way meant that photoconductive materials were ideal for photographic light meters. This meant that the light meter could operate without a power supply. It was not until the 1950's however that through the development of good quality silicon wafer; potentially useful quantities of power were produced by photovoltaic devices in crystalline silicon [10].

Further development in silicon electronics lead to the manufacturing of *p-n* junctions in silicon. The first silicon solar cell was reported in 1954 and was recorded to have converted sunlight with an efficiency of six times higher than selenium. This early silicon cell introduced the possibility of power generation in remote locations where fuel could not easily be delivered. It was also used in satellite development where the requirement for reliability and low weight made silicon solar cells widely developed for space application.

In the 1970's, the crisis in energy supply paved the way to a sudden growth of interest in alternative sources of energy. Photovoltaics became a subject of intense interest during this period of time and strategies for producing cheaper photovoltaic devices and materials were explored.

Routes to lower cost included photo electrochemical junctions and alternative materials such as polycrystalline silicon, amorphous silicon, other 'thin film' materials and organic conductors. This interest continued to expand in the 1990's, along with the growing awareness of the need to secure sources of electricity alternative to fossil fuels.

At present, the majority of PV modules currently in use are based on monocrystalline and polycrystalline silicon. Crystalline means that the material in the PV has a regular ordered internal structure within each grain. The electrical properties of the crystalline PV are affected by the boundaries between grains. The PV modules made from monocrystalline silicon offer the highest efficiencies because they have no grain boundaries, but are also most expensive to manufacture. To contrast, the poly-crystalline PV modules are somewhat less efficient, but are cheaper to produce. Currently two types of PV modules have very similar cost of per watt electricity. In comparison with the crystalline silicon PV, thin film technology holds the promise of reducing the module cost through low material and energy consumption during the fabrication [2].

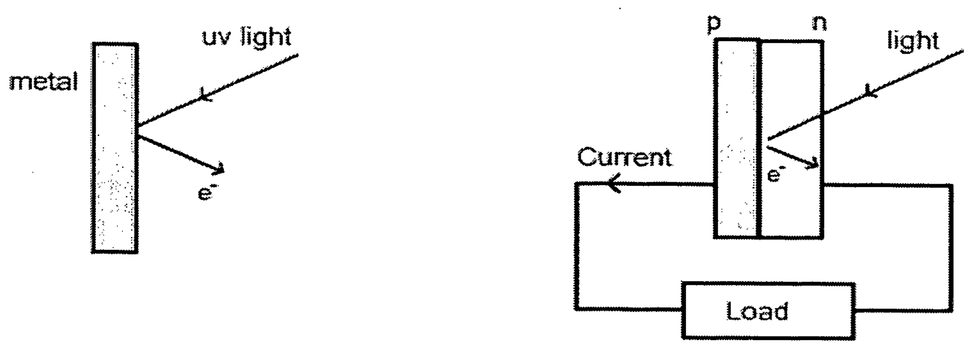
During this current period, the economics of photovoltaics is continuously expanding and has become competitive with conventional electricity supply for remoter low power applications such as navigation, telecommunications and rural electrification as well as for enhancement of supply in grid- connected loads during peak usage.

2.3.2 How a Solar Cell Works

Solar photovoltaic conversion is a one-step conversion process which generates electrical energy from light energy. This explanation relies on ideas from quantum theory. Light is made up of packets of energy, called photons, whose energy depends only upon the frequency or colour of light. The energy of visible photons is sufficient to excite electrons, bound into solids up to higher energy levels where they are freer to move [10].

Normally, when light is absorbed by matter, photons are given up to excite electrons to higher energy states within the material, but the excited electrons quickly relax back to their ground state.

This action can be described further through Figure 2.1. The diagram on the left (a) shows the photoelectric effect where ultraviolet light liberates electrons from the surface of a metal [10].



(a) (b)

Figure 2.1 Comparison between (a) Photoelectric effect in metal, and (b) Photovoltaic effect in a solar cell

However, in a photovoltaic device, as seen on the right, (b) in Figure 2.1, when electrons are knocked loose from their atoms, there is some built in symmetry which pulls away the excited electrons before they can relax and feeds them to an external circuit, thus allowing them to flow through the material to produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.

The extra energy of the excited electrons generates a potential difference or electromotive force (emf). This force is then converted into a usable amount of direct current (DC) electricity as shown further in Figure 2.1 and drives the electrons through a load in the external circuit to do electrical work.

On the whole, the effectiveness of a photovoltaic device depends upon the choice of light absorbing materials and the way in which they are connected to the external circuit.

2.4 Battery Charger

Battery chargers are generally used to recharge rechargeable batteries. Some common types of rechargeable batteries are nickel cadmium (NiCd), nickel metal hydride (NiMH) and lithium ion (Li-ion). However in some cases, disposable alkaline batteries can also be recharged. The idea of recharging alkaline batteries is not new. Although not endorsed by manufacturers, ordinary alkaline batteries have been recharged in households for many years.

Recharging these batteries is only effective, however, if the cells have been discharged to less than 50 % of their total capacity. The number of times a battery can be recharged depends on many factors. These include the discharging drain load or depth of discharge, the frequency of use, the length of time in a discharged state, charge temperature and conditioning. With each recharge, the amount of capacity the cell can hold is reduced.

Recharging batteries reduce the ecological impact as for a same quantity of energy produced; rechargeable batteries have up to 32 times less impact on the environment than disposable batteries. When batteries are improperly disposed of in household and workplace waste, they can leak toxic heavy metals into the environment as batteries leach heavy metals slowly into the soil and ground and surface water. When batteries are incinerated, certain metals may be released into the air or concentrated in the ash that has to be disposed.

Heavy metals from batteries can make it into the food chain where they pose health impacts on humans. Mercury was phased out of certain batteries starting in 1996 with the signing of the Battery Act, but other heavy metals such as cadmium are still used, which are very toxic [11].

Recycling of batteries through the proper collection and disposal at a municipal collection location will greatly reduce their impact on the environment. Using rechargeable batteries reduces the manufacturing levels of heavy metals and greatly reduces disposal requirements. It also lessens the impact on air pollution, global warming, air acidification and water pollution. In short, by recharging batteries, we are reducing waste [11].

Hence, when a battery charger is combined with a solar panel as its power supply, it creates an environmental friendly battery charger. A solar battery charger is also simple and inexpensive method for recharging batteries. It may be applied for small power battery charging or for direct solar power supplies such as in calculators, signs and lightings etc [5].

One obvious specialty of the solar battery charger is that we do not need a power outlet for it to function. The solar battery charger fully relies on the sun alone for its charging energy and can be used in any location where sunshine is available. Since an external electrical source is not required to recharge batteries, the solar battery charger offers freedom of movement. This type of charger can be fully portable, lightweight and user friendly.

However, most solar chargers require a longer period of time to charge a set of batteries compared to other conventional chargers [12]. This is because even in bright sunlight, most solar cells currently in production are only about 10 percent efficient, which makes them slower than chargers that plug into a wall outlet.

2.5 Solar Powered Battery Charger Development

A simple solar battery charger is generally made up of four parts. A common solar powered battery charger is shown in Figure 1, with the various possible subsystems that comprise it [2].

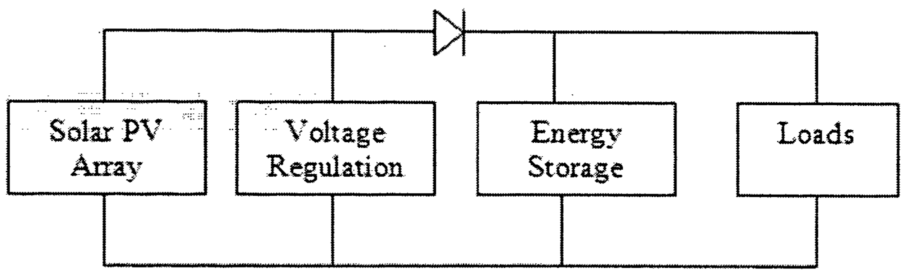


Figure 2.2 Subsystem of a solar powered battery charger

The solar PV array is the source which generates electricity when exposed to sunlight, thereby producing DC power. The solar array is made with multiples of solar cells. The solar cells are connected in a series-parallel configuration to match the required solar voltage and power rating [7].

As shown in Figure 2.2, the solar PV array is then connected to the voltage regulation subsystem. The voltage regulator maintains the system's voltage between low and high voltage limits when power is available from the array and creates a constant-current constant-voltage charge.

To understand the concept of a constant-current constant-voltage charge, we must first realize that there are several techniques used in the conventional approach to charging a battery. The first and the most common in consumer products is the constant current trickle charge. These chargers provide a very low, constant current rate to the battery and rely on the user to stop the charge when the battery has returned to full capacity [13].

A deviation on the constant current charge approach is the constant–current constant-voltage charge profile. Under this arrangement, a constant current is applied until battery voltage rises to a predetermined value, at which point the charging voltage is held constant and the current is reduced. When the current has reached a minimum value, the charging stops [13].

In some applications, the solar battery charger is a stand-alone system which includes a power converter which is used to control the solar array voltage into desired voltage. This power controller is usually either a buck converter which steps-down the input voltage or a boost converter that steps-up the voltage. In short, the power converter plays an important role in the voltage regulation of the charger [7].

The voltage from the regulator then is channelled to a diode as shown in Figure 2.2. The blocking diode controls the direction of the flow of energy between the array and the system to prevent discharge of the energy storage system through the solar array and subsequent loss of energy or damage to the array.