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Design and Implementation of Photovoltaic-Based Boost Converter to Supply Pacemaker and Sensor under the Skin

Nada Abed Mhmood Hussein [1]

Zahraa Hussien Hamza Saleh [2]

Shafaq Huseein Saeid Abd [3]

Maryam Ahmed Jassim Abbas [4]

Abstract

Most of the medical devices requires a power supply to continuous their operation, any failure on the power supply system may cause an unexpected health damage or even a death specially for a life related medical sensor or medical device such as a peacemaker and sensor under the skin. Thus, sustainable power supply system based on photovoltaic energy is significant for healthcare sensors and devises. This project aims to design and implement photovoltaic based boost converter to supply peacemaker and sensor under the skin. In order to achieve the proposed system, three objectives have been set as follow: First, to design and implement photovoltaic based boost converter. Second, to design and implement a backup power supply system based on rechargeable lithium battery. Third, to test and evaluate the system performance. Our proposed system has been tested successfully. The result shows a good performance in both sate: First: When there is an enough solar energy (100% depend on solar energy). Second: When there is no enough solar energy.

Keywords: Pacemaker power supply. Design and Implantation Pacemaker. Photovoltaic cells. Under-skin sensor.

[1] Department of biomedical Engineering, University of Technology

[2] Department of biomedical Engineering, University of Warith Al_Anbiyaa

[3] Department of Biomedical Engineering, University of Al_Mustaqbal

[4] Department of Medical Instrumentation Engineering Techniques, Al_Frahidi University

1. Introduction:

Photovoltaic power generation refers to the process of generating electricity through the use of solar cells. A solar cell is an apparatus that directly transforms solar optical energy, or solar radiation, into electrical energy. [1]A semiconductor device is fundamentally constructed to produce a voltage when exposed to solar radiation. [2].

The advancement of renewable energy has emerged as a vital subject in the 21st century, particularly in light of the escalating challenges posed by global warming and various environmental concerns. Enhanced research efforts have underscored the significance of alternative renewable sources, including wind, hydropower, geothermal, and solar energy, for electricity generation. While photovoltaic cells have been in existence for some time, their application has become more widespread, practical, and beneficial for individuals around the globe. A key feature of solar cells is their ability to convert solar energy directly into electrical energy via the solar photovoltaic module, which consists of silicon cells. [3].

The majority of solar cells are constructed from semiconducting Mult crystalline silicon, which presently exhibit efficiencies ranging from 10% to 15%. According to the Encyclopedia of Energy, even at these efficiency levels, it would require solar modules occupying an area that is merely 0.25% of the total global land designated for crops and permanent pasture to fulfill the entire primary energy needs of the world, assuming that most or all of this land would otherwise remain unutilized. [4]. It is numbers like these that demonstrate the importance and potential that solar cells have in becoming one of the most important sources of energy used around the world [5]. The challenges associated with the utilization and manufacturing of solar cells are evident, particularly due to their low efficiency and elevated costs. The incorporation of renewable energy sources into medical devices is essential for ensuring uninterrupted functionality and averting severe consequences in the event of a power outage. This initiative investigates the application of photovoltaic technology to create a dependable and sustainable power system for pacemakers and subcutaneous sensors.

1.2 Project Objectives:

The main goal of this project is to design and implement a sustainable power system based on photovoltaic technology for life-critical medical devices. The specific objectives are:

1. Designing and Implementing a Photovoltaic Boost Converter: The boost converter ensures that the solar energy collected is converted and managed to meet the voltage requirements of medical devices.
2. Designing a Backup Power Supply Using Lithium Batteries: To provide uninterrupted power when solar energy is insufficient, a lithium-ion battery backup is integrated into the system.
3. Testing and Evaluating System Performance: Performance evaluation under various conditions ensures reliability for medical applications.

1.3 How Solar Cells Work:

Solar cells produce energy by performing two basic tasks: (1) absorption of light energy to create free charge carriers within a material and (2 The process involves the segregation of negative and positive charge carriers to generate an electric current that travels unidirectionally between terminals exhibiting a voltage differential. Solar cells accomplish this through the use of semiconducting materials. The separation of charges is generally facilitated by a p-n junction. The various regions of a solar cell consist of materials that have been intentionally "doped" with distinct impurities, resulting in an abundance of free electrons (n-type) on one side of the junction, while the other side experiences a deficiency of free electrons. [6]. electrons (p-type) on the other. This behavior creates an electrostatic field with moving electrons and a solar cell is essentially, a large-area diode

Figure 1 The overall process of solar energy conversion is outlined as follows: Initially, photons penetrate the surface of the solar array. Upon absorption, the energy of the photon is imparted to an electron within the semiconductor material. This interaction liberates the electron from its associated atom, resulting in the creation of a positively charged vacancy, commonly referred to as a "hole." [4] The dynamics of electrons and holes within the cell are affected by the electric field and by diffusion towards areas of reduced electron concentration. A robust electric field leads to the separation of electron-hole pairs generated in proximity to the junction. Minority carriers, comprising electrons in p-type material and holes in n-type material, are propelled across the junction, thereby converting into majority carriers. This movement of individual carriers is essential for the generation of the cell's output current. Ultimately, the metal contacts on the cell enable the transfer of the generated current to an external load. [7].

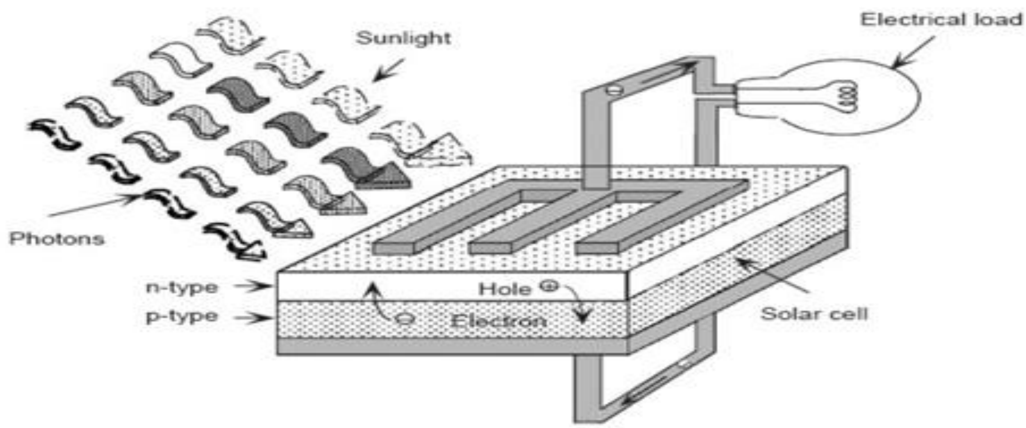

Figure: 1 Solar cell operation

2. Pacemakers:

Cardiac pacemakers deliver electrical impulses to induce heart contractions during instances when the heart's natural electrical activity is either insufficiently slow or completely absent. These pacing systems are composed of a pulse generator and pacing leads. Typically, the pacemaker's output stimulates the interior of the right atrium and/or right ventricle, a process known as endocardial pacing. Alternatively, epicardial leads may be surgically affixed to the surface of the heart. The lifespan of the battery varies based on the specific type of pacemaker and its intended use, with manufacturer estimates ranging from 5 to 13 years. The heart is a muscular organ composed of four chambers that plays a vital role in receiving and distributing blood throughout the pulmonary and systemic circulatory systems of the human body. The pulmonary system includes the left atrium, which collects oxygenated blood from the lungs, and the right ventricle, which is tasked with pumping deoxygenated blood back to the lungs. In contrast, the systemic system comprises the left ventricle, responsible for delivering oxygen-rich blood into the arteries and capillaries to supply the body's tissues, and the right atrium, which collects deoxygenated blood returning from the systemic veins. The tricuspid valve, situated between the right atrium and right ventricle, along with the mitral valve, found between the left atrium and left ventricle, functions to prevent the backflow of blood from the ventricles into the atria. Within the heart, there are two primary types of cardiac muscle cells: pacemaker cells, which lack a resting membrane potential and depolarize spontaneously, and non-pacemaker cells, which maintain a resting potential and rapidly transmit electrical impulses upon activation. The atria and ventricles are mainly composed of non-pacemaker cells, allowing a stimulus applied to the atrial non-pacemaker cells to propagate throughout the atria, leading to their simultaneous contraction. This mechanism similarly applies to the non-pacemaker cells in the ventricles, where an applied stimulus results in the contraction of both ventricles. Pacemaker cells are essential for initiating the rhythmic contractions and relaxations of the heart muscles at regular intervals, thereby facilitating the critical pumping action that circulates blood throughout the body. Each heartbeat represents a single cardiac cycle, which consists of the systole phase (when the atria and ventricles contract) and the diastole phase (when the atria and ventricles relax). The cardiac cycle of the heart is defined by a sequence of rhythmic contractions and relaxations of the muscle. It begins with the initiation of an electrical impulse from a group of Pacemaker cells located in the sinoatrial (SA) node, which is positioned in the upper right lateral wall of the right atrium. The frequency of depolarization within the SA node determines the standard heart rate and rhythm, generally falling between 60 and 100 beats per minute (bpm).

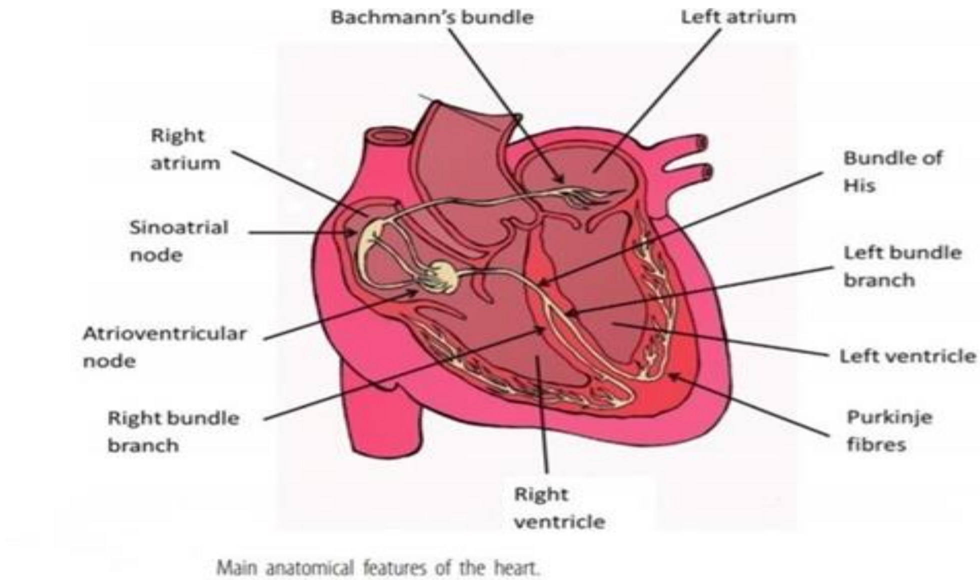

Figure 2.1 Heart anatomy

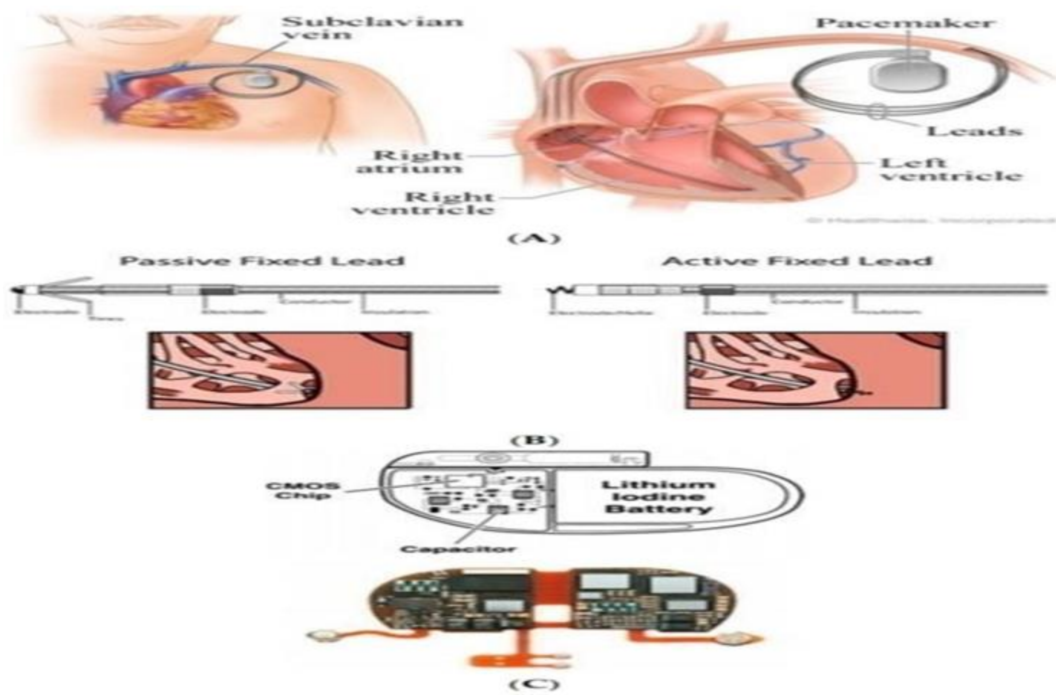

Figure 2.2 Solar Boost Converter to Supply Power for Cardiac Pacemakers

3.1. Project Component:

The proposed system consists of the following key components:

1. Solar Cell: A polycrystalline silicon solar cell with a maximum working voltage of 5V and a power capacity of 0.15W is used. The compact size (53×30×3 mm) makes it suitable for implantation beneath the skin.
2. PWM (Pulse Width Modulation) - NE555 IC: This timer IC generates PWM signals to control the delivered power, ensuring efficient energy management.

3. MOSFET Transistor: An IRFP450 MOSFET is used for switching operations in the boost converter, with specifications like 500V maximum drain-source voltage and 14A maximum drain current.
4. Fast Recovery Diode: A 1N4007 rectifier diode with a maximum recurrent peak reverse voltage of 1000V is employed for rectification and minimal power loss.
5. Inductor and Capacitor: An inductor (1 mH) and capacitors (47µF and 100µF) stabilize the voltage output and store energy for consistent power delivery.
6. Battery: A rechargeable lithium-ion battery stores surplus energy and provides backup power during insufficient sunlight.
7. Measurement Tools: DC voltmeters, ammeters, and an oscilloscope are used to monitor and analyze the system's performance.

3.2. The proposed system circuit diagram

In order to achieve the objectives of our proposed system. The proposed system circuit diagram is as in Figure 3.1 it is mainly consist of solar cell to convert the light energy into electrically energy , electronic component to deliver and manage the follow of electricity and battery to store and manage the energy.

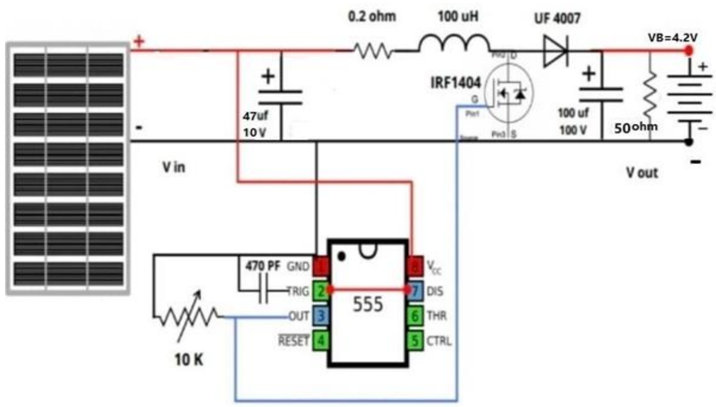

Figure 3.1 Circuit Diagram

4.1 Result and Discussion :

After the reposed system has been designed and implemented as illustrated in chapter 3. The final proposed system shown as in Figure 4.1 and Figure 4.2. Our proposed system has been tested successfully. The output of the PWM signal is shown in Figure 4.3, Figure 4.4 and Figure 4.5 The result shows a good performance in both sate: First: When there is an enough solar energy (100% depend on solar energy). Second: When there is no enough solar energy (using the backup method to supply the load- lithium battery). From the result, the proposed system is able to be used to supply peacemaker or sensor under the skin. Our propose system objective has been achieve suessfully.

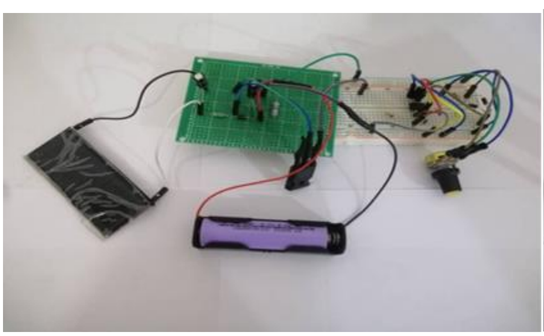
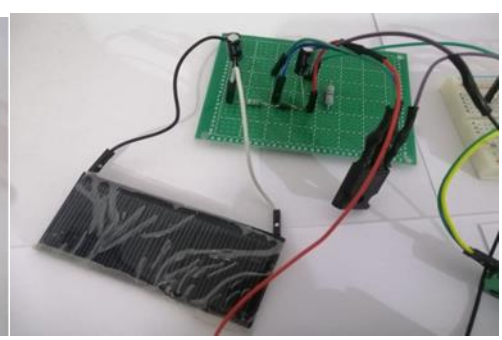

Figure 4.1 The final proposed system 1 .   Figure 4.2 The final proposed system 2

Figure 4.3 Result 1

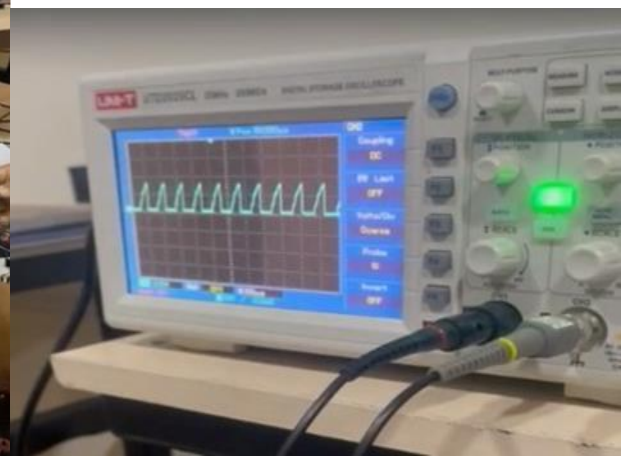

Figure 4.4 Result 2

Figure 4.5 Result 3

5. Conclusion:

This initiative effectively developed and executed a photovoltaic-based boost converter intended for the operation of life-sustaining medical devices. The system exhibited exceptional reliability in both solar and backup configurations, guaranteeing continuous power supply for pacemakers and subcutaneous sensors. Future endeavors will concentrate on reducing the size of the system, enhancing battery capacity, and conducting tests in real-world environments.

6. References:

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