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RESEARCH ARTICLE

Development of an Intelligent Solar-Powered Immunization Vaccine Storage System

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ABSTRACT

Immunization is a key component of primary health care organized by the World Health Organization globally to boost the human immune system through vaccination. The vaccine is given during immunization to reduce the risk of infection and drastically lower the number of deaths among Africans who are temperature-sensitive biological products. To maintain the product qualities of the vaccine from the time of manufacture to the point of administration during immunization exercise need cold chain. However, cold chain infrastructure is not available in rural areas of Nigeria due to the inaccessibility of electricity supply. This research is aimed at improving the vaccine cold chain system in rural areas through the provision of an intelligent solar-powered immunization vaccine storage system. The system's circuit diagram was first designed and simulated using Proteus 8 software. Solar panel of 300W, battery of 180AH, thermoelectric of 12V, 10mA, 120W, Temperature sensor of 5V,20mA, 0.1W, LED of 2V,10mA, 0.04W and ATMEGA 328P of 5V,16mA, 0.08W were the hardware used. For the software requirements, Arduino Integrated Development Environment (IDE) was used to write and upload the program using the C++ programming language. The developed prototype was tested satisfactorily to ensure that vaccines were kept and preserved at the required temperature of 2 ℃ and 7 ℃.

Keywords: *Immunization, Vaccination, Cold-Chain, Cooling-Holder, Solar-Panel*

1. Introduction

Immunization is the process by which the human immune system is fortified against diseases through vaccination. Vaccination is an effective way of protecting people against viruses and bacteria. It does so by training the immune system to recognize the invading viruses or bacteria, produces antibodies that will quickly destroy or fight off the germs before becoming sick or unwell. Every vaccine contains antigens, adjuvants, preservatives, and stabilizers but it must go through rigorous testing to ensure its safety before it can be introduced in a country.

Rural areas in Nigeria have one of the lowest vaccination rates and highest mortality rates of children in the world. Most people in rural communities do not have access to vaccines while some cannot complete the required doses of vaccines. This is as a result of the health care center's inability to sustain a vaccine in a temperature-controlled supply chain from the time of manufacturing to vaccination due to lack of access to electricity.

In the absence of access to electricity, the storage and handling plans such as ordering and accepting vaccine deliveries; storing and handling vaccines; managing inventories, and managing potentially compromised vaccines will not be developed and maintained in Health care centers. These are challenges that have led to unreliable delivery of supplies and vaccine stock-outs. Some of the vaccines given to people have reduced potency and protection because of their exposure to out-of-range temperatures. Many health care centers are closing and leaving people to travel long distances for care. A proper solution to this problem to boost the human immune system cannot be overemphasized. This will increase the economic growth of a country as it is driven by improved health and people will now contribute to economic growth by better physical, cognitive and educational performance.

In response to this problem, an intelligent solar-powered immunization vaccine storage system is developed to alleviate the challenge of electrical energy in rural areas.

Solar Powered Vaccine Storage System is cooling equipment powered by a solar system to ensure that vaccines are kept and maintained at the required temperature of 2℃ and 8℃, as they are distributed from the manufacturer to the locations for vaccination. The solar-powered vaccine storage system uses solar energy to ensure that consistency, reliability, and uninterrupted refrigeration of vaccines are maintained in off-grid communities. It converts sunlight into electrical energy through photovoltaic panels. The photovoltaic panels absorb the sunlight, create electrical charges that move in response to an internal electric field in the cell, causing electricity to flow.

Solar energy is one of the best renewable energy technology that is cost-effective, environmentally friendly, and the most abundant form of energy available to the world. Bosshard (2019) estimated that 10000TW worth of solar energy is incident on earth's surface in a day. According to the report made by Seger (2019), the world energy consumption in 2019 was 18.8TW. Comparing the world energy consumption and the amount of solar radiation received in an hour shows the potential solar energy holds. Despite the solar energy potential, its current utilization is less than 5% globally.

Sergio et al (2019) proposed a conceptual model for temperature monitoring systems in the medicine cold chain. The system was based on identifying product attributes such as location and shelf life, providing a temperature-controlled environment for the product, and using a sensor network to monitor the product temperature. The system will also study the variables affecting product temperatures such as temperature inside a vehicle, amount of gel packs used, amount of product in a thermal box, and position of temperature sensor inside a thermal box. Unfortunately, the conceptual model was not validated in the medicine and vaccine cold chain system.

Anderson et al (2019) developed a cold chain information system that tracks health facility information and cold chain equipment. The system uses a web-based health indicator and is integrated with SMS for regular reporting of vaccine stock levels and vaccine refrigerator status. The problem with the system is that it requires internet and it is guaranteed in remote areas.

Junshan et al (2020) developed a highly efficient storage and phase change material freezing device. The system employs thermoelectric cooling technology and maintained temperatures within 3-5℃ all the time. The authors recommended that the sign should be revised in the commercialization phase to improve the easiness of assembling the device and reduce the desk accumulation at the fan area

A design of a photovoltaic system using thermoelectric Peltier cooling for vaccine refrigeration was proposed by Jose and Arturo (2020). The system can store 51 of the Thermo medicines or vaccines. Though the system was designed for operation in remote rural areas the work was not validated. Sasikila et al (2020) developed a portable solar cooler and heater. The power sources were helpful to maintain the reliability of heating and cooling. The authors also used the Peltier module to replace the conventional compressor, condense, and heating coils

Sabah et al., (2020) designed a solar-powered refrigerator that is based on the principles of a thermoelectric module to create hot and cold sizes. The authors utilized cold size for refrigeration purposes while the hot side is rejected to ambient surroundings using heat and sinks. However, the design needs modification in terms of size and selection of material.

Ismail and Mehmet (2019) designed a portable medical cooler with artificial intelligent control by assembling a Peltier, solar battery, and dry accumulator to protect and transport vaccines. Unfortunately, the Peltier draws excessive current and more efficient cooling can be achieved by using materials that may absorb heat faster than the aluminum plates.

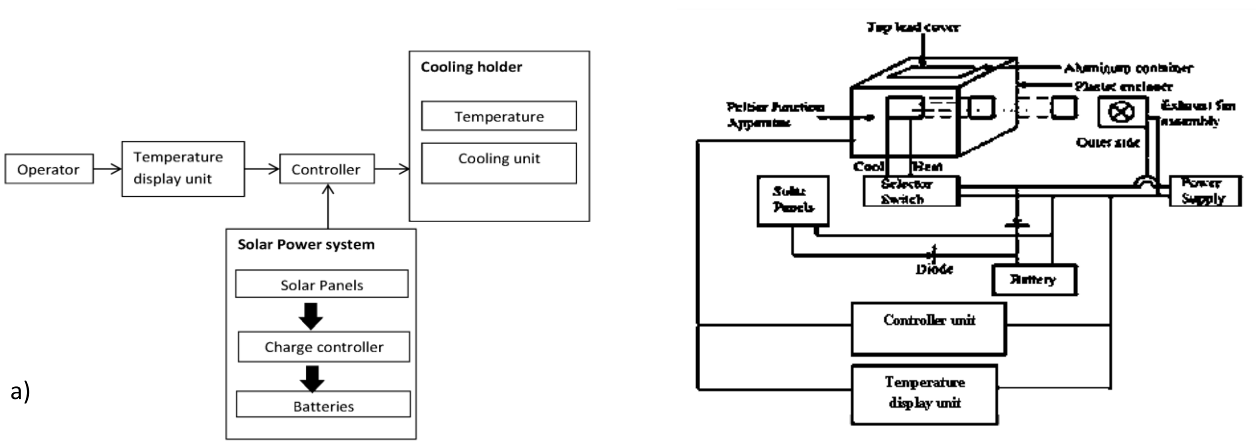
2. Methodology

The block diagram of the system is shown in figure 1.

Materials Used: Both hardware and software requirements are used to achieve this system.

Hardware requirements: Solar panel (300W), battery of 180AH, thermoelectric (12V,10mA, 120W), Temperature sensor (5V,20mA, 0.1W), LED (2V,10mA, 0.04W) and ATMEGA 328P (5V,16mA, 0.08W) were used.

Software requirements include Proteus 8 and C++ programming language, Arduino Integrated Development Environment (IDE) used to write and upload the program.



a)

b)

Figure 1: Block diagram of Intelligent Solar-Powered Immunization Vaccine Storage System

Figure 1a shows the block diagram of an intelligent solar-powered immunization vaccine storage system while figure 1b reveals the internal structure of the cooling holder unit. The Solar Panel was developed through the Solar cells template. The solar cell template was created using plywood, cardboard, tile spacers, and a staple gun. The solar cells were assembled by placing the tabbing wire on all the bottom of the solar cells with a soldering iron and connecting all the solar cells in series. A bus was used to connect the strings of solar cells. The stings of solar cells were glued down to the pegboard using silicon. After hooking all the strings of solar cells in series, the gauge wires were soldered. The solar panel connections were connected to the solar side of the charge controller which was used to determine the maximum power point of the electricity supplied by the solar panel and then the battery was connected to the charge controller. Since the net load of the system circuit is 120.22W the power supply must be not less than 120.22W.

Calculation for the power bank is as detailed below
Expected backup time = 18 hours

Battery bank capacity = Load power x Expected run time 120.22 Watts X 18 hours = 2,163.96 WH

Since system voltage is 12V

Required power banking in AH = 180.3 ≈ 180AH 12V battery = 180AH Battery

Calculation for solar panel rating
Solar panel rating = (Battery bank capacity ÷ Daily sunlight hours) ÷ Unit solar panel wattage

For battery 180AH 12V

Battery bank capacity = 12 x 180 = 2,160WH

Number of solar panels = (2160 ÷ 7) ÷ 100

= 3.08 ≈ 300W solar panel

Then, the cooling holder was developed using a thermoelectric device, to isolate vaccines and have a control system that ensures that temperature is maintained within 2-8℃. The thermoelectric device as shown in figure 1b has a fan internally located on top of the lead cover that draws the ambient air into the device and circulates it through the heat sinks. It then blows through two rectangular holes, allowing the air direction to be adjusted by the solar panels. The heat from the air would be properly transported to the heat sinks as a result of this. The cooling unit, temperature probe, controller, and user interface were mechanically connected to the cooling holder. The temperature probe captures the temperature inside the cooling holder and sends information to the controller. The user interface is where the temperature and energy consumption are displayed.

The system's circuit diagram shown in figure 2 was first designed and simulated using Proteus 8 software. The internal clock signal of the microcontroller (ATMEGA328P) was generated using a crystal oscillator of 8MHz, 10 ohms resistor, and 2 (22pF) capacitors. The internal clock frequency is 2 MHz which is one-fourth of that supplied to the crystal pins and is measured using an oscilloscope. An NPN transistor (BC337) was used to actualize the MOSFET driver. The MOSFET driver activates the buzzer on error detection.

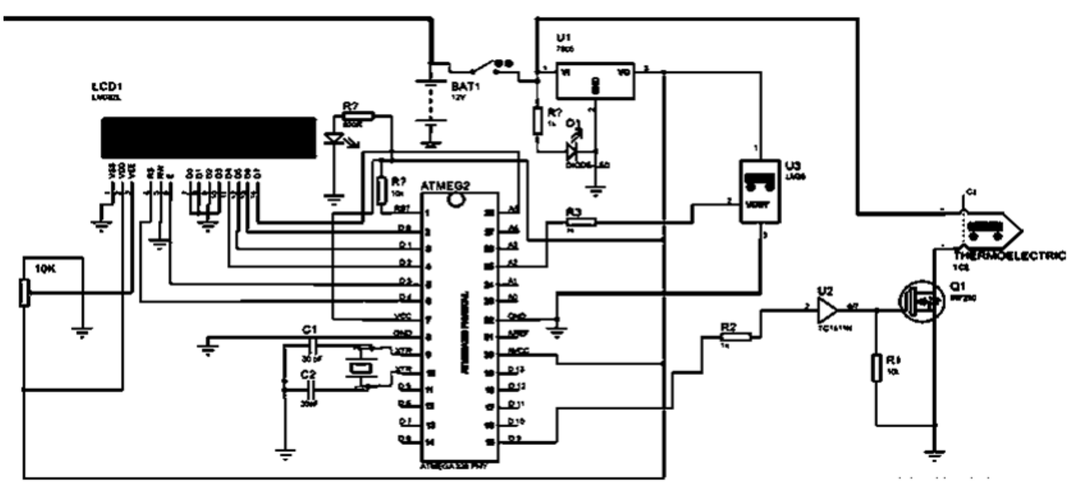


Figure 2: Circuit Diagram of Intelligent Solar-Powered Immunization Vaccine Storage System

3. Implementation and Result

The circuit diagram was then implemented on the breadboard as shown in figure 3 while figure 4 shows the developed prototype of the system. The codes were written in C++ programming language, compiled, and debugged using Arduino IDE before it was copied to the microcontroller using the ATMEL ISP burner. The temperature sensor was tested using a voltage divider circuit and displayed a temperature range between 2℃ and 7℃.

Figure 3: Implemented of the System Circuit Diagram on the Breadboard

Figure 4: Developed Prototype of Intelligent Solar-Powered Immunization Vaccine Storage System

Discussion and Conclusion

The prototype was satisfactorily tested to display temperature within 2 to 7˚C and to trigger a buzzer if not within the stated range.

The systems solar-powered and portability makes it convenient for use of vaccines in rural/ remote area. In Conclusion, an intelligent solar-powered immunization vaccine storage device to help alleviate vaccination challenges in the rural area has successfully been achieved.

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