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Design and Construction of Solar Powered DC Fridge for Storage of Varieties of Fruits and Vegetables

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ABSTRACT : *Preserving perishable goods as soon as they are harvested is the main concern for the farmers in the rural areas of Nigeria for lack of cold storage facilities and absence of electricity supply. To supply ample facilities in the rural areas of the country this project is aimed to provide cold storage facilities incorporating renewable energy (Solar energy) and batteries; which can give a total off grid solution to the problem of storing perishable goods and food security. The prototype of the cold storage system consists of solar Photovoltaic (PV) panels, batteries, charge controller, freezer unit and a DC compressor. The DC compressor, which replaces the AC compressor in the freezer, is the most vital component of the system as it runs the freezer taking DC output from the PV panels. The power supplied from the PV panels simultaneously runs the DC compressor and charges the batteries through the design charge controller. The batteries give back up and run the DC compressor at night in the absence of solar energy. The system also has a keypad where range of temperature values can be inserted to be control the cooling of the freezer by the compressor. The system has been developed and implemented at the JOSEPH SARWUAN TARKA University, Electrical and Electronic Engineering building block where all the tests was carried out and the results show that the system to can be used for fruits and vegetable storage.*

KEYWORDS: *Agriculture produce, charge controller, solar PV, microcontroller and temperature controller.*

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I. INTRODUCTION

A refrigerator is a cooling appliance which comprise of a thermally insulated compartment and a mechanism to transfer heat from the fridge to the external environment, cooling the contents to a temperature below ambient (room temperature) [7]. Refrigerators are generally used at homes, restaurants and supermarkets to store foods which deteriorate at ambient temperatures, and also to keep water and other drinks cold. In hospitals and industries, they are used to store drugs and chemicals which require being stored under certain low temperatures, because spoilage from bacterial growth and other processes are much slower at low temperatures. Before the invention of refrigerator Icehouses were used to provide cool storage for most of the year. After that, the first known artificial refrigeration was demonstrated by William Cullen at the University of Glasgow, Scotland in 1748. In 1805, Oliver Evans designed refrigerator based on a closed cycle of compressed ether, his invention represented the first effort to use simple vapor instead of vaporizing a liquid. In 1857, James Harrison introduced vapor-compression refrigeration to the brewing and meat packing industries. By the beginning of the 20th Century, all refrigerators use the vapor-compression refrigeration cycle till date [5].

The design for contemporary refrigerator is based on two basic laws of physics: first, which is; heat flows from warmer material to cooler materials and never the reverse and second is; pressure decrease of a gas lead to temperature decrease. The refrigeration systems typically include a compressor, a condenser, an expansion valve (capillary tube), and an evaporator. All of these components interconnected to form a fluid circuit. Cooling is accomplished through evaporation of a liquid refrigerant under reduced temperature and pressure [6].

Cold storage of fruits and vegetables was used extensively by our ancestors to keep food after the harvest season. In modern times, the all year round availability of fresh produce in the supermarket has reduced the use of home storage, however, even today there are benefits to home storage. Home gardeners often have excess fruits and vegetables that cannot be consumed immediately but would store well. Even people without home gardens can buy food in season when it is fresh and inexpensive and then store it at home until a later date. Farmers of perishable produce can store these produce in controlled cool room for later date too. Once harvested, fruits and vegetables must be stored under proper conditions and these can be classified into four groups: fruits and vegetables that require cold, moist conditions, vegetables that require cool, moist conditions, vegetables that require cool, dry conditions and vegetables that require warm, dry conditions. Fruits and vegetables that require cold, moist conditions can be store between 32^{o}F and 50^{o}F temperature which elongates their life span for days for some, weeks for other and months for the rest. Vegetables that require cool, moist conditions that require minimum temperature of 40^{o}F to 70^{o}F, this storage temperature increase their storage life in days and weeks. Vegetables that require cool, dry conditions require temperature 32 which make them last for 6-7months. Vegetables that require warm, dry conditions require temperature of 50^{o}F to 60^{o}F can last for 2-6 months [15]. From this summary it shows that the average temperature of vegetables and fruits ranges from 32F to 60F.

This project design and constructs a DC fridge focuses on utilizing the above principles used in contemporary refrigerators to build a circuitry to control a DC fridge. This DC fridge can be used in homes and outdoor activities and areas where there is no electricity and for the delivery of special drugs to hospitals in remote places, but in this research we focus on using on agricultural produce. The other capability of the design is to select any temperature range for any selected fruit or vegetable.

There are several attempts to control fridge using solar PV. In [8], review on standalone solar refrigerator powered by DC motor was done. Their proposed model was a refrigeration system whose conventional compressor was replaced by DC compressor. The DC compressor was then powered by DC source which was produced by solar panel. The remaining cycle operate like conventional refrigeration system. [14] researched on design and fabrication of thermoelectric solar refrigerator that utilizes the Peltier effect to refrigerate and maintain a selected temperature. The requirements were to cool the refrigerator volume to a temperature within a time period of 2 hours and provide retention coldness for at least half an hour. This fabricated project also utilizes the solar energy to run the thermoelectric system and also electrical power supply. [7] worked on development and performance evaluation of a solar energy based portable micro-cold storage where the conventional alternating current (AC) compressor of a freezer was replaced by a DC compressor. The solar energy was used to energize the refrigeration unit of the system as well as to charge the batteries which were used at the nighttime or the daytime when sunshine is not available. The major components of the system are solar PV panels, a deep freezer, a DC compressor-based refrigeration unit and batteries. [3] researched on analysis key to performance of refrigerator prototype with photovoltaic, this study is a preliminary study which focused on the calculation and analysis of coefficient of performance (COP) of the refrigerator. The results obtained were to show that the photovoltaic arrays can provide energy continuously during high solar intensity (during the day). The performance of the refrigerator is quite good, with an average COP of 3.2. [10] researched on solar powered DC refrigerator for small scale applications which uses PV units to convert sunlight into electricity. A DC compressor of 12 V/80 W, battery of 12 V/50 Ah, a pair of 12 V/175W solar panels connected in parallel to power a 10 A charge controller was used for the refrigerator. The control and monitor the ON/OFF states of the DC compressor was achieved using ATMEGA16 microcontroller with temperature, weight and momentary sensors interfaced together with C language programmed in to ATMEGA16 microcontroller. [4] designed, developed a portable thermometric refrigeration system that uses a thermometric module as a cooling generator along with insulated cabin, battery and charging unit which maintains the temperature of vaccines at the temperature range of 8℃ to 13℃. The design was based on the Peltier effect which employed a device called Peltier device that was used for the purpose of cooling. In 2023, [17] design and fabrication of a solar powered portable thermoelectric with the goal study which will create a functional thermoelectric refrigerator that uses the peltier effect to cool and maintain a low temperature. The research aim at identifying the best heat sink through thermal analysis of various heat sources in order to maximize heat transfer efficiency and improve coefficient of performance (COP) using solar energy as the power source. [16], a refrigerator cabinet was fabricated with inner storage container within the walls of the refrigerator cabinet that can store four liters of water to maintain the temperature of the freezer of refrigerator as icepacks which maintains the coldness of the freezer during the night or during low sunny days. The design uses, PIC18f microcontroller which is interfaced with temperature, voltage and current sensors to control temperature and power of the refrigerator during sunny hour, when solar energy is used to power the system.

II. MATERIALS AND METHODS

The block diagram of the solar powered dc fridge for storage of varieties of fruits and vegetables is shown in figure 1.

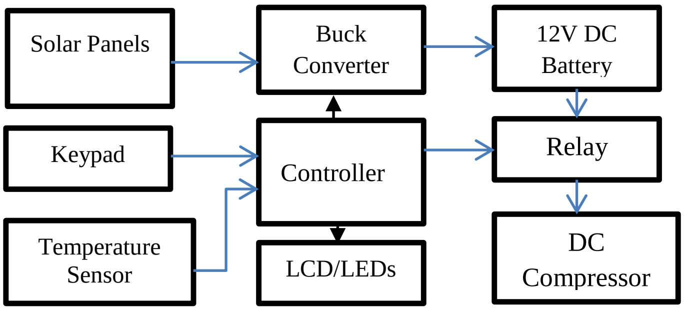


Figure 1: Block Diagram of the DC Fridge.

Figure 2 shows the circuit diagram of the solar powered DC fridge for storage of varieties of fruits and vegetables. The system comprises of two units: the temperature control unit and the solar power control unit. The temperature control unit is made of temperature sensor and keypad. The keypad is made of four buttons to either increase or decrease the upper and lower temperate limit of the rated temperature with is pre-set to 10℃ and 0℃ respectively. The first button is to increase the upper temperature while the second is to decrease the upper temperate level. The third button is to increase the low temperature limit while the fourth button is to decrease the upper temperature limit respectively. Whichever value the upper and lower is set to the system automatically uses that range to control the temperature of the fridge. The solar control unit is made of the solar PV, charge controller circuit (buck converter) and battery. The solar PV supplies voltage above 12Vdc to the buck converter circuit, the buck converter converters this voltage to a rated 12Vdc to the direct drive DC compressor via relay. The temperature of the fridge will start at the room temperature 27℃ which is always higher than the upper limit temperature of storing fruits and vegetable, the controller will connect the direct drive to the solar power through battery being charge using the buck converter. The fridge temperature will continue to drop till it reaches the set lower limit temperature then the controller will turn off the direct drive using the relay. The fridge temperature will be allow to maintain itself with the help of the ice park already frozen in the fridge which will help in the slow increment of the fridge temperature while the direct drive is off. But when the fridge temperature exceeds the set upper temperature limit the controller will turn on the direct drive again as long as there is charge in the battery from the solar PV.

Figure 3 shows the flow chart of the system which is divided into two unit figure 3a and figure 3b. Figure 3a shows the flow chart of the temperature control unit of the solar powered DC fridge for storage of varieties of fruits and vegetables. When the fridge is turned ON, the temperature sensor measures the internal temperature of the fridge and sends a signal (value) to the microcontroller unit (MCU). The MCU compares this temperature value to the preset temperature levels selected using the keypad. If the measured temperature is greater than upper set limit then the MCU sends control signal to the relay which triggers ON the DC compressor. When the compressor starts working cooling commence in the fridge, therefore temperature in the fridge starts to drop as the compressor is turned on. The MCU runs a continuous check on the temperature comparing the temperature to the preset levels each time the check is run. When the Temperature level drops below the set lower limit temperature the MCU sends a signal to the relay which turns OFF the DC compressor. When the compressor is turned off, the temperature in the fridge begins to rise after a while. As the temperature rises, in-between temperature levels lower and upper limit temperature range the compressor is kept off until when the temperature gets to the upper limit temperature level then the microcontroller signals the relay to turn on the compressor again and these process is repeated over and over again. While Figure 3b shows the buck charge controller section of solar powered DC fridge for storage of varieties fruits and vegetables. The microcontroller unit (MCU) sets the operating voltage levels to between 18V – 12V as input to the charge controller. MCU initializes the pulse width modulation (switching frequency), then reads the input voltage and compares it to the preset input voltage level. If the input voltage (V_{in}) is greater than the desired voltage value of 12 and less than desired voltage of 18V, then the MCU reduces the duty cycle and the output voltage is reduced 12V. But, if the voltage value is outside this range the buck converter charge controller output no voltage (0V). The MCU monitors and compares the input voltage to the preset voltage level. This process is repeated continuously.

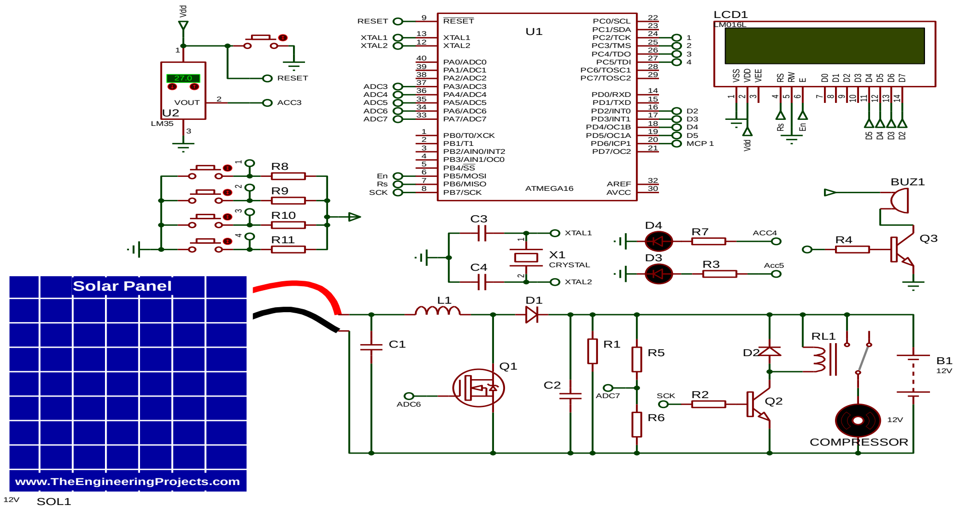
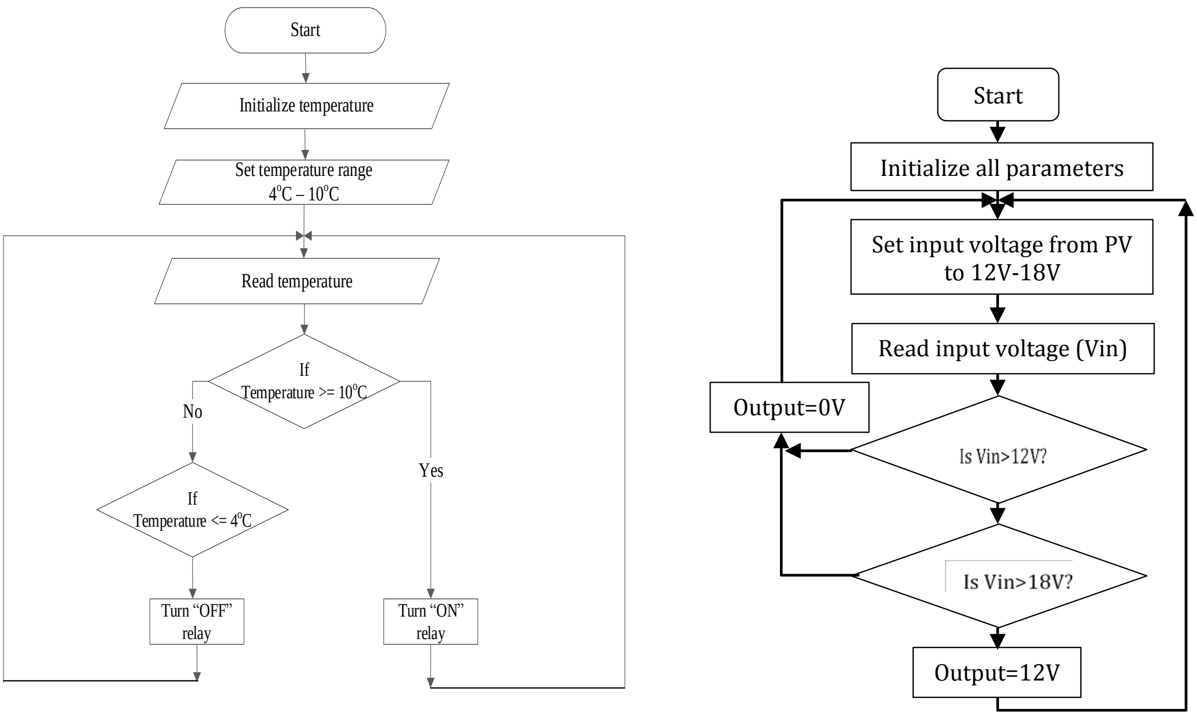


Figure 2: Circuit Diagram of the DC Fridge.



(a): Temperature Control Flow Chart (b): Buck Converter Flow Chart

Figure 3: Flowchart of the DC Fridge

III. RESULTS AND DISCUSSION

The following figures 4 to 9 show the results obtained while testing the DC Fridge using this methodology. Figure 4 shows when the battery voltage is below the rated voltage of the battery so the charge controller charges the battery using the power generated by solar PV while Figure 5 shows when the battery is fully charge by the power generated by the solar PV. Figure 6 shows the Initial Display of the temperature unit of the system when the system is turned ON, while Figure 7 shows the selection of the Upper and Lower Temperature Levels range for the testing 4-10ºC was used. Figure 8 shows when the freezer Temperature is 6ºC so the DC Compressor will continue to Running. Figure 9 shows the DC Compressor is Turned OFF via relay as the Freezer Temperature reaches 4ºC which is the lower set limit of the freezer temperature. Figure 10 shows the Compressor been Turns On as Temperature Rises above the Upper temperature limit. Figure 11 shows the complete setup using 100Ltr Thermocool Deep Freezer to test the designed electronic circuit. Figure 12 shows the Graph of temperature with respect to Time from the temperature Data logger kept inside the fridge during testing, which depict the control of temperature for nine days when the system is working.

Figure 4: when the battery voltage is below the rated voltage the charge controller charge the battery via solar PV

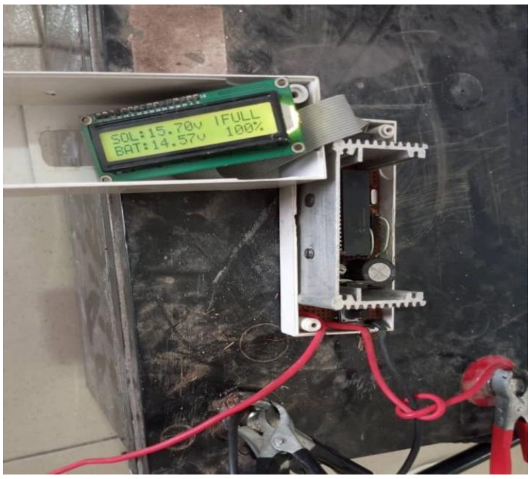


Figure 5: when the battery is fully charge via solar PV

Figure 6: Initial Display when Fridge is turned ON

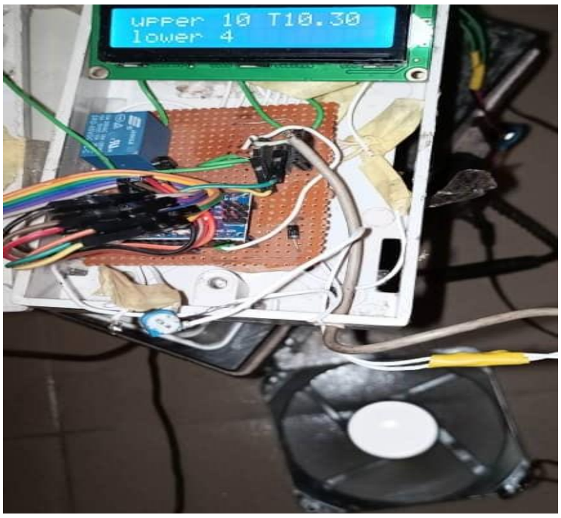


Figure 7: Upper and Lower Temperature Levels Initialized

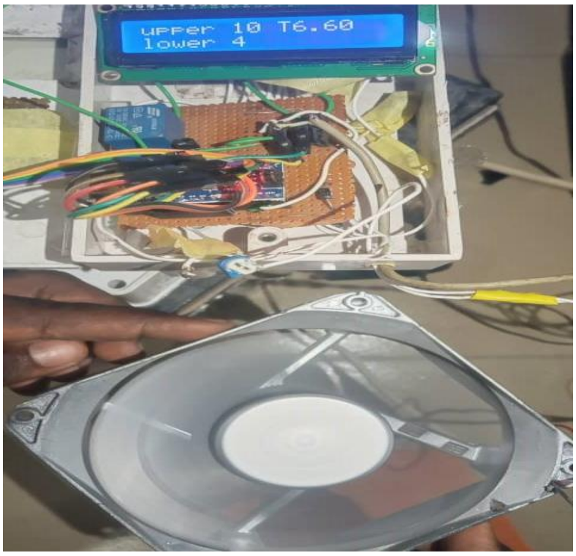


Figure 8: Fridge Temperature is 6ºC Compressor Running

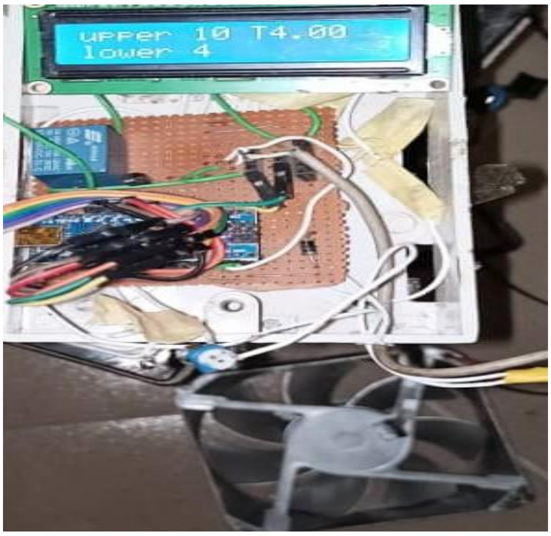


Figure 9: Compressor is Turned OFF as Fridge Temperature Reaches 4ºC

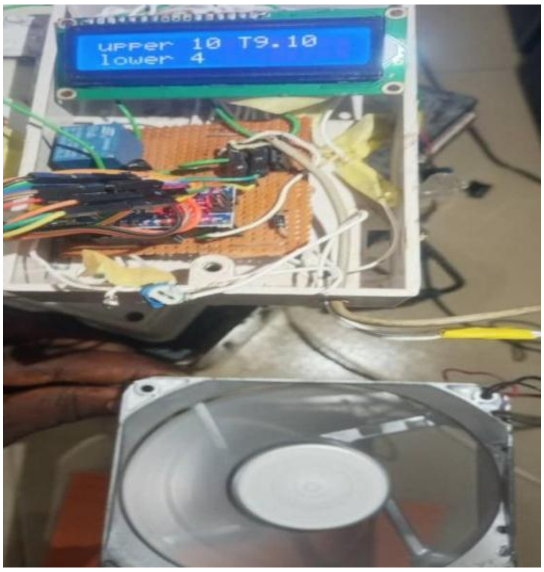


Figure 10: Compressor Turns On as Temperature Rises to Upper

Figure 11: The Complete Design using 100Ltr Thermocool Deep Freezer

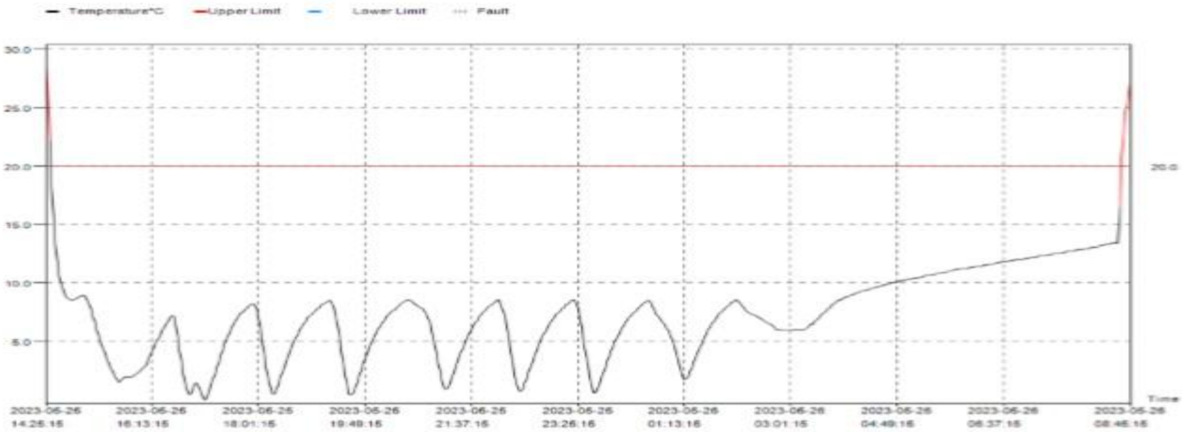


Figure 12: Graph of Temperature With Respect To Time from the Temperature Data Logger Kept Inside the Fridge during Testing

IV. CONCLUSION

This is a result of the achievement of objectives of this research earlier stated. The monitoring and control unit of the freezer add to the efficient utilization of the system. The DC output from the PV panels controlled by a charge controller simultaneously runs the DC compressor and charges the battery. An operating temperature was set and the freezer was observed to operate perfectly according to the temperature settings, turning on the compressor and off when required. The results obtained showed that the design can be applied in the design of DC fridge of various sizes and applications.

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