JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

LOW – COST SOLAR POWERED SMART COLD STORAGE FOR FARMERS

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Abstract : A low-cost solar-powered smart cold storage system for agricultural applications. The system utilizes photovoltaic energy with an energy-efficient cooling unit to provide reliable operation in rural and off-grid areas. A multi-rack architecture with distinct temperature zones enables storage of diverse perishable products under optimal conditions. Integrated sensors are used for real-time temperature monitoring and control. The proposed design minimizes post-harvest losses, reduces energy dependency on conventional sources, and enhances storage efficiency. The system offers an economical and sustainable solution to improve farmers' productivity and income.

IndexTerms **- Solar-powered cold storage, Photovoltaic (PV) system, Smart agriculture, Temperature monitoring, Energy-efficient refrigeration, Post-harvest loss reduction, IoT sensors, Sustainable farming**

I. Introduction

Post-harvest losses in agricultural products remain a significant challenge, particularly in developing regions where access to reliable cold storage infrastructure is limited. Perishable commodities such as fruits, vegetables, dairy products, and flowers require controlled temperature conditions to maintain quality and extend shelf life. Conventional cold storage systems are capital-intensive and depend on uninterrupted grid power, making them unsuitable for rural and remote areas. In addition, frequent power outages further reduce the effectiveness of traditional refrigeration systems. To address these issues, renewable energy-based solutions, particularly solar photovoltaic (PV) systems, have gained considerable attention due to their sustainability and cost-effectiveness. This work proposes a low-cost solar-powered smart cold storage system integrated with temperature monitoring and control mechanisms. The system is designed with multiple storage racks, each maintaining distinct temperature zones to accommodate different types of agricultural produce.

The proposed solution aims to reduce post-harvest losses, improve storage efficiency, and provide an affordable and reliable alternative for small and medium-scale farmers. By leveraging solar energy and smart monitoring techniques, the system ensures energy-efficient operation and enhanced preservation of perishable goods.

II. literature survey

[1] A. Ashish et al. A low-cost solar PV-based cold storage system was proposed for small-scale farmers. The system uses photovoltaic panels, battery storage, and a DC compressor for efficient cooling. The design focuses on reducing dependency on grid electricity in rural areas. Experimental results showed significant reduction in post-harvest losses. The system is portable and suitable for remote agricultural locations. It provides an economical and sustainable solution for food preservation.

[2] J. G. M. Alonzo et al. They designed a solar-powered low-cost cold storage system for agricultural products. The system integrates solar panels with a vapor compression refrigeration unit. It maintains consistent temperature levels for different perishable goods. The study demonstrated improved storage life and reduced spoilage. The design is optimized for energy efficiency and affordability. It is suitable for developing regions with limited power supply.

[3] S. Kumar et al. This work presents a smart solar PV cold storage system using a modified split air conditioner. IoT sensors are used for real-time monitoring of temperature and humidity. The system allows remote control and automation of storage conditions. It reduces operational costs compared to conventional storage systems. The results show improved performance and reliability. It is highly beneficial for modern smart farming applications.

[4] H. Hendra et al. This review paper discusses the role of solar cold storage systems in India. It highlights the importance of renewable energy in agriculture. The study compares different solar cooling technologies and their efficiency. It emphasizes cost reduction and sustainability benefits. The research shows that solar storage improves farmers' income. It also reduces dependency on conventional energy sources.

[5] G. Hussain et al. The authors developed and evaluated a solar-powered cold storage system for perishable goods. The system integrates advanced cooling techniques with solar energy. Performance analysis shows stable temperature control under varying conditions. The study demonstrates reduced food spoilage and energy consumption. It is designed for high efficiency and reliability. The system supports sustainable agricultural practices.

[6] S. D. Gowda et al.. An AI-integrated solar-powered cold storage system was proposed with advanced environmental sensing. The system uses intelligent algorithms to optimize temperature and humidity levels. It ensures efficient energy utilization and improved storage performance. Real-time monitoring enhances system reliability. The study highlights the benefits of automation in cold storage. It is suitable for next-generation smart agriculture..

[7] R. Badia-Melis et al.. This study focuses on new trends in cold chain monitoring systems. It highlights the use of sensors and IoT for real-time data collection. The system improves transparency and efficiency in storage and transportation. It reduces product loss through continuous monitoring. The research emphasizes the importance of data-driven decision-making. It enhances overall supply chain performance.

[8] Y. Zhang et al. The authors developed a solar-powered cold storage system for agricultural products. The system uses renewable energy to maintain required temperature conditions. It is designed for energy efficiency and low operational cost. Experimental results show improved preservation of perishable goods. The system reduces dependency on fossil fuels. It is suitable for rural and remote applications.

[9] Patil et al. This paper reviews recent developments in solar-powered refrigeration systems. It analyzes different cooling technologies and their performance. The study highlights the advantages of solar energy in cold storage applications. It focuses on improving efficiency and reducing environmental impact. The research supports the adoption of renewable-based storage systems. It provides insights for future technological advancements.

[10] S. Kumar and H. Singh The authors proposed an IoT-based controlled environment storage system for post-harvest management. The system integrates temperature and humidity sensors with cloud-based monitoring for real-time data analysis. It enables remote supervision and automated control of storage conditions. The study shows a significant reduction in spoilage and improved storage efficiency. The system is energy-efficient and suitable for integration with solar-powered units. It provides a smart and scalable solution for modern agricultural storage applications.

III. SUMMARY OF LITERATURE SURVEY

The literature survey shows that solar-powered cold storage can help farmers reduce post-harvest losses and preserve fruits and vegetables for a longer time. Existing research uses different cooling methods, such as Peltier cooling, solar refrigeration and evaporative cooling, to maintain suitable storage temperatures.

The studies also highlight the use of sensors, microcontrollers and IoT technology for automatic temperature monitoring and cooling control. However, some existing systems are expensive and difficult for small-scale farmers to operate.

To overcome these challenges, our project uses solar energy, DHT11 sensors, Arduino Uno, relay modules and Peltier cooling units to maintain the required temperature in two storage racks. An LCD displays the temperature and battery voltage, providing an affordable and simple cold-storage solution for farmers.

III. PROBLEM IDENTIFICATION

Small-scale farmers face major difficulties in storing harvested fruits and vegetables due to the high cost of cold storage facilities and expensive electricity consumption. In rural areas, unreliable power supply makes it difficult to maintain the required storage temperature, resulting in food spoilage and post-harvest losses. Manual temperature monitoring also makes it difficult to maintain proper storage conditions continuously. Therefore, there is a need to develop a low-cost, solar-powered smart cold storage system that provides automatic temperature monitoring and cooling, reduces dependence on conventional electricity and helps farmers preserve their agricultural products for a longer period.

IV. OBJECTIVES

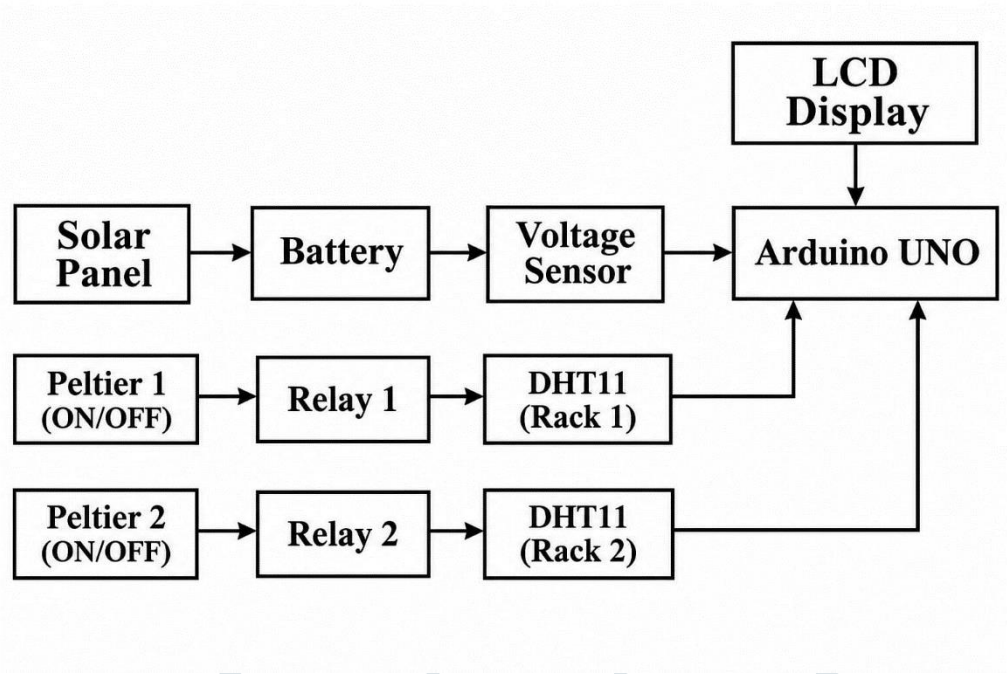
- To develop a low-cost cold storage system using solar energy as the primary power source.
- To maintain suitable temperatures for preserving fruits and vegetables.
- To continuously monitor the temperature in two separate storage racks using DHT11 sensors.
- To control the Peltier cooling units automatically using Arduino Uno and relay modules.
- To monitor battery voltage using a voltage sensor.
- To display rack temperatures, battery voltage and cooling status on a 16×2 LCD.
- To reduce electricity consumption and minimize post-harvest losses.
- To provide an affordable and energy-efficient storage solution for small-scale farmers.

V. METHODOLGY

The proposed system, Low-Cost Solar-Powered Smart Cold Storage for Farmers, is designed to preserve fruits and vegetables using solar energy and automatic temperature control. Initially, the solar panel converts sunlight into electrical energy, which is regulated through a solar charge controller and stored in a rechargeable battery. The stored energy is used to operate the cooling system and electronic components. The system consists of two separate storage racks, each equipped with a DHT11 temperature sensor and a Peltier cooling unit. The DHT11 sensors continuously measure the temperature inside both racks and send the readings to the Arduino Uno. The Arduino compares the measured temperatures with the predefined temperature limits and controls the Peltier cooling units through relay modules. When the temperature rises above the set limit, the corresponding cooling unit switches ON and operates until the required temperature is reached. A voltage sensor is used to monitor the available battery voltage and check the power condition of the system. A 16×2 I2C LCD displays the temperature of both racks, battery voltage and cooling status. A staggered

switching mechanism is also used to avoid starting both cooling units simultaneously, reducing sudden current demand. Finally, the complete system is tested by observing temperature variations, automatic cooling operation and battery voltage. This methodology aims to provide an affordable, energy-efficient and reliable cold storage solution for small-scale farmers.

VI. BLOCK DIAGRAM



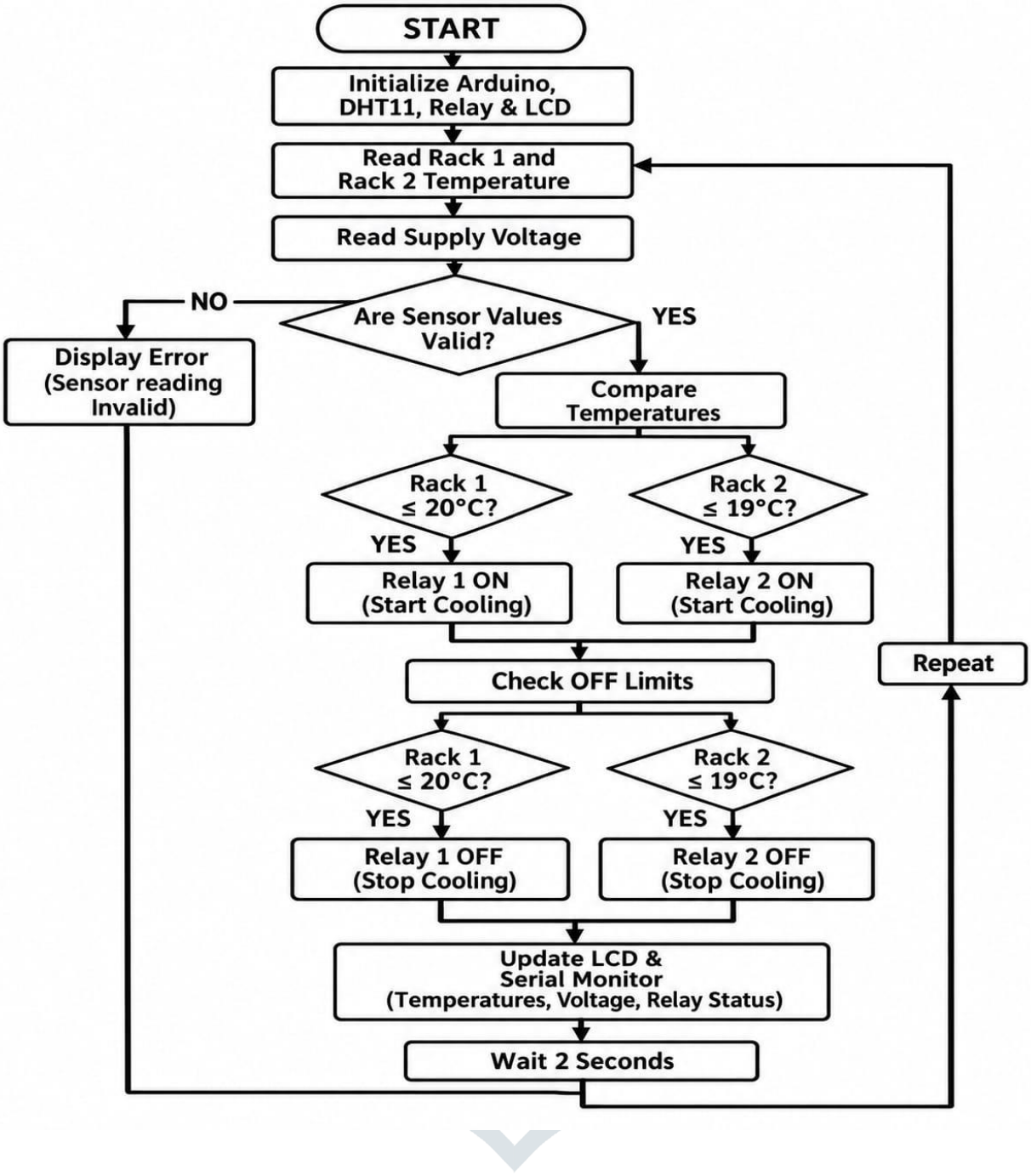
The solar panel is used to convert sunlight into electrical energy, which is stored in the battery for continuous power supply. The voltage sensor measures the battery voltage and sends the information to the Arduino UNO. This helps to monitor the battery level and manage the power supply of the cold storage system.

The Arduino UNO acts as the main controlling unit of the system. It receives the voltage, temperature, and humidity readings from the sensors and processes the collected data. The LCD display is connected to the Arduino UNO to display the battery voltage, temperature, and humidity values, allowing the user to monitor the storage conditions easily.

Two Peltier modules are used to provide cooling inside the cold storage system. Relay 1 and Relay 2 control the ON/OFF operation of the respective Peltier modules. Based on the temperature readings, the Arduino UNO controls the relays to switch the cooling modules ON or OFF as required. This helps maintain the desired temperature and reduces unnecessary power consumption.

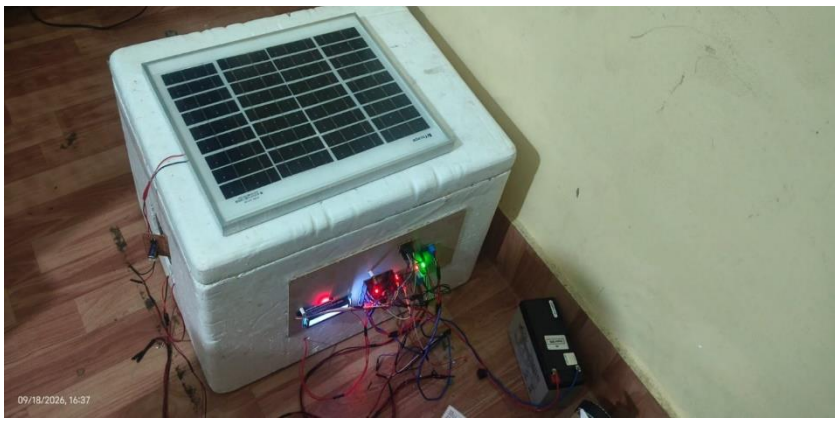
Two DHT11 sensors are used to monitor the temperature and humidity levels of Rack 1 and Rack 2 separately. The sensors continuously collect environmental data and send it to the Arduino UNO for processing. Based on these readings, the system monitors the storage conditions and controls the cooling operation. This helps maintain suitable conditions for storing agricultural products, reduces food spoilage, and improves the efficiency of the solar-powered smart cold storage system.

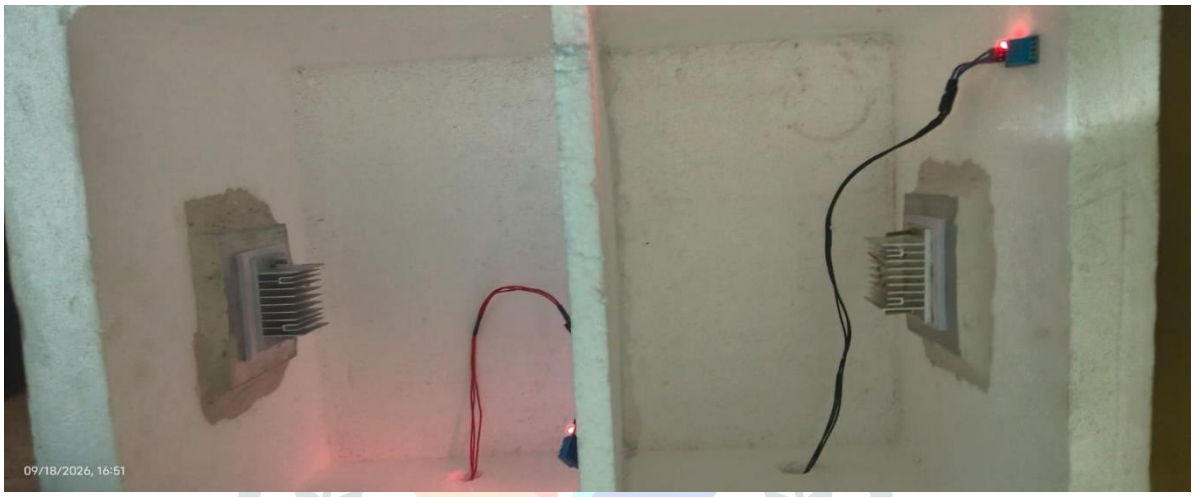
VII. FLOW CHART



- Based on the provided flowchart, the process begins by initializing the Arduino, DHT11, relay, and LCD components. The system then reads the temperature for both Rack 1 and Rack 2, followed by reading the supply voltage. Next, a decision block checks whether the sensor values are valid. If the values are invalid ("NO"), an error message stating "Sensor reading Invalid" is displayed, and the loop skips to updating the display and waiting. If the sensor values are valid ("YES"), the system proceeds to compare the temperatures of the racks.
- For Rack 1, if the temperature is less than or equal to 20 degree ("YES"), Relay 1 is turned on to start cooling. Similarly, for Rack 2, if the temperature is less than or equal to 19 degeree ("YES"), Relay 2 is turned on to start cooling. Following this, the system checks the OFF limits for both racks. If Rack 1's temperature condition or Rack 2's temperature condition is met, the respective relay (Relay 1 or Relay 2) is turned off to stop cooling.
- After managing the relays, the system updates the LCD and Serial Monitor to show the current temperatures, voltage, and relay status. It then pauses for a duration of 2 seconds before repeating the entire monitoring cycle by looping back to read the rack temperatures.

VIII. RESULTS





The proposed Low-Cost Solar-Powered Smart Cold Storage System provides an affordable solution for preserving fruits and vegetables. Solar energy supplies power to the cooling system and electronic components. The temperature and humidity sensors continuously monitor the storage conditions. The microcontroller automatically controls the cooling system based on the sensor readings. The system helps maintain suitable storage conditions, reduce electricity consumption and minimize manual effort. It can also help farmers reduce post-harvest losses and increase the shelf life of agricultural products.

IX. FUTURE SCOPE

1. IoT-Based Remote Monitoring and Control: The system can be enhanced by integrating IoT capabilities using controllers like ESP32, enabling users to monitor temperature, humidity, and system status remotely through mobile or web applications. This allows real-time control and quick response to any abnormalities.

2. AI-Based Smart Temperature Optimization: Artificial Intelligence algorithms can be implemented to automatically adjust cooling levels based on the type of stored products, environmental conditions, and usage patterns, improving energy efficiency and storage performance.

3. Advanced Solar Panel Efficiency: Future systems can utilize high-efficiency Solar Panel technologies such as monocrystalline panels to increase power generation, especially in low-light conditions, reducing dependency on battery backup.

4. Hybrid Energy System Integration: The system can be upgraded to support hybrid energy sources like solar combined with wind or grid power, ensuring continuous operation even during prolonged periods of low sunlight.

5.Multi-Zone Temperature Control: Each rack in the storage system can be equipped with independent temperature and humidity control, allowing different products to be stored under their optimal environmental conditions, thereby improving preservation quality.

X. APPLICATIONS

- Post-Harvest Storage of Agricultural Products: The system is widely used for storing freshly harvested fruits and vegetables, helping to maintain their freshness and nutritional value for a longer duration.
- Dairy Product Preservation: It can be used to store milk and dairy products at controlled temperatures, preventing spoilage and ensuring safe consumption.
- Storage of Flowers and Floriculture Products: The system is suitable for preserving flowers such as roses and lilies, maintaining their quality and extending their market life.
- Use in Rural and Remote Areas: Powered by a Solar Panel, the system is ideal for villages and off-grid locations where electricity supply is unreliable or unavailable.
- Small and Medium Farmer Support: It provides an affordable and easy-to-use storage solution for small-scale farmers, helping them reduce losses and increase profits.

- Cold Storage for Root Crops: It is effective in storing root crops like potatoes, carrots, and onions, preserving them for extended periods without quality degradation.
- Food Supply Chain and Transportation: The system can be adapted for use in cold chain logistics to maintain temperature during transportation of perishable goods.
- Retail and Local Market Storage : Shopkeepers and local vendors can use this system to store products safely, reducing wastage and improving product availability.
- Disaster Relief and Emergency Storage: It can be deployed in disaster-affected areas to preserve food supplies using renewable energy sources.

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