Application of Intelligent Solar Panel Repositioning System for Improved Charging of Battery Cells

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Abstract — This study presents intelligent re-calibration of mechanical and power electronic systems to carryout detection of the position of highest sunlight intensity; to intelligently repositioning of the solar panel to that direction for improved charge rate over short time ranges. The study also puts forward an additional feature being the deployment of IoT technology and internet communication protocols to achieve remote battery level monitoring and supply deactivation from an inverter driven by batteries to loads. The system was tested on two premises, the charge time for fixed panel as well as the charge time for sunlight position tracking panel. It was observed that the intelligent repositioning system offered significant reduction in the overall charge time. The battery level monitoring and power supply deactivation intelligence were tested and observed to offer improvements to the overall efficiency of the system.

Keywords — Intelligent Solar Panel, Repositioning, Improved Charging, Solar Energy Battery Cells.

I. INTRODUCTION

The sun deposits over 130,000 TW of radiation on the surface of the Earth, which exceeds human needs even in aggressive energy demand scenarios. Since it expands beyond 0.18% of land mass, with about 15% efficient solar conversion systems would provide over 25 TW of power, this provides twice as much the world’s fossil energy demand. The above information provides an energy flow that supersedes what the current human technology can achieve. [1]. Because of the nature of solar energy, two operational components are required to operate a solar energy generator. They are the solar collector and the solar storage unit. The solar collector absorbs the radiation that falls on the Photovoltaic panels and converts it to the needed energy for usage. Photovoltaic panels produce electricity by converting energy from the rays of the sun into electrical current. However, the capacity of maximizing the output of electricity of solar panels has been a huge problem for a very long time. This is because the sun is not stationary; it changes position, rising from the east and setting in the west; this makes it hard for solar panel systems to efficiently provide power. Solar Photovoltaics are growing quickly, and worldwide power production capability has reached 227 gigawatts (GW) by the top of 2015. [2] reports that since 2000 put in capability has seen an associate growth of fifty-seven percent. The world’s power output in terms of PV capability during a twelve-month period in 2014 is currently on the far side of Two Hundred Tera- Watt-hours of electricity. The power produced by a single panel is usually insufficient for commercial use; therefore, panels are combined to form an array [3],[4]. PWM and MPPT are widely used in the solar power generation sector and are equally efficient charging systems. The choice of either the PWM or the MPPT technique is not a question of which is a more efficient charge control method, but which controller suits a particular system’s design [5]. Maximum Power Point (MPPT) is the ratio of current to voltage that is required to produce maximum power. Depending on irradiation constraints, there are usually variations all through the day [6],[7]. [8],[9] presented a system designed to observe per time, the Solar Photovoltaic System (SPV) outputs utilizing the Internet of Thing (IoT). The essential parameters of the SPV system that will be sensed using the required sensors are Voltage, Current, and panel temperature, while the most crucial parameter that is the Power of the SPV will be computed. With the help of node MCU Esp8266, these variables are transmitted through the cloud. An android application is developed to fetch the cloud data. This software is built on android platform for up- to-time observance of the panel output like Temperature, Current, Power, and Voltage [8],[10]. The system proposed by [8],[9] are isolated or single panel systems. [11] had proposed a smart monitoring device (SMD) designed to control remote solar farms/ solar arrays. A large number of panel installations are fixed solar arrays that are carried out particularly in our country today. This in itself is troublesome due to the fact as a measured day progress, the solar moves away from the position of the sun light that reduces the output power of that particular panel. The best way to overcome this problem as presented by [12] is to adapt a repositionable solar panel making use of a Solar monitoring mechanism. [13] postulates that using some mathematical algorithms, the sun’s coordinates from the solar tracker and the direction of the average sun path from the location of the tracker can be determined at any time. [14] implemented a single axis tracking of the solar PV module along with the automated cleaning mechanism. For tracking the sun, the module was
made to rotate 360 degrees angle in a day [15]. The module initializes rotation from a vertical position at the time that sunrise is oriented eastward, rotating at 15 degrees per hour. The systems only implemented wireless communication for transmitting data such as panel fault, repositioning alert as well as temperature readings, but none for battery level indications.

However, the goal of this study is to design and evaluate an intelligent solar system based on a sunlight tracking system that can maximize the utilization of solar energy to proffer power solution.

II. MATERIALS AND METHODS

The proposed system is an Intelligent Solar Panel Repositioning System for Improved Charging of Battery Cells. The concept behind the execution is tracking the point of highest light intensity to generate faster charge on the solar panel in a short period. This system moves a step further in the direction of remote monitoring of the power generation process. This is achieved through the aid of an IoT board (microcontrollers with Internet connection capabilities as well as other wireless communication facilities), this board employs Wireless Fidelity (Wi-Fi) protocols to network to the web and transmit data in real-time; data which in this sense consists of the power generation data and also the position coordinates of the solar panel [16]. This operation is aimed at determining the optimal charge position for a larger solar farm with the aid of information on one.

A. Materials

1) Hardware

The materials used to design the hardware for the sun intensity tracking mechanism is given in a stepwise manner which constitute of the following parts of the complete system: (1) solar panel power and charge control system (2) panel repositioning mechanical system and (3) the electronic control and IoT system.

2) Solar panel power and charge control system

This system designed makes use of a pair of 20-watt solar panels that is expected to provide a total wattage of 40watt on full light supply over the panels. A good number of factors were considered before arriving at the particular choice of panels being used for the study. These parameters include the electrical load to be driven; which is directly based on the combined choice of the battery used as well as the output capacity of the solar panels, the type of electrical loads; implying if the loads are AC or DC oriented, as well as other mechanical factors like weight and the size of the panels; which are core parameters required so as to achieve agreeable compatibility between the mechanical weight of solar panels that the mechanical structure can carry (Fig. 1). The design used a pair of 12V/20W solar panels each.

3) Battery level indicator

The module employed for this operation is the LM3914 IC. LM3914 is an integrated circuit that senses voltage in 10 levels divided as 10% (very low) to 100% (battery full) and is capable of providing a visual display through directly powering 10 LEDs to signify the voltage levels or by sending the 10 different signals to the microcontroller which is programmed to process the data as battery levels for more graphic screen display. The second option is chosen in this work and an auxiliary microcontroller known as the Arduino Uno is used to process the IC’s power level information.

4) Panel repositioning system

The panel repositioning system chassis is divided into the mobile panel rack and the actuation and adjustment system. The mobile panel rack for holding the solar panels is designed to be moveable. The mobile panel rack is equipped to carry two 20-Watt solar panels. The rack is a rectangular post with a partition made from an angle-iron bar. The panels are fixed to the rack with screws, which are driven sideways to connect each panel to the rack. Two angular-iron bars hang the rack on each side of the structure.

B. Methods

1) Motor driver module

The mobility unit is the part of the system that drives the actuator. It is comprised of the motor driver IC and the direct current (DC) based motors. The mobility unit functions according to the instructions of the processing unit. The microcontroller is responsible for driving the actuator unit.

2) L298N driver module

This L298N motor driver module is the device used as the motor driver. A high-power module is capable of driving any DC motor and even some Stepper Motors. This module is based on an L298 motor driver IC. Fig. 2 shows the schematic diagram of the L298N motor driver module.
3) Sunlight Intensity sensors/light-dependent resistors
Light Dependent Resistors (LDRs) are resistors that are inversely dependent on the level of light incident on their surface, with variable resistances. Cadmium sulfide (CdS), an active semiconductor layer that is deposited on an insulating substrate, is what makes up LDR. The semiconductor layer is lightly doped to allow for the compulsory conductivity level. If there is a sufficiently high frequency of light incident on the LDR, photons absorbed by the semiconductor generate enough energy for the bound electron to jump into the conduction band.

The resulting free electron, thus decreasing resistance, conducts electricity. In this design dissertation, two LDRs are being used as sensors for the light intensity as shown in Fig. 3.

4) The microcontroller unit
The ESP32 Development is a microcontroller and an internet module all in one; this makes it the ideal choice for the implementation of the proposed IoT enabled solar tracking system [18]. This is because it is economical as it performs efficiently in the full range of requirements for both a microcontroller and an internet module while reducing cost. The ESP32 is a 32-bit single 2.4 GHz Wi-Fi-and-Bluetooth enabled chip designed with the ultra-low-power 40 nm technology by TSMC (Taiwan Semiconductor Manufacturing Company). The ability to implement both Bluetooth and Wi-Fi communication is what confirms the ESP32 as an IoT Board. It can also interact with a wide range of peripherals, including capacitive touch, ADC, DAC, I2C, SPI, UART, I2S, PWM and much more. In a broad range of applications and power eventualities, it is designed to give the best power consumption, radio frequency effectiveness, while promising versatility and robustness. See peripheral schematic diagram of ESP32 in Fig. 4.

5) ESP32 design features and specification
The ESP32 is a highly integrated microcontroller chip with built-in antenna switches; radio frequency balloon, power amplifier, and low noise receive amplifier, filters, and power management modules, all of this on a miniaturized board. ESP32’s circuit structure needs only 20 resistors, capacitors and inductors, one crystal and one SPI flash chip. Due to the high integrating nature of ESP32, simple peripheral circuit design is possible. ESP32 can function as a self-contained device or as a slave to a host processor, reducing the operating costs of the communication stack on the main application processor. With its SPI/SDIO or I2C/UART interfaces, ESP32 has the capacity of interfacing with other devices to provide Wi-Fi and Bluetooth connectivity. The ESP32 is capable of dynamically removing external circuit imperfections and adapting to changes in external conditions, due to its advanced calibration circuitries. ESP32 can function reliably in industrial environments, with operating temperatures ranging from −40 °C to +125 °C. The ESP32 implements ultra-low power consumption. The latest features in ESP32 include fine-grained clock gating, diverse power modes, and dynamic power scaling. The power amplifier output is also adjustable, thereby contributing to an optimal trade-off between the range of communication, the data rate and the consumption of power.

6) Programming tool
The tool used for programming both microcontrollers and the Arduino IDE (Integrated Development Environment) is written in C and C++, it is also an open source. It is originally built to write codes to the Arduino series boards but can also be used for other compatible controllers with the aid of third-party communicators. The Arduino IDE is where the codes that serve as the intelligence of the system are written, compiled and sent to the Arduino Uno board as well as the ESP32 CAM.
As mentioned in the preceding section, the ESP32 is also employed as a web server. This means that the board will be configured to store the files that are needed to build the web application pages. Like an actual server, the ESP32 board will respond when it receives a request from the web-client (user accessing the web application from a web browser). In this case, the request will be triggered when the user opens the web page, by a JavaScript function to request the LDR sensor readings to be displayed as position coordinate charts. The web application has been implemented utilizing: HTML, CSS and JavaScript.

The solar panel repositioning system is fully autonomous; operating entirely based on the coded intelligence programmed into the ESP32 IoT Board. As the core processor of the system, all operations are managed by the ESP32. This function is only as efficient as the program embedded into the microcontroller board. The web application codes are quite complex but execute a simple result of displaying the charge operation and rack positioning; the web application build-up is of a complexity that is not covered in the scope of this work.

C. Steps to Implement of Solar Panel Repositioning System
Step 1: System Initialization from power button input signal
   i. Initiate Wi-Fi connection
   ii. Extract Wi-Fi Configuration API and generate IP address for Web server
   iii. Go to Step 9
Step 2: Set all output to default:
   i. Get Battery level data and LDR readings then go to step 9
Step 3: Standby for Charging rate (battery level IC) and Light Intensity (LDR) readings
   i. Get Battery level data and LDR readings then go to step 9
Step 4: Get LDR readings and Check if Light intensity is high
Step 5: If Light intensity is high, go back to step 3; if NO, go to step 7
Step 6: Activate Motor Driver with PWM signals
Step 7: Get LDR readings to check for Light intensity
Step 8: If Light intensity is high, go back to step 3; if NO, go to step 7
Step 9: Activate data streaming at a static IP address of Web server
Step 10: Run Web application on web browser with IP address to access data streaming
III. RESULTS AND DISCUSSIONS

A. Run-time results of sun-light intensity

The repositioning motor relies on an analog stream of data ranging from 0v to 5v to determine the position of the sun itself [19],[20] and further determine which direction on the single axis the panel tray will tilt towards. The serial monitor facility on the integrated development environment provides an added feature to view experimental run-time results. The response of the repositioning motor actuator depends on the analog readings from each of the two sensors. The approach in design used assumes that the single axis is divided into two directions, eastward and westward directions. The behavior of the sensors is shown in Fig. 7.

B. Charge rate comparison

Fig. 8 illustrates the system efficiency of the charge time, being the time required for the system to charge the battery to full capacity. This is relevant to the study and system at times when there is no sunlight supply; and if the battery is not fully charged, there are certainties of not having enough power supplies.

Table I and Fig. 9 illustrate the charge rate curves of both the stationary and optimized charging tests and results. It shows that the solar panel programmed repositioning system offered good results in improving the charge rates of the battery since the intelligent system tracked the highest intensity of sunlight and focused the panel on that direction. The optimized charge time amounted to almost 0.82 hours.
market demand, when the system is commissioned for mass charging. This would without doubt convert itself to a high system.

repositioning methodology. This makes this Solar Panel Modulation System and the proposed light sensing efficient charging of batteries: the Existing Pulse Width Modulation System.

CR is the charge rate without solar positioning; CRSP is the charge rate with solar positioning.

Table I: Charge Rate of Solar System Without Repositioning and With Reposition System

| State of Charge (%) | CR (hours) | CRSP (hours) |
|---------------------|------------|--------------|
| 10                  | 0.18 (11 minutes) | 0.09 (6 minutes) |
| 20                  | 0.26 (16 minutes) | 0.18 (11 minutes) |
| 30                  | 0.46 (28 minutes) | 0.2 (12 minutes) |
| 40                  | 0.58 (35 minutes) | 0.3 (18 minutes) |
| 50                  | 0.70 (42 minutes) | 0.36 (21.6 minutes) |
| 60                  | 0.82 (49 minutes) | 0.4 (24 minutes) |
| 70                  | 1.00 (60 minutes) | 0.44 (26 minutes) |
| 80                  | 1.15 (69 minutes) | 0.54 (33 minutes) |
| 90                  | 1.30 (78 minutes) | 0.7 (42 minutes) |
| 100                 | 1.60 (96 minutes) | 0.88 (55 minutes) |

Discussion of findings

This system combines two methods of achieving fast and efficient charging of batteries: the Existing Pulse Width Modulation System and the proposed light sensing-based repositioning methodology. This makes this Solar Panel system highly efficient in power generation and battery charging. This would without doubt convert itself to a high market demand, when the system is commissioned for mass production and distribution. This system can be modified to serve as the secondary power supply system of a domestic setup. The System charges in half the time that existing solar panels take; this will prove attractive to the general consumers nationwide; especially in areas with poor primary power generation sources. In Private Sector of Commerce, power costs have been known to be one of the highest recurring expenses annually. With this system, companies get to cut down on fuel consumption and save money constantly for a long period just with a one-time purchase of the finished product of this system. This benefit alone makes this feasible in the commercial sector.

The tracking capabilities of the solar system will ensure fast and effective charge [21],[22]; which at the capacity of a solar farm would yield power at optimal levels; this will then serve as an auxiliary power generation system added to the National Grid. This system is obviously highly relevant in a multifaceted manner; the system is capable of catering for the power needs of various sectors. This, along with the relatively minimal cost of production, makes the system feasible for commercial distribution.

IV. Conclusion

The study implemented an intelligent programmed based controlled robotic feature capable of tracking the highest intensity of sunlight in a single axis orientation and using information as a premise for repositioning the trays or holders to which the solar panels have been fixed on. This feature is done to optimize the charging speed and efficiency of the battery pack. Because the solar panels will always face the direction of highest sunlight intensity, the charge rate has been significantly improved as opposed to static charging or manually readjusting the solar panels. The system designed makes use of a very delicate interaction between power electronic circuits as well as mechanical setups capable of angular movements; the system is able to interpret all incoming data from sunlight into mechanical position.

The implementation of dual or triple axis panel repositioning systems will be more accurate than single axis repositioning system. The limitation with optimal repositioning is largely due to the challenge of the fact that the mechanism operates in a single axis orientation. However, a more optimal implementation of the system will imply the use of a three-axis mechanical actuation gearing system design. Although the program algorithms required to achieve efficient and accurate working of this is higher, it will increase the charge rate even more significantly.

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DOI: http://dx.doi.org/10.24018/ejeng.2022.7.6.2863