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Design and Implementation of an Automated Self- Cleaning Solar Panel using Microcontroller

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***Abstract**: Over the past years, Uganda has seen a large increase in the reliance on solar power as a source of energy. Solar energy as a mode of power generation is said to be a cost-effective source of off-grid energy as opposed to the conventional way where huge capital investments have to be made in putting up transmission and distribution networks. This paper aim to design an embedded real time and a low cost system based on Microcontroller for an automated self-cleaning solar panel. The panel detects the presence of an obstruction shading a cell, and actuates a cleaning mechanism that cleans off the obstruction and, therefore, restores the panel to normal capacity. This system is powered via 12V battery, this battery is charged by solar power when the cleaning mechanism is idle and automatically cut-off when the battery is fully charged*.

Keywords: Microcontroller, Solar panel, Battery, Self-cleaning

1. Introduction

It is estimated that some 73 percent of the Uganda’s population live in rural areas and less than 7% of the rural population have access to electricity(NPA, 2015). Over the past years, Uganda has seen a large increase in the reliance on solar power as a source of energy. Mr Dirk Kam, the Barefoot Power Uganda managing director, says not more than 5 per cent of Ugandan households that are not connected to the national grid, have access to solar power.

There has been a steady and significant growth in uptake and usage of solar energy solutions in Uganda over the past few years and that the number of players dealing in solar has increased to about 50. It is estimated that about 600 kilowatt-peak (kWp) – 1 megawatt-peak (MWp) of solar capacity is imported into Uganda on a monthly average, up from about 50 – 100kWp per month in 2002.

Solar energy as a mode of power generation is said to be a cost-effective source of off-grid energy as opposed to the conventional way where huge capital investments have to be made in putting up transmission and distribution networks. For instance, Umeme, Uganda’s largest electricity distributor’s capital expenditure – which includes putting up a distribution network and maintenance, stood at about Shs78 billion in 2011, up from Shs51 billion in 2010. According to the Electricity Regulatory Authority (ERA), Uganda's energy development program will convey 30 MW of new solar power supply into the national grid by end of this year 2018.

This particular development is now strengthening the base pyramid of energy consumption in the country, where actual penetration of usage is under 10%. With the above statistics, it is worth noting that majority of solar users are rural people in dust enriched areas of the country.

1.1Aim and Objective

- Design a mechanism to detect obstructions on solar panels causing significant loss of power.
- Design a cleaning mechanism that runs across the length of the panels.
- Improve overall solar panel efficiency.

2. Literature review

As accumulation of dust on the PV panel reduces its transmittance which results in the reduction of the power output, thus resulting in loss of power generation. This particular problem is also responsible for the short life span of many interplanetary exploration missions such as Mars Exploration Mission of Curiosity Rover as the power output from their solar panel reduces over time because of the accumulation of dust. At a point of time density of dust increases to level where power output declines to the extent which is not able to support its vital functions. Further this problem has also resulted in huge losses for the solar power plant operators which suffer from reduced power output because of frequent dust storms. Most widely used method of cleaning the solar panels is through the manual labor. Apart from being time taking and cumbersome, there is also a risk of damage to the expensive solar panels by the unskilled labor which is involved in this method. The purpose of this project is to develop a semi-automatic self-cleaning mechanism for cleaning the solar panel so that the process can become more reliable and fast, thus increasing the power output of the solar power plant.

Various technologies being developed around the world for self-cleaning of solar panels are discussed below:

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The information on the effects of soiling on solar panels comes from research funded by both universities and solar energy-oriented associations. The studies that were examined all analyzed different aspects of soiling. One study, sponsored by the Power Light Corporation in Berkeley California, found a daily loss of 0.2% in power output.

The report also noted a 7.5% to 12% efficiency increase due to rain. Another study, performed by Boston University's Department of Electrical and Computer Engineering, observed the loss of efficiency from soiling in Lovington, New Mexico. The area had an observed 24% drop in efficiency over the course of a month. The study also found that while rain is the primary cleaning agent for panels, it is not sufficient. The Boston University Study also reported the costs and benefits of three current methods of cleaning solar panels. These methods include natural cleaning through rain and snowfall, manual cleaning, and cleaning by an electrodynamic system (EDS).

In general, it was concluded that in order to maximize the cleaning effect of rain, the panels needed to have a glass shield and be oriented in the near vertical position. Manual cleaning by water and detergent was effective; however, it required costs set aside for labor (45.7% of the total cost) and fuel (20.5% of the total cost). An emerging technology, called an EDS, consists of interdigitated electrodes (made of indium oxide) in transparent dielectric film. The cleaning process is orchestrated by low power, three phase pulsed voltages (from 5 to 20 Hz). This process led to a reflectivity restoration of 90% after only a few minutes. The University of Sonora analyzed the effect of naturally occurring dust and residue on the energy generation of solar panels. A standard 'dirt' layer was chosen and was tested on three types of photovoltaic cells, monocrystalline, polycrystalline, and amorphous. The maximum reduction in electric production was 6% for monocrystalline and polycrystalline and 12% for amorphous.

3. Methodology

The solar panel cleaning system consists of two basic system unit depending on their functioning, namely Locomotion Unit and Cleaning Unit.

Locomotion Unit

Locomotion Unit is responsible for the movement of robot on the surface of the solar panel. Since the solar panels are mounted at an angle to ground level so as to capture maximum solar irradiance, the robot cannot rely entirely on the conventional wheel based system for its movement. The inclined surface of the solar panel demands for a movement mechanism that can stick to the surface of the panel and prevent the robot from sliding on the surface. So the pneumatic suction system was used along with a double rack and pinion mechanism.

The design consists of two legs present at the top and bottom of the robot. Each leg has two moving platform which move parallel to each other with the help of a double rack and pinion mechanism. Cleaning Unit is responsible for taking care of the cleaning action of the robot. It is placed perpendicular to both the legs. Both the legs are present in at the opposite end of the cleaning unit. Cleaning unit consists of two main parts, namely, Linear Actuator and the Rotating Brush.

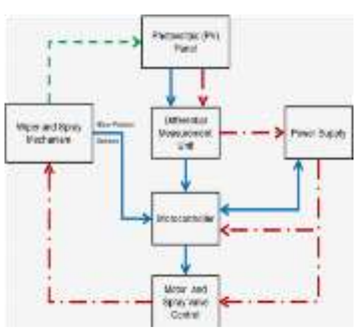
Linear Actuator

Linear actuator is an actuator that creates motion in a straight line, in contrast to the circular motion of a conventional electric motor. Linear actuator is used in machine tools and industrial machinery, in computer peripherals, in valve and dam and dampers.

Brush

The brush is responsible for scrubbing and dusting away of the dust accumulated on the surface of the solar panel. It is attached to the v-slot gantry plate platform which moves in the linear actuator. The brush is mounted on radial bearing which is rotated with the help of a 12.

3.1 Block Diagram



3.1.1Microcontroller

The Microcontroller chosen is the MSP430G2553. It is specifically chosen because it has 16MHz speed and we need up to 20 I/O pins. It is powered from a 3.3V source.

3.1.2 PV Panel

The PV cells were chosen to provide the series combination of voltage and current at peak power. Additionally, the PV Panel provides 6 differential voltages from the PV Cells. The differential voltages provide both the signals and source of power to the DMU. A glass and metal frame was manufactured by ECE Machine Shop to protect the PV Cells from the cleaning operation. The spray and wiper mechanism perform the cleaning operation on the PV Panel.

3.1.3 Differential Measurement Unit

The only method to convert the cell voltages was to use op-amps in either an instrumentation or difference configuration. The difference configuration was chosen since low input resistance was not a concern. Also, the difference configuration used far less resistors and op-amps [2].

The DMU uses 6 operational amplifiers connected in a difference amplifier configuration. According to Equation 1, R1 was chosen to be 1.5MΩ to have a large input resistance. If the assumption of Equation 2 is true, each difference amplifier changes the differential voltage input from a PV cell to a ground referenced voltage according to Equation 3. R2 was chosen based on Equation 4. The 0.5 ratio was selected to keep a maximum 6V PV cell voltage from exceeding the maximum 3.3V input rating of the microcontroller.

3.1.4 Power Supply

Battery Charger

The battery is charged at 15V. The charger takes a 30V nominal input from the solar panel. Building a buck converter is the best fit for this situation because the output of the charger has lower voltage than the input. The input of the charger is limited to greater than 28V otherwise the converter shuts down from the microcontroller. This is because at approximately 28V, the solar panel voltage drops out. The switching frequency is selected to be 50kHz as supplied by the chosen microcontroller. Equation 5 describes the buck converter duty ratio. An important aspect of selecting the inductor is its current rating and its size.

Logic Power Supply

The Logic Power Supply uses two linear regulator IC's to step a nominal 12VDC down from the Battery to the two logic level voltages (3.3VDC and 5VDC nominal) needed by the various other IC's in the system.

Each linear regulator can handle up to 100mA of load current. The expected load current is less than 50mA for each linear regulator. The 3.3V regulator was chosen because it needed to have a tolerance of less than 1%. This tolerance ensured that the voltages measured referenced to 3.3V on the ADC of the microcontroller, when considered with the 1% measurement tolerance of the DMU, would not erroneously show a 10% drop in a PV Cell voltage.

3.1.5Cleaning Mechanism

This block of the project takes care of the required cleaning functions. The sprayer sprays water onto the panel, and the wiper mechanism wipes the panel.

3.1.6 Wiper

The wiper mechanism, which wipes the PV Panel in a linear motion, was fabricated by the ECE Machine Shop. The wiper mechanism consists of a linear actuator, along the center of the panel frame, driven by a DC motor. One wiper bar is connected at the actuator and stretches on both sides of the PV Panel. It is driven by the threaded rod's rotation.

3.1.7 Sprayer

The spray mechanism consists of pipes stretched along both sides of the panel. A sprayer nozzle for each solar cell is present on the pipe. This nozzle has an optimal spray angle. The solenoid valve controls the flow of water through the pipes. The source of water is a pressurized public water supply connected with a hose. This was fabricated by ECE Machine Shop.

3.1.8 Motor Control

The DC motor needs to have its own separate control circuit. The main component of the control circuit is a L298N H-Bridge Driver. The L298N is a high voltage, high current dual full-bridge driver. The full bridge will be required to switch the direction of motor rotation with input combinations. The L298N IC needs to be supplied with 5V±5% for logic supply and 7.2V±0.1V for the motor supply as shown in Appendix A. Both these supplies are designed separately.
We initially designed the motor control circuit to include a rotary encoder. The rotary encoder serves the purpose of signaling to the microcontroller that the direction of the motor needs to be changed. This is done by counting the number of rotations the rotary encoder goes through. After a certain number of rotations, which signals the end of the panel, the rotary encoder sends a signal to the microcontroller that the direction of the motor needs to be changed.
Fly-back diodes are used to prevent a strong electrical pulse from being sent through the circuit. The enable pin and the input pins come in from the microcontroller.

3.1.9 Valve Control

A solenoid valve is used to control when water is sprayed onto the panel. It is actuated at 12VDC, but according to the distributor, can also work down till 6VDC. It will be supplied with a voltage of 12VDC ± 10%. The N-channel MOSFET is connected between the valve and the ground and will work as a control to open and close the valve.

Whenever the N-Channel MOSFET gets a high input from the microcontroller, greater than 3VDC, it will cause the valve to open. The valve will only be opened for about 2-3 seconds before being closed again.
This timing of the duration will be done through the microcontroller.

4 Test Results

4.1 System Overview

4.2 Microcontroller

We observed all the actions happening according to the code and circuit, and also all requirements are met.

4.3 PV Panel

Load testing was performed on the PV Panel to test for the requirements of the Design Review. The test was performed according to the Design Review Verification with two exceptions. First, the sunlight was artificially simulated in the PV Panel using a PV emulation technique. Second, an electronic load was used to find the I-V curve of the PV Panel, which includes the open circuit voltage. The short circuit current was based on a single PV cell held directly up to a spot light: ISC = 0.9A. All Design Review requirements were met.

5. Conclusion

The fully assembled system was able to detect a shaded cell from debris. Furthermore, it initiated the wiper motion down and up the panel to clear the debris. Also, the system maintained the battery charged when there was no cleaning and sufficient power was available.
More importantly, the project decreased the daily energy lost compared to the case where the

PV panel was left shaded for an entire day. In order to determine energy savings, the PV Panel was placed under a solar test bed under identical conditions to test the energy loss from one half shaded g a cell. The losses due to shading alone was determined by taking the difference between the maximum power of the unshaded PV Panel and the maximum power of with one PV cell half shaded. The power losses of the entire Automated Self-Cleaning Solar Panel was also measured. Energy loss was normalized for one day of operation with one cleaning cycle.

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