Microcontroller Based Dust Cleaning System for a Standalone Photovoltaic System

E. M. Al-Qubaisi[1], M. A. Al-Ameri[1], A. A. Al-Obaidi[1], M. F. Rabia[1], L. El-Chaar[3*], L. A. Lamont[2*]
IEEE-Student Member[1], IEEE Member[2], IEEE Senior Member[3]
Electrical Engineering Department
Petroleum Institute,
P.O. Box: 2533, Abu Dhabi, UAE.

Abstract:- This paper highlights and presents a solution to reduce the effect of shading and staining on photovoltaic (PV) modules on offshore platforms. Knowledge of the negative consequences of this factor on the PV panels' output has led to recognizing the importance of regular cleaning. Due to the system's location, the research had to take into consideration several constraints such as lack of power supply, availability of distilled water, maintenance and available space. Microcontroller technology was used as the electrical basis for the design because of its many advantages especially due to its low power consumption.

I. INTRODUCTION

The sun emits energy at an extremely large and relatively constant rate, 24 hours per day, 365 days per year. If all of this energy could be converted into usable forms on earth, it would be more than enough to supply the world's energy demand. However, this is not possible because (1) the earth intercepts only a small fraction of the energy that leaves the sun; (2) the earth rotates such that a collection device on the earth's surface is exposed to solar energy for only about half of each 24-hour period; and (3) conditions in the atmosphere, such as clouds and dust, sometimes significantly reduce the amount of solar energy reaching the earth's surface.

The intensity of solar energy on a surface oriented perpendicular to the sun's rays above the earth's atmosphere (known as the solar constant) has been measured by satellite to be between 1,365 and 1,367 W/m^2 [1]. This energy is transmitted through the atmosphere and reaches the earth's surface at a rate that varies over time at a particular location because of the angle at which the sun's rays strike the earth (called the zenith angle). This angle establishes the path length through the atmosphere for incoming sunlight and varies with latitude, date, and local time of day. Weather patterns and other atmospheric conditions which scatter incoming rays affect the rate at which solar energy reaches the earth's surface. The summation of the amount of solar energy arriving at a unit of area (1 m^2) during 1 hour is called the solar radiation or insulation. The solar radiation is typically expressed in units of watt-hours or kilowatt-hours per square meter (Wh/m^2 or kWh/m^2) averaged over the period of a day, month, or year. The direct solar radiation in the United Arab Emirates has an overall average rate of 2,200 kWh/m^2.

Solar energy can be converted to more usable energy forms through a variety of demonstrated technologies that are divided into two categories: thermal and photonic. Solar thermal technologies first convert solar energy to heat, which can be used directly (such as heating water for residential or commercial use), stored in a thermal medium (such as heating water or dry rocks) for later use, or converted to mechanical and/or electrical energy by an appropriate device (such as a steam turbine). Solar photonic technologies directly absorb solar photons—particles of light that act as individual units of energy—without complete conversion to heat. The absorber then either converts the photon energy to electricity (as in a photovoltaic (PV) cell) or stores it as chemical energy through a chemical reaction (as in photosynthesis or the dissociation of water into hydrogen and oxygen).

Selecting a solar energy conversion technology for use in an offshore setting would be influenced by differences in technological approach. PV cells provide a viable solar photonic technology approach for generating electricity for either distributed or dispatchable applications. PV systems generate electricity wherever the sun shines, making them especially useful for producing electricity in places where no other form of electricity is available. Such systems are suitable to operate automation equipment used by Oil and Gas Industry such as powering high efficiency gas flow computers, remote telemetry units, supervisory control and data acquisition. The equipments low power requirements and typically remote locations often make a PV system the most cost effective power source.

Photovoltaic installations are invariably vulnerable due to shading as a result of exposure to contaminants from a variety of natural elements or obstruction from surrounding bodies. These often result in performance degradation and possible damage to the panels. Many field researchers have in the past grappled with the problems of energy loss and panel damage as a result of shading and staining of PV panels after installation. A number of solutions have been proposed to try and minimize the effects of this problem in the field [2-5]. The problem with all these solutions is that they address inter-panel connection topologies for very large installations. No particular attention has been paid to the topologies of individual panels. In the Oil and Gas Industry, especially in the offshore oil rigs, most installations are small multiple

*Corresponding Authors – llamont@pi.ac.ae & lelchaar@pi.ac.ae

panel solar systems and therefore small shading can result in an entire installation being disabled. This paper aims to study the effect of shading and staining on photovoltaic modules and propose a new topology that will reduce the effect of shading on the performance of individual photovoltaic modules.

II. Photovoltic Modules

Photovoltaic modules are semiconductor devices that convert solar energy into electrical energy. Most commonly used PV modules are made of silicon and consist of 36 cells connected in series with two bypass diodes, each across 18 cells as shown in Fig. 1 [6].

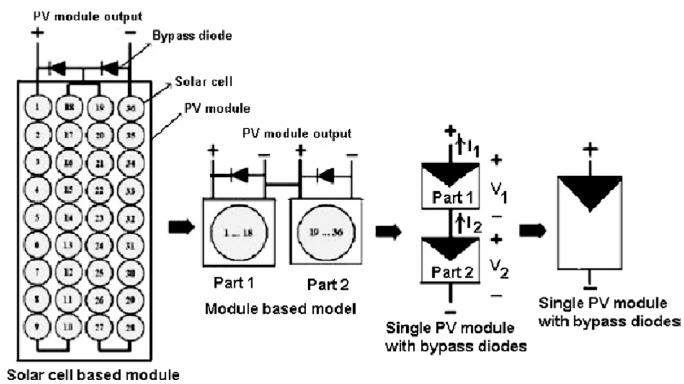


Fig. 1. Connection schematic of the solar cell and bypass diodes in the PV module [6].

Photovoltaic cells have a circuit equivalent model, as illustrated in Fig. 2 where, I_{ph} is the photocurrent source, D is a diode, R_{sh} is a shunt resistance and R_s is the series resistance.

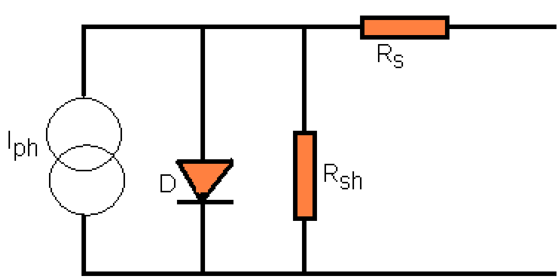


Fig. 2. Standard model [2,7].

The current source I_{ph} generates a current proportional to the amount of light falling on the cell. With no load connected, nearly all the current generated flows through diode D, whose forward voltage determines the solar cell's open-circuit voltage (V_{OC}). This voltage varies depending on the properties of each type of solar cell, but for most silicon cells, it is in the range 0.5–0.6 V (the normal forward voltage of a p–n junction diode) [8]. The series resistance (R_s) represents the ohmic losses of the cell and the shunt resistance (R_{sh}) represents the losses due to diode leakage currents. The current produced by a cell is directly proportional to the amount of light that the cell absorbs. A reduction in the light due to insufficient sunshine, as a result of partial or complete shading of a cell, will reduce the current produced by the PV cell. A reduction of the current in one PV cell will force down the current output of the entire string of series connected PV cells [9], changing the output characteristics of the PV panel. For example, shading 5% or two cells could reduce the output power to as low as 50% [2].

Depending on the area, shadings can vary due to the surroundings. Soft shading blocks the direct light from being absorbed by the cells, and it can be due to nearby buildings, telephone and electric poles. When a cell is under soft shading, only 10% of the available radiation (diffuse radiation) is absorbed. Hard shade on the other hand does not allow the cell to absorb any light, be it direct or diffuse. This can be found when the panel has bird dropping or staining on them. In both cases, because the shaded cells produce little or no current, the cells behave as resistive loads. Kovach and Schmid, [10] studied the output power losses due to shading, where subsequent energy losses can noticeably reduce PV's energy output, and the amount of energy lost because of this effect depends on whether the modules are connected in series or parallel.

III. Design Development

Abu Dhabi Marine Operating Company (ADMA-OPCO), an oil company based in (Abu Dhabi), UAE, deploys PV panels on its offshore facilities to generate the electrical power needed to operate the telemetry and controlling systems of the oil and gas well-head towers. However, due to staining factors such as dust, birds' droppings, and nests around the panels, the efficiency of the panels is reduced, hence causing negative impact on the system performance. To boost the efficiency, manual cleaning takes place but due to the location of these panels this process is expensive and a more cost effective solution is required. This solution should be proactive and not only cleans but also deters the birds from getting close to the panels.

In designing such solution for the well-head towers, several factors need to be taken into consideration such as lack of distilled water, power source accessibility, space availability and maintenance. To resolve some of these issues, the cleaning system should consume low power and require minimal maintenance. Due to space constrains, the design must be integrated on the original frame of the solar system and is divided into two sub-systems: mechanical (section IV) and electrical (section V). The mechanical system deals with the water supply, cleaning and deterring parts of the design. The electrical system utilizes the excess power obtained from the PV panels along with a microcontroller to provide power and control for the mechanical system. Fig. 3 shows the block diagram of the overall system with both the cleaning and bird deterring incorporated.

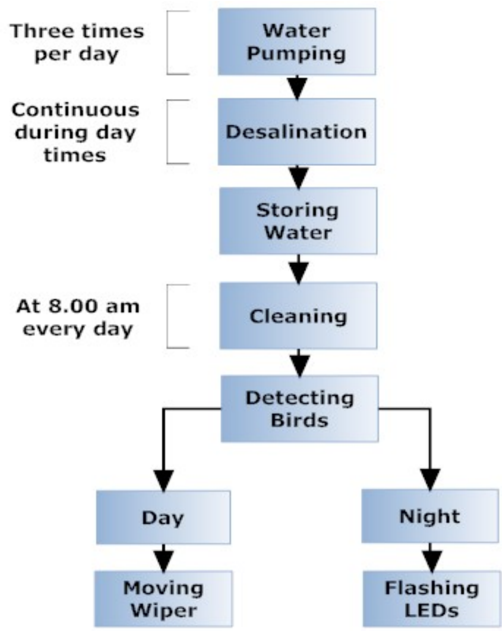


Fig. 3. Block Diagram of the Overall System

IV. MECHANICAL SYSTEM

The mechanical system consists of 1) water supply and 2) wiper movement. The first system uses submersible pump to drive water from sea level to a solar heater located on the tower (Fig. 4) via plastic pipes. This heater consists of two tanks. Tank 1 collects the filtered sea water which then gets purified in the tower by means of the heat generated by the sun rays. The evaporated water condenses in tank 2. This purified water is supplied to the cleaning system nozzles by switching on a solenoid valve which is activated by the electrical system. The water supply process ensures continuous availability of desalinated water, hence both reducing the cost of the system and guaranteeing full automation.

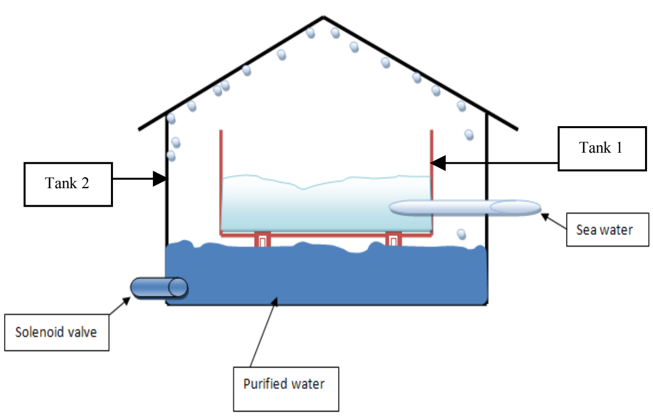


Fig. 4. Solar Heating Tower

When the light sensor attached to the panels detects sun light, an electrical signal (generated by the microcontroller) opens the solenoid valve and sprays the purified water over the panels for a specified time. In order to clean the panels, wipers, initially located at the bottom of the solar system to prevent shading of solar panels, are initiated. The electrical system activates two DC motors to trigger the wiper through two rails connected on each side of the panel (Fig 5). The two motors have a common shaft to ensure synchronization of both sides of the wiper. The innovation of this system lies in the fact that the rails used are nonmetallic and therefore reduces the corrosion factor that may be caused in a metallic component used in a marine surrounding. The mechanical system also includes two limit switches to set the boundary for the wiper and send a signal to the motors to reverse.

In order to reduce the amount of bird dropping on the panel, a deterring system is integrated into the cleaning mechanism. The design uses motion sensors to detect any movement on or around the PV. If motion is detected, a signal is sent to the microcontroller to move the wiper back and forth once to scare the birds away during daylight. At night time however, green and red flashing lights flash three times to scare the birds. The operation of these mechanical devices depends on the electrical system in section V.

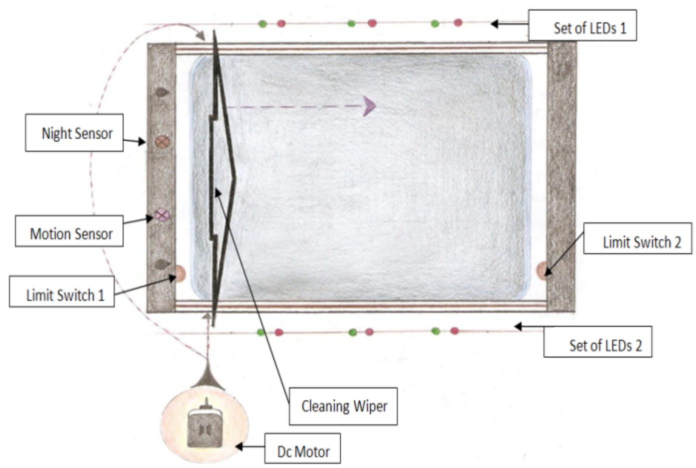


Fig. 5. Mechanical System Process

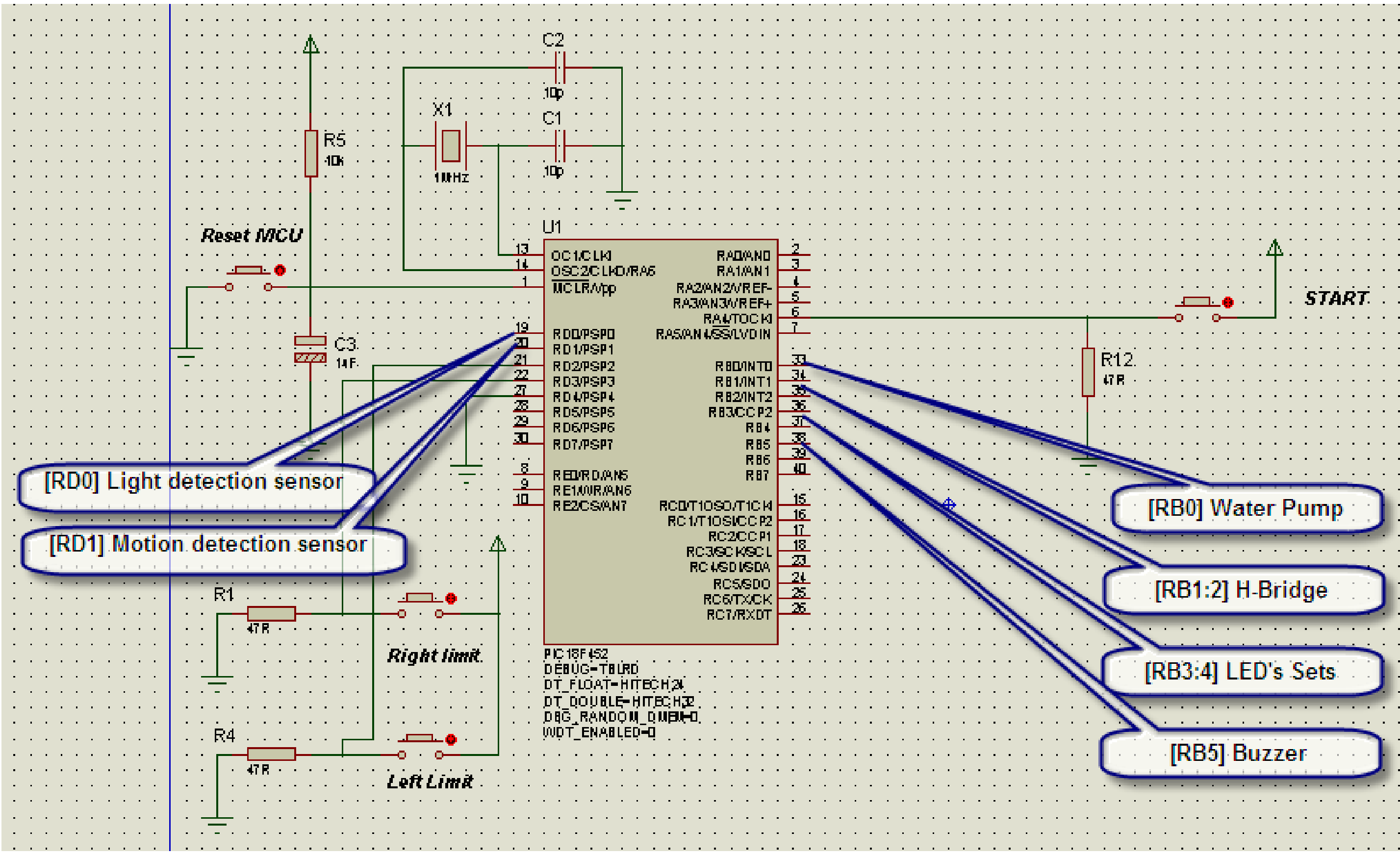


Fig. 6. Microcontroller Circuit Diagram

V. ELECTICAL SYSTEM

The main objective of the electrical system is to control and power the mechanical components (Fig. 6). There are many methods to accomplish this aim such as electronic circuits, programmable logic controllers (PLC), and digital devices (microcontrollers). Based on the low power consumption, space and cost constraints, a PIC microcontroller was chosen [11]. The microcontroller PIC18F452 (Fig. 7) was selected according to its peripherals and features that would enhance the performance of this system. Its memory (32 KB) is suitable to handle the designed program and allows any further modification. In addition, it has a wide operation voltage range (2.0 V to 5.5 V) with high performance of 100K samples per second. This device is fabricated using CMOS technology which is characterized by its low power consumption (< 1.6 mA typical @ 5V, 4 MHz, 25 mA typical @ 3V, 32 kHz and < 0.2 mA typical standby current). Moreover, it has high speed FLASH/EEPROM with retention greater than 40 years [11]. The connection of the inputs and outputs with the overall system can be easily described by the algorithm shown in Fig 8. The microcontroller provides control using specified inputs to generate specified outputs. The inputs are the signals from light sensors (LDR), motion sensors, limit switches, and start-up switch. The outputs are the control of the DC motors, light emitting diodes (LED), and solenoid value. Fig. 8 graphically demonstrates the operation flow of system's circuit. This section highlights the function of the microcontroller within the overall system.

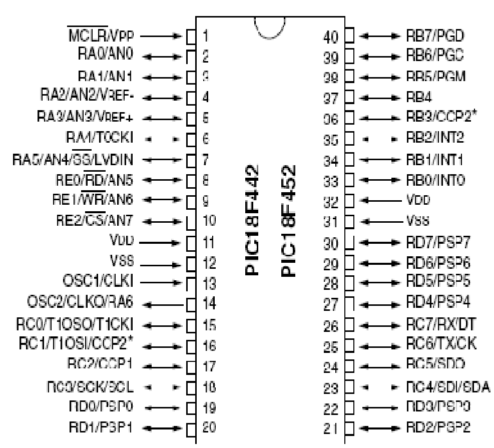


Fig. 7 View of Microcontroller

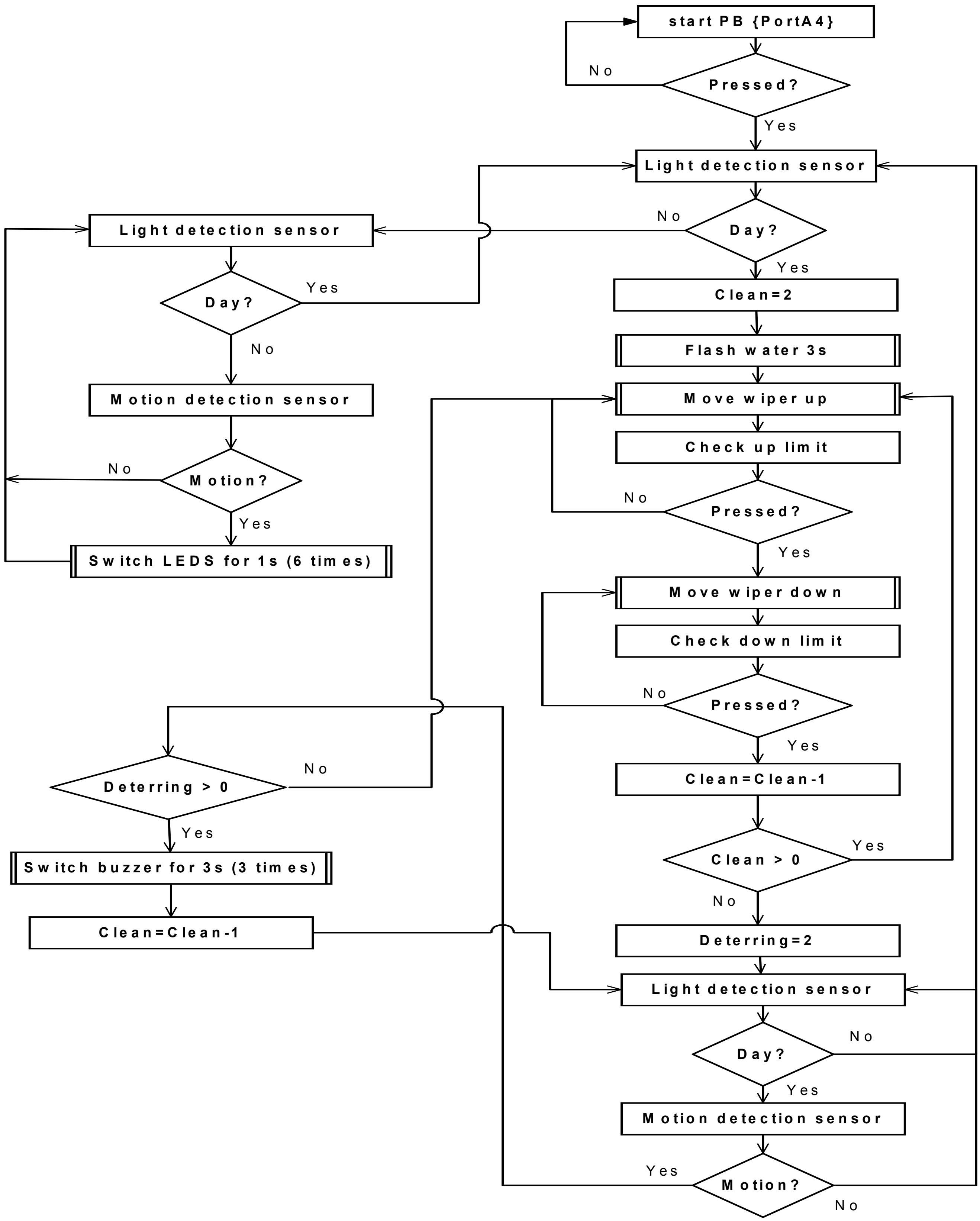


Fig. 8. Microcontroller Logic Flow Chart

VI. Overall System

Fig. 9 shows the cleaning process where the wiper is pulled upwards by two motors attached to the rails. It also shows the electric circuit designed to power and control the mechanical section.

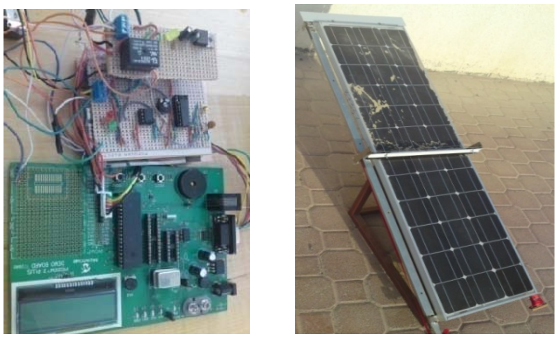


Fig. 9 The Electrical System (left) and Device picture during the cleaning process (right)

The device is currently under testing for six months to ensure its durability, efficiency and performance before being transferred offshore on the well head tower by ADMA-OPCO for testing in a remote unfriendly environment. Power losses were calculated and found to be minimal because of the implementation of the microcontroller technology in this design.

VI. Conclusion

As a conclusion, this paper presented an automated microcontroller based cleaning system that reduces the effect of shading on the output power of the PV panels. This design was built and tested for a short period of time. However, more testing is ongoing to ensure the reliability prior to location testing.

Acknowledgment

The authors would like to thank ADMA-OPCO for their help and support for this project especially Nasser Al Tamimi and Alan Holland. Acknowledgments must also go to the Petroleum Institute for their financial support.

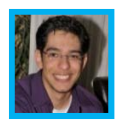
References

[1] J. M. Kusterer, Site Administration/Help: NASA Langley ASDC User Services, March 26, 2008Available at: http://eosweb.larc.nasa.gov/sse/
[2] E. Karatepe, T. Hiyama, M. Boztepe, and M. Çolak, "Voltage based compensation system for PV generation system under partially shaded insolation conditions." Energy Conversion and Management, vol. 49(8), pp.2307–16, 2008.
[3] D. Uchida, K. Otani and K. Kurokawa, "Evaluating the effect of shading factor by fitting a clear day pattern obtained from hourly maximum irradiation data." Solar Energy Materials and Solar Cells, 67, pp.19–28, 2001.
[4] M. Drif, P.J. Perez, J. Aguilera and J. D. Aguilar, "A new estimation method of irradiance on a partially shaded PV generation in grid-connected photovoltaic systems." Renewable Energy, vol.33(9), pp.2048–56, 2008.
[5] M.C. Alonso-Garcia, J.M. Ruiz and W. Herrmann, "Computer simulation of shading effects in photovoltaic arrays." Renewable Energy, vol.31(12), pp.1986–93, 2006.
[6] E. Karatepe, M. Boztepe and M. Çolak, "Development of a suitable model for characterizing photovoltaic arrays with shaded solar cells." Solar Energy, vol.81(9), pp.77–92, 2007.
[7] A. Wagner, "Peak-power and internal series resistance measurement under natural ambient conditions." EuroSun 2000 Conference, Copenhagen; 19–22 June 2000.
[8] A. Ubisse and A. Sebitosi, "A new topology to mitigate the effect of shading for small photovoltaic installations in rural sub-Saharan Africa." Energy Conversion and Management, vol.50(7), pp.1797-1801, 2009.
[9] N. Kaushika, A. Rai, "An investigation of mismatch losses in solar photovoltaic cell networks." Energy, vol.32, pp.755–9, 2007.
[10] A. Kovach, J. Schmid, "Determination of energy output loss due to shading of building-integrated photovoltaic arrays using a raytracing technique." Solar Energy, vol.57(2), pp.117–24, 1996.
[11] Corporate Headquarters. Microchip Technology Inc. http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en010297 Accessed 29th May 2009.

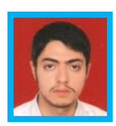
Biography

Eisa M. Al Qubaisi joined the Petroleum Institute in 2004. He is a senior student in Electrical Engineering, active member of IEEE, expected to graduate in 2010. He is interested in power system and programming.

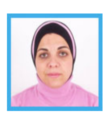
Malek A. Al Ameri joined the Petroleum Institute in 2004. He is a senior student in Electrical Engineering and an active member of IEEE. His area of interest is in control systems, power distribution and also in programming.



Mohamed F. Rabia joined the Petroleum Institute in 2006. He is a sophomore student in Electrical Engineering, expected to graduate in 2011. He is intersted in power electronics and power distribution.



Abdulla A. Al-Obaidi joined the Petroleum Institute in 2006. He is a sophomore student in Electrical Engineering, expected to be graduated in 2011. He is interested in circuits and micro electronics.



Lana El Chaar, IEEE senior member**,** graduated from the University of Minnesota, USA with BS, MS and PH.D. in Electrical Engineering. In July 2007, she joined The Petroleum Institute in Abu Dhabi, UAE. Her research interests lie in the areas of power electronics in particular rectification and power quality. In addition, her recent research has been mostly concentrated in renewable energy in general and photovoltaic and wind energy in particular.

Lisa Lamont (M'03) obtained BEng (Hons) degree from University of Ulster, UK in 2001 and PhD degree from the University of Ulster, UK in 2005. Since September 2005 she has been employed as an Assistant Professor with the Petroleum Institute, Abu Dhabi, UAE. Her research interests lie in the areas of Control Systems, Controller Design, Multivariable Analysis, System Modeling and Simulation, Stability Studies, HVDC and VSC, Damping Vibrations in Oil Platforms, Solar Energy, Non-Linear System Identification and Fault Detection and Diagnosis.