Control of Photovoltaic Cells System Based on Its Output Voltage Characteristic

Trinh Trong Chuong[1], Do Cong Ngon[2,*], Doan Van Binh[3], Nguyen Quang Ninh[3], Nguyen Hoai Nam[3], and Nguyen Duc Minh[3]

A B S T R A C T

This paper studies the output voltage variation of solar panels obscured by obstructions, to control the solar directional system and automatic solar panel cleaning system. The change in the output voltage of the hidden solar panel will be different from when the solar radiation is reduced. Automatic cleaning system, based on the output voltage characteristic of photovoltaic cells (PV cells), is stable at defined temperature and solar radiation conditions; when hidden, the output voltage drops abnormally, with a large change in value. The voltage read through Arduino is stored in Excel by Matlab program, thereby based on the available Matlab program to detect incidents and control the automatic cleaning system.

1. INTRODUCTION

Recently, distributed generations such as wind energy and photovoltaic have been experiencing a rapid development in a global scale. The size of distributed generations is increasing quickly, especially solar power sources [1]. Photovoltaic cells (PV cells) are being developed and used extensively to generate electricity from solar energy sources based on the photovoltaic effect. The output characteristics of PV cells such as current and voltage are closely related to natural environmental conditions such as solar radiation or temperature [2]-[4]. Also, in the literature it is shown that the surface of PV cells has a great influence on the performance of the panels [2], [4]. There are research on the properties of the panels, how to reduce the effect of natural conditions on PV cells efficiency or how to increase the efficiency of PV cells photoelectric conversion.

Mathematical models have been developed for PV cells based on simulation environments such as Matlab/ Simulink or PSCAD/EMTDC [5]-[7]. These simulations were undertaken in order to identify the effect of solar radiation S (W/m^2) and temperature (^{o}C) on the output characteristics of PV cells. Currently, studies are focused on measures to improve the efficiency of PV cells by creating an automatic solar orientation rotation system and cleaning the panel surface.

For solar orientation systems, one of the comment solutions is using Light Dependent Resistor (LDR) to receive light radiation and then transfer it to a microcontroller such as Arduino [8]-[11], IC 8051 [12], [13], or AT89S52 [14], etc. to control the rotation of solar panel spindle by motor. Motors are used such as stepping motors [11], [12], servo motors [8], [10] or DC motors [13], [15], [16] and AC motors [17]. Control programs written on the Arduino IDE software can also be used on C [13], specialized software [12] or using the algorithm of fuzzy logic control in Matlab/Simulink [9], [13], [15], using Multifunctional Robot with Quadcopter [18]-[20], and Automated Battery Management System to Enable Persistent Missions with Multiple Aerial Vehicles [21] - [25].

For cleaning solar panels, it is still mostly manual work or using robots. In addition, many researchers have recently focused on cleaning materials that can clean the surface of PV panel with TiO_2 or TiO_2/SiO_2 [26]-[28]. However, it is found that cleaning material only provide only cleaning effect and it is required a cleaning system to remove the dust and dirt from the PV panels. Also, the cleaning works are now irrelevant to the output characteristics of the PV panel to achieve high efficiency or detect unusual obscure incident on PV panels.

Therefore, in this article, we present a method to improve the efficiency of the PV panel based on the design of the cleaning system based on its output voltage characteristics in terms of temperature and pressure. determined solar radiation. This is also considered a study aimed at detecting abnormal solar panel failures based on

[1]*HaUI Institute of Technology, Hanoi University of Industry, 298 Cau Dien Road, Tuliem North District, Hanoi, Vietnam.*
[2]*Shanghai University of Electric Power, 2588 Changyang road, Yangpu District, Shanghai, China.*
[3]*Institute of Energy Science - Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet Road, Hanoi, Vietnam.*
Corresponding author: Do Cong Ngon; Email: dugongyan@163.com.

output voltage signal. Solar navigation system is designed on Matlab platform, Arduino and Microsoft Excel software, bringing convenience to system technicians.

2. MODELING AND SIMULATION OF PV CELLS OUTPUT VOLTAGE CHARACTERISTICS

2.1. Mathematical model

There are variety of mathematical models given for PV cells output voltage characteristics depending on the purpose of the study or the characteristics of different complexity and accuracy to be surveyed. For a simple and complete visualization, a PV panel has an equivalent circuit [5], [6] as shown in *Figure 1*, in which I_{sc} is the short-circuit current or the current generated by the solar radiation; I_d is the electric current through the imaginary diode of PV cells or the positive current of the PV panel; V_d is sealing voltage on a PV panel; R_p is a parallel resistor (probe resistor), mainly caused by defects of silicon chips and dirty insulation edges; R_s is the internal series resistor of the PV panel (including the external resistor, the internal series loss of the electrode resistor and material; and V, I are the voltage and current of the PV panel output. The number of output voltages V is a quantity of the focus of this paper.
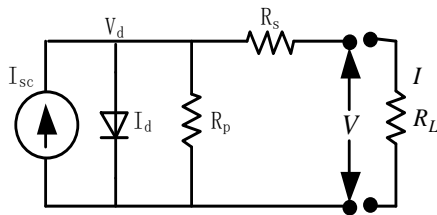

Fig. 1. Equivalent circuit of PV cell.

The general equation for the corresponding I-V characteristic of the PV panel is:

$$I = I_{sc} - I_0 \left\{ \exp[q(V+I.R_s)/kT] - 1 \right\} - \left[(V+I.R_s)/R_p \right] \quad (1)$$

in which, I_o is the reverse saturation current $I_o = 10\text{-}12A/cm^2$; $q = 1,602.10^{-19}C$ is the electron charge, $k = 1,381.10^{-23}J/K$ is the Boltzmann coefficient and T is the contiguous temperature ^oK; In addition, the effects of environmental factors on the output characteristics of PV cells are calculated according to the following formulas [3]:

$$I_{sc} = I_{sc}^{ref} \left[S*(1-a.\Delta T)/S_{ref} \right] \quad (2)$$

$$V_{oc} = V_{oc}^{ref} (1-c.\Delta T).\ln(e+b.\Delta S) \quad (3)$$

$$\Delta S = \left[(S/S_{ref})-1 \right] \quad (4)$$

$$\Delta T = T - T_{ref} \quad (5)$$

in which, S (W/m^2) is the solar radiation, in this paper, the values taken are [200, 400, 600, 800, 1000]; the solar radiation value $S_{ref} = 1000W/m^2$ is the standard installed solar radiation parameter; I_{sc}^{ref} is the standard short circuit current; $T_{ref} = 25^oC$ is the standard working temperature of PV cells; ΔS is the difference between actual and installed solar intensity; ΔT is the difference between actual temperature and installed temperature; e = 2,71828; constants of $a = 25.10^{-4}$, $b = 5.10^{-4}$, $c = 288.10^{-5}$.
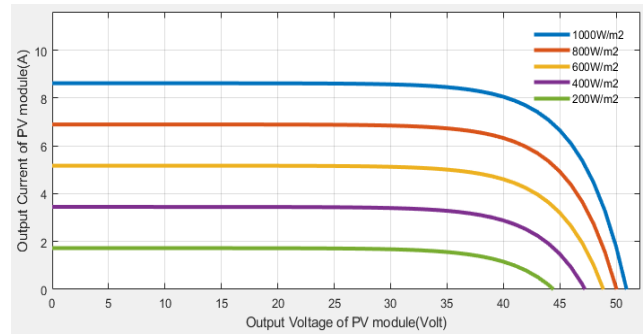
(a) V-I characteristic curve according to S radiation (W/m^2)
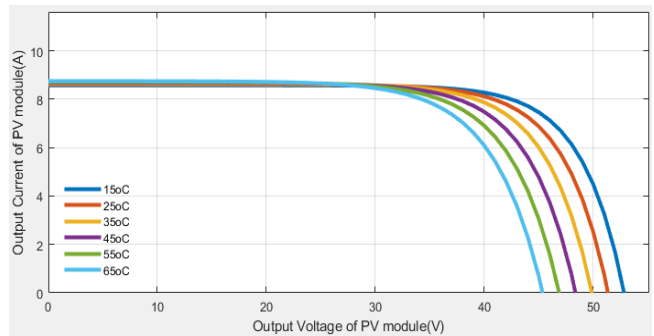
(b) V-I characteristic curve according to temperature t (^oC)
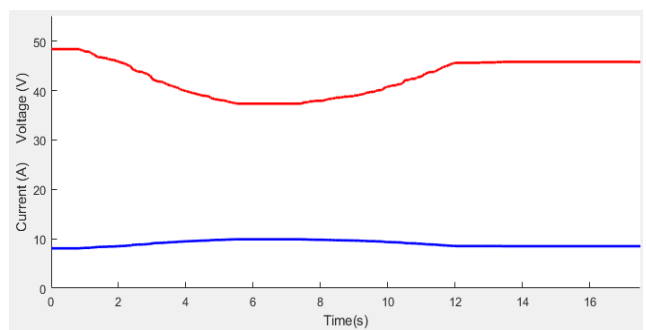
(c) Characteristic curves of current I (t), voltage V (t) and temperature t (^oC)

Fig. 2. Voltage-current characteristic curve of PV cells.

2.2 Matlab simulation programming

Matlab software is used to program the Guide interface. The V-I lines are chracterized by solar radiation and the

ambient temperature for PV panels. Following parameters are assumed for the study: standard solar radiation $S_{ref} = 1000W/m^2$, standard working temperature $T_{ref} = 25^oC$, installed short-circuit current $I_{sc.ref} = 3.75A$, open circuit voltage $V_{oc.ref} = 42V$, saturated current $I_d = 2.1.10^{-5}$, energy exceeds the threshold of semiconductor $E_g = 1,166eV$, temperature-dependent current coefficient $k_I = 23.10^{-5}$ (A/^oC), voltage dependent coefficient $k_U = -80$ (mV/^oC) number of cells: 60, parallel string $n = 4$ (these are the parameters for the PV panel sample).

The actual PV cells parameters are taken from the manufacturers, and stored in Excel sheets for the investigation with results presented in *Figure 2* below. The development of this Guide interface model combined with saving and reading data from Excel file can be easily changed or surveyed any kind of PV cells, from which the operator can compare with the actual operational parameters of the PV panel. The simulation results in *Figure 2a* show that as the solar radiation increases, the current increases almost proportionally and the voltage increases at lesser extend. This variable voltage value is only within a few Volt when the solar radiation varies from the maximum to the minimum values. According to the simulation results in *Figure 2b, c* it is showed that as the ambient temperature rises, the current also increases slightly (*Figure 2c*, the blue line below) while the voltage decreases significantly (*Figure 2c*, red line above).

The results indicate that PV cells operates more efficiently when it receives large solar radiation and at lower temperatures than in conditions of low radiation and high temperature. Therefore, when PV cells is operated, there should be a solar orientation system and the surface of the panels should be clean to maximize radiation S (W/m^2).

3. CONTROL PRINCIPLES

3.1. PV cells cleaning system

In this paper, the method of cleaning PV cells is based on the output voltage characteristic of the cell panel. Under certain conditions such as solar radiation S (W/m^2) and temperature t (^oC) are determined, the output voltage of the cell panel will be fixed. In the event that the solar radiation changes, the output voltage of the PV panel will change, but in the scale of a few Volts, as analyzed in section 2.2 above. Therefore, if during operation, the voltage of PV cells is dropped sharply, which means the value changes greatly, the operator will be notified to investigate. The cleaning system will be activated the cleaning system for PV panel so that the voltage recovers to its correct value.

In practice, parameters such as solar radiation and ambient temperature are always changing, so adjustments will be made by entering actual measurement parameters on the Guide interface as shown in Figure 2, or connected with actual measurement devices to recover the signals. In this paper, these parameters are adjusted on the Guide interface. However, the solar radiation or the temperature may be changed corresponding to radiation S and the specified temperature, the output voltage of PV cells is completely determined as in formula (3) above.

In this cleaning system, in addition to the automatic operating mode, an additional manual option (manual) is also designed to assist the operator to be able to monitor and operate the system. In addition, all working parameters of PV cells system will be saved in Excel file for checking, operating and monitoring. The flowchart of the algorithm for the battery cleaning system is shown in Figure 3 below.

As Arduino can only read voltage at the analog pin below 5V, when the output voltage of PV cells (V_{OC}) is higher than this threshold, DC voltage of PV cells is lowered before putting into Arduino.

Because the battery voltage is large, about 20-50VDC, but the Arduino input signal only takes 0-5VDC value. Therefore, we use a voltage divider circuit through two resistors R_1 and R_2; $R_1 = 10R_2$. The voltage measured in Arduino through R_2, so the actual voltage of the panel is equal to $11*U_2$.
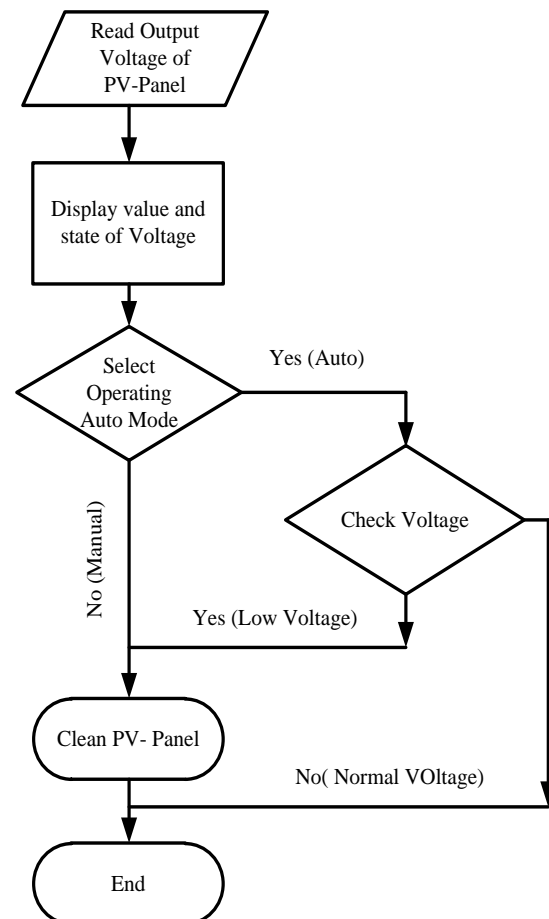

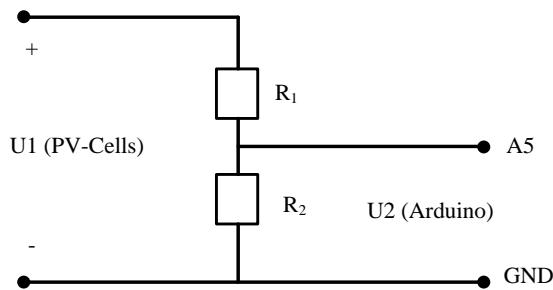**Fig.3. Flowchart of algorithm for cleaning system control**

Fig.4. Principle diagram of circuit divider.

In this paper, two resistors are used: $R_1 = 470\Omega$ and $R_2 = 47\Omega$; therefore, the voltage of U_2 will be reduced according to a factor of $k = (R_1 + R_2)/R_1 = 11$, so the display will be levelized to the factor k.

The voltage of PV cell connected to the analog pin of Arduino is read on Matlab with the following syntax:

dienap=readVoltage(a,'A5');

Were *a* is the Arduino variable

The voltage value of PV cells is read through the analog pin of Arduino which is saved by Maltab software in Excel sheet with the following syntax:

xlswrite(filename,B,sheet);
filename='PV_CELLSOP.xlsx';
sheet=1;
xlswrite(filename,B,sheet,'A2:I500');

Then, the following syntax is used to be displayed again on the Guide interface:

set(handles.uitable1,'Data',matrandulieu);

The voltage data is checked through a pre-installed program in Matlab, if the voltage drops sharply after a period of $\Delta t = 10s$, the automatic cleaning system will be activated. The motor is controlled via a L298 bridge circuit connected to two digital pins of the Arduino in positive and negative directions to clean the PV panel in the form of a command structure as follows:

writePWMVoltage(a,'D5',2);
writePWMVoltage(a,'D6',0);

In this paper, the cleaning system is two DC motors fitted with two wheels that slide along the PV panels in a fixed rail system. The model is shown in the last section of this paper.

3.2. Solar orientation system

The PV cells orientation system operates based on the integration of LDR photoelectric sensors. The sensor signal is converted to the corresponding voltage and compared. In the condition that the sunlight received by the two sensors is equal, the voltage generated of the two sensors is equal. The sensor will produce a larger voltage if there is more

sunlight received compared to the other sensor. The motor is controlled based on the difference voltage between two sensors. Solar orientation system only operates when PV cells system is in operation. In this paper, we designed the solar orientation system in two directions of East-West based on the algorithm diagram shown in Figure 5 below.

In this paper, the analog signal of the LDR optical sensor is used to read voltage signals through the Arduino and the command in Matlab is used as follows:

cb1=readVoltage(a,'A4')
cb2=readVoltage(a,'A5')
delta=cb1-cb2;

PV panel is driven by a 12VDC motor; in order to ensure the accuracy of the rotation angle of the orientation system, it will be processed as follows:

Firstly, the signal of the LDR resistive sensor will be read and compared with each other and set at a certain value (V_o).

Second, the motor's rotation is controlled by adjusting the input voltage to the motor via the command: write PWM (pulse width modulation) voltage (a, 'motor control', voltage value).
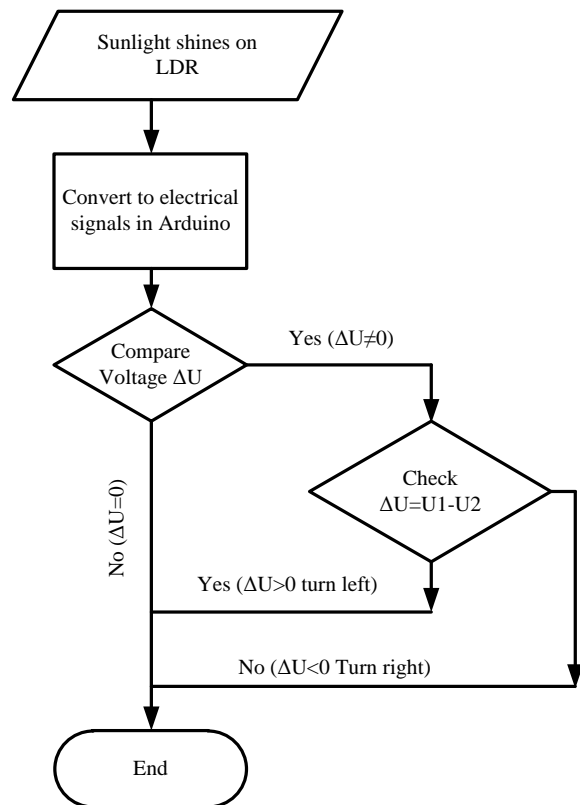

Fig. 5. Algorithm flowchart of the Solar orientation system

The command in Matlab is written as:

Vcb1=readVoltage(a,' foot sensor1');
Vcb2=readVoltage(a,' foot sensor2');

deltaVcb=(Vcb1-Vcb2);
if deltaVcb>Vo
% drive the motor to the east;
elseif deltaVcb<-Vo
   %   drive the motor to the west;
    else
   %   Keep the engine not rotating;
    End.

With *deltaVcb* value, the sensitivity of the system must be ensured to command the exact position of this solar orientation system.

4. MODEL RESULTS

4.1. PV cells cleaning system

Base on principles of the above-mentioned cleaning control system, the Arduino board is used to read the input voltage data of Matlab, write the data into Excel and display the voltage. With data written in Excel, the pre-installed program available in Matlab will detect a problem to bring the DC motor control signal through Arduino and L298 bridge circuit.

Test results (shown in *Figure 6*), indicate that, initially PV cells had a voltage of about 12.5V. At the time of t=30 seconds, the PV panel was hidden by obstructions, then the PV panel voltage was dropped sharply by about 3.5V. This is an important sign to distinguish the obscure phenomenon from the decrease in voltage when the solar radiation changes normally.

After t = 10 seconds, the system detects the problem and activates the automatic cleaning system, to remove obstructions hiding the PV panel. After cleaning, the voltage of the PV panel is restored. It is also found that when the PV panel is wiped cleaner, its output voltage is even higher than the original, at about 14.5V.
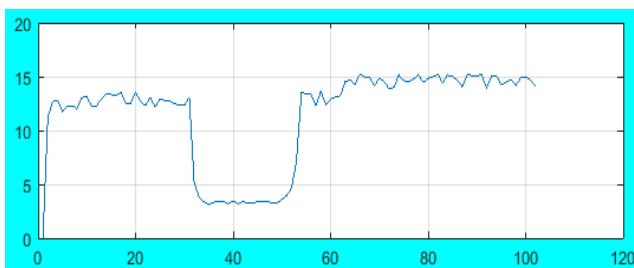

Fig. 6. Result of voltage characteristic using cleaning system

In this simulation, the delay in response of the cleaning system is one of the key concerns. The time to set for the failure is t = 10s, but cleaning system only activate after about 20 seconds. This is because the program has been pre-installed in Matlab, when the voltage drops sharply for 10 seconds, it will notify the operator on the failure. At the same time, it was the time interval to verify the obscure incident that allowed the activation of the cleaning system.

Therefore, the system runtime has a delay of 20 seconds. However, this result is technically acceptable. The obscure phenomenon needs to be verified. It is needed to avoid the misconception of the system due to other reasons but not the obscure phenomenon. If there is sudden decrease in solar radiation and voltage drops sharply, the cleaning system should not be activated to avoid the adviser impacts on the performance of PV cells.

If the value of the solar radiation is changed, the operator will cancel the command made by the program or move to manual processing. This does not mean that the system does not work automatically, but to make it more reliable and stable.

4.2. Solar orientation system

The result of the output voltage value of PV cells before and after using the solar orientation system is shown in Figure 7 below.
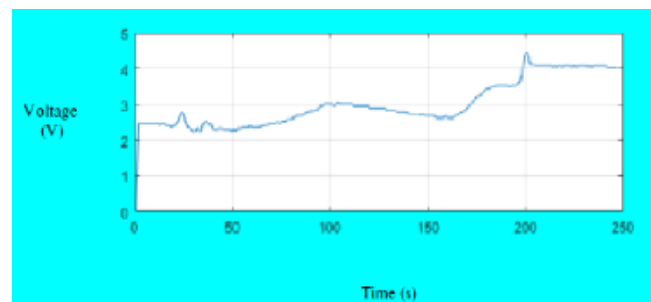

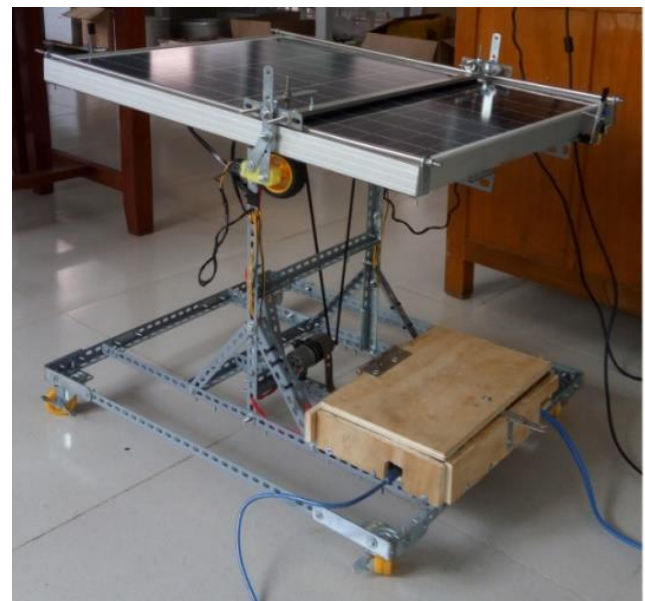**Fig. 7. Voltage characteristics before and after the Solar orientation.**

Fig. 8. The physical model used for this study.

With simulation results in the period t = 0 to t = 200s, the system has not used the solar orientation system, the solar

radiation panel is not the largest, the voltage has a low value. After t = 200s to t = 250s, the solar cell orientation system was used. When the panel is oriented towards the sun, the radiation on the panel is large and stable, so the output voltage of the panel is raised and stable compared to the previous time.

Based on the result of Figure 7, it is shown that before using the solar orientation system, the voltage was low, after the solar orientation system, the voltage value was significantly improved to be much more stable. The physical model is built and tested in the paper as Figure 8.

5. CONCLUSION

The paper presents a method to improve the efficiency of PV cells system by performing the rotation of the PV panel in the direction of the sun and automatic cleaning based on the output voltage characteristic of the PV panel to overcome abnormal obscuring phenomena. Based on temperature signal and solar radiation, it is identified that in the event of determined solar radiation and ambient temperature, if the voltage is dropped sharply over a certain time interval, it is likely to be hidden by an obstacle.

The results suggest that, firstly, the control system operated based on the characteristics of the PV panel and improved its working efficiency. Secondly, the operating parameters of the PV panels are recorded in the Excel file for the operation without using specialized software. Thirdly, if the system is combined with SiO_2/TiO_2 detergent mentioned by many researchers, it could greatly improve the efficiency of PV cells system.

The use of Matlab software supports simulation of the characteristics of PV cells from specifications provided by the manufacturer in the Excel file that will allow the operator to simulate and check the output parameters of the PV panel. The Guide interface accommodate more conveniences for the operation, control, and management.

REFERENCES

[1] Trinh Trong Chuong, 2008. Voltage stability analysis of grid connected wind generators, International Conference on Electrical Engineering (ICEE), No. O-054, Japan.

[2] Nguyen Duc Minh, Bui Van Huy, Ngo Thi Quan, Nguyen Quang Ninh, Trinh Trong Chuong, 2019. Research and design of Grid connected inverter in photovoltaic system with SVPWM Technique. International Journal of Engineering Technologies and Management Research, 6 (11), 18-31. Doi: 10.5281/zenodo.3563050.

[3] Bao Cun-hui, 2014. Modeling and MPPT of photovoltaic power generation system. China Academic Journal Electronic Publish House. 5(38), No.5, pp 851- 854.

[4] Rauschenbach H S, 1980. Solar cell array design handbook. USA: Litton Educational Publishing Inc.

[5] M.B. Eteiba, E.T. El Shenawy, 2013. A Photovoltaic (Cell, Module, Array) simulation and Monitoring Model using Matlab/Gui Interface. International Journal of Computer Applications, Vol. 69, No.6, May, pp 14-28.

[6] Tang Binwei, Yuan Tiejiang, Chao Qin, Tuerxun Yibulayin, 2012. Simulation Models for Photovoltaic and Grid Connected Simulation Based on PSCAD. China Academic Journal Electronic Publish House. No 21, pp 31-35.

[7] Von K. Sudhakar, 2013. Matlab modelling and Simulation of solar PV panel. Lambert Academic Publishing, ISBN: 978-3-659-41080-2.

[8] Jyoti Mishra, Ritula Thakur, Alok Deep, 2017. Arduino based Dual Axis Smart Solar Tracker. International Journal of Advanced Engineering, Management and Science (IJAEMS), ISSN: 2454-1311. Vol.3, Issue 5, May, pp 532-535. https://dx.doi.org/10.24001/ijaems.3.5.20.

[9] Dipti Bawa, C.Y. Patil, 2013. Fuzzy control based solar tracker using Arduino Uno. International Journal of Engineering and Innovative Technology (IJEIT), Vol. 2, Issue 12, June, pp 179-187.

[10] Sapthashree, Anvitha S Acharya, Namratha N Rao, Bhagyashree, Carol D'Almeida, Ms. Sowmya Bhat, 2018. Arduino Base low cost Active dual Axis Solar Tracker. International Journal of Scientific & Engineering Research. Vol. 9, Issue 4, April, pp 152-154.

[11] Pratik Pawar, Ashish Yadav, Pritam Makwana, Shubham Pati, 2018. Solar Tracking System Using Arduino. International Journal of Scientific & Engineering Research Vol. 9, Issue 2, February, ISSN 2229-5518, pp 102-104.

[12] Syed Arsalan, 2013. Sun Tracking System with Microcontroller 8051. International Journal of Scientific & Engineering Research, ISSN 2229-5518. Vol. 4, Issue 6, June, pp 2998-3001.

[13] Shubhangibhatambrekar, Savitamohurle, Madhurikhandagale, Madhavichandlekar, Kavitachaudhar, 2015. A Tool for Solar Panel Tracking System using 8051 Microcontrol. International Journal of Advanced Computational Engineering and Networking, ISSN: 2320-2106. Vol.3, Issue 4, April.

[14] Shreyasi Chakrabory, Nilanjana Mukherjee, Rashmi Biswas, 2015. Microcontroller based Solar Tracker system using LDRs and Stepper Motor. International Conference on Microelectronic circuit and System (Micro-2015), pp 38-41.

[15] Yousef, H, 1999. Design and implementation of a fuzzy logic computer controlled sun tracking system. Proceedings of the IEEE International Symposium on Industrial Electronics, Vol. 3, pp 12-16. Doi: 10.1109/ISIE.1999.796768.

[16] F. Huang, G. Zhimin, T. Forughian, D. Tien, 1997. A new microcontroller based solar energy conversion modular unit. Proceedings of Power Conversion

Conference. 6 Aug. Doi: 10.1109/PCCON.1997. 638283.

[17] Jing-Min Wang, Chia Liang Lu, 2013. Design and Implementation of a sun tracker with a dual axis single motor for an optical sensor based Photovoltaic System. Sensors, pp. 3157-3168. Doi: 10.3390/s130303157.

[18] Kurdi, M., Dadykin, A., and Elzein, I, 2017. Navigation of Mobile Robot with Cooperation of Quadcopter, 9th International Conference on Advanced Computational Intelligence, Doha - Qatar, IEEE: pp. 30-36, ISBN: 978-1-5090-4726-0.

[19] Kurdi, M., Dadykin, A., and Elzein, I, 2017. Model Predictive Control for Positioning and Navigation of Mobile Robot with Cooperation of UAV, Communications on Applied Electronics. February, Vol.6, No.7, pp. 17-25.

[20] Kurdi, M., Dadykin, A., and Elzein, I, 2017. Design and Development of Efficient Guidance System Using Multifunctional Robot with Quadcopter, International Journal of Electrical Energy. June, Vol. 5, No. 1, pp. 81-86. Doi: 10.18178/ijoee.5.1

[21] Mei,Y., and Lu, Y, 2006. Energy efficient mobile robot exploration. International Conference on Robotics and Automation, 15-19 May, pp. 505–511.

[22] Erikson, R., and Dragan, M., 2001. Fundamentals of Power Electronics, Springer, Eddition 2.

[23] Michaelis,R., Mutti, R., Overmyer, J., and Taylor, O., 2004. All About Motors an NJATC Textbook, Thomson, pp. 202- 211.

[24] Ure, N., Chowdhary, G., Toksoz, T., Jonathan, P., Vavrina, M., and Vian, J., 2013. An Automated Battery Management System to Enable Persistent Missions with Multiple Aerial Vehicles, IEEE/ASME Transactions on mechatronics.

[25] L. Liqun, L Zhiqi, Chunxia, S. Zhiyi, 2012. Degraded output characteristic at atmotspheric air pollution and ecocnomy analysis of PV power system: a case study. Przegl. Elektrotech (Electr.Rev) 88 (9A), pp 281-284.

[26] Sami Virtanen, 2015. Self-Cleaning Technologies on solar modules and their effect on performance. Bachelor's Thesis. Technology Degree Program in Energy Technology. JAMK University of Applied Sciences.

[27] Sami Virtanen, 2018. Photocatalytic, superhydrophilic, self-cleaning TiO_2 coating on cheap, light-weight, flexible polycarbonate substrates. Applied Surface Science. Vol. 458, 15 November, pp 917-923.

[28] A. Syafiq, A. K.Pandey, 2018. Advances in approaches and methods for self-cleaning of solar photovoltaic panels. Solar Energy. Vol. 162, March, pp 597-619.