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Studying and analyzing the performance of photovoltaic system by using fuzzy logic controller

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ABSTRACT

The main objective of this paper is to implement a circuit-based simulation model of a photovoltaic (PV) cell in order to investigate the electrical behavior of the practical cell with respect to some changes in weather parameters such as irradiation and temperature. The research focuses on using a simulation model to achieve the maximum power of solar energy by using the maximum power point tracking (MPPT) controller. The circuit simulation model consists mainly of three subsystems: PV cells: DC/DC converter; and MPPT controller-based logic fuzzy control. Dynamic analysis of the system is carried out and the results are recorded. The maximum power control function is achieved with the appropriate power control of the power inverter. Fuzzy logic controller has been used to perform MPPT functions to get maximum power from the PV panel. The proposed circuit was implemented in MATLAB/Simulink and the results show that the output sequence is non-linear and almost constant current to the open circuit voltage and the power has maximum motion to voltage for certain environmental conditions.

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1. INTRODUCTION

After centuries of using fossil fuel power the global image is changing, and renewable sources are increasingly considered to be one of the key factors for the future development of the earth. The main source of energy is still fossil fuels that give 85-90% energy [1]. Oil is the most significant of 35%, while coal and natural gas are equally represented. Almost 8% of the energy comes from nuclear power plants, and only 3.3% of energy comes from renewable sources [2]. Since we will have to meet all of our energy needs in renewable energy sources in the future, we need to invent a way to turn renewable resources into useful energy and thereby ensure the further advancement of mankind [3]. Therefore, the use of renewable energy sources has an increasing role in world energy production. Nature supplies us daily, free of charge, with large quantities of sun and wind. On the other hand, there is less and less oil, coal and other exploited assets on our planet, whose cost is parallel to that fact [4]. In addition, over the last few years, man is increasingly apparent that excessive utilization of fossil fuels has significantly and most probably irreparably damaged the living environment, not only himself, but also all species on earth. The conclusion is that by using the sun and the wind we save the material to achieve the same goal we would achieve by using traditional means at a much higher cost [5]. In order to overcome this obstacle as soon as possible, new technologies, management methods and other elements that would contribute to the lower cost of energy produced are intensively explored. Less than one sunny hour is enough to cover the total energy need of nearly 7 billion people living on this planet [6].

There are some studies on the design of solar system which conducted by some researchers such as Bong Yann Kai. The survey shows that a new design that has some economic advantages of the photovoltaic (PV) system in the residential sector in Malaysia [7]. According to the new renewable energy policy, the 10th Malaysian Plan will be implemented in 2011. This designed renewable energy generator can be installed in homes with a dedicated network boot system [2].

Regarding the application of solar energy, this job is to conquer unique space and street lighting [8]. One of the oldest investigations was Park Albuquerque and the Recreation Department of New Mexico [9]. The system design uses two PV panels of 50 W with a 35 W sodium lamp. Standard systems will last six hours at night and are designed to use conventional conversion due to the maximum design of the racing force in the development phase. The results of the study showed the potential of solar energy to illuminate street lights and laid the foundations for future plans [10].

In this study, it had been shown how to build alternative energy systems, connect them to a traditional electricity network, and increase the volume or amount of energy resources to meet load needs [11]. The influence of alternative energy on the traditional electrical network is also considered to improve the stability of the system [12]. However, most design rules are based on a "need for implementation" strategy instead of reliability. Alternative alternatives, diseases and some results for assessing the reliability of energy systems [9].

Jasvir Singh studies is based on the research and design of a network. These systems are connected to a wider network. The PV system connects to the user's network using a high-quality converter that converts DC power from the AC solar panel to meet the electrical requirements of the network [13]. The solar energy generated by the system during the day is immediately used or sold to electric power companies. In the evening, when the system cannot provide power in case of an emergency, electricity can be charged from the network [14].

2. CIRCUIT CONFIGURATION

The PV system consists of a PV panel, a DC/DC converter, a regulator and a load. Figure 1 shows PV. The PV system consists of a PV panel model, a DC/DC converter and PV panel monitoring controller. Figure 2 shows the PV system implemented in the MATLAB/Simulink software package [15].

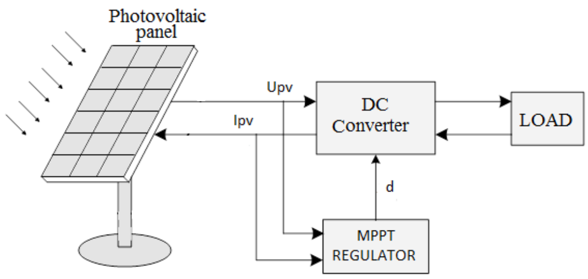

Figure 1. Block diagram of the PV model

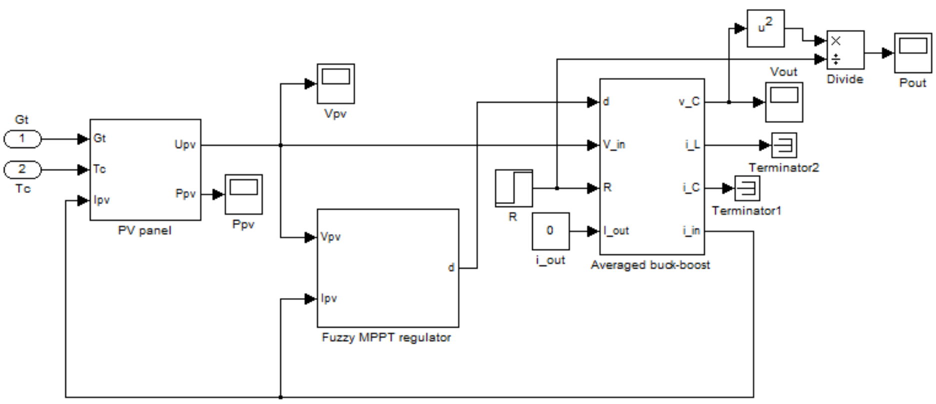

Figure 2. PV model implemented in MATLAB/Simulink

3. CONTROL STRATEGY

The input parameters in the model are the solar allowance Gt, the temperature of the cell Tc and the current of the Ipv panel, while the output parameters of the panel control voltage and the power of the panel Ppv [16]. During the simulation, 3 PV panels were used in the series. The simulation parameters were taken from the real SOLVIS SV215 PV panel, and are shown in Table 1.

Table 1. Parameters of the PV panel SOLVIS SV215 [17]

Parameter description	Symbol	Value
Reference solar allowance	Gt, Ref.	1000 (W/m^2)
Solar allowance	Gt	Variable
Reference temperature of PV cells	Tc, Ref.	298 K
Temperature PV cells	Tc	Variable K
Reference current of PV panel	Ipv, Ref.	7.97 A
Reference current of saturation diode	I0, Ref.	1.76 E-7 A
Reference voltage PV panel	Voc, Ref.	35.4 V
Temperature dependence coefficient (Ipv)	KI	0.0049
Temperature dependency coefficient (Voc)	KV	- 0.12
Serial resistance	Rs	0.3 Ω
Parallel parasitic resistance	Rp	400 Ω
Ideal diode factor	a	1.35
PV number of cells connected in series	ns	60
Number of serial assemblies	Ns	3
Number of panels connected in parallel	Np	1
Semiconductor energy	Eg	1.14 eV
Boltzmann constant q C Elemental	K	1.3806 X 10 $^{-23}$ J/K

3.1. DC converter

The rotor drive role is that, together with the power-limiting power regulator, ensures the operation of the PV panel at the maximum power point [18]. Figure 3 shows the general buck-boost converter scheme. The DC converter can be obtained by means of a cascade connection of two basic DC inverters: downstream and upstream. When the switch is turned on, the source transmits the energy coils and the diode is loosely polarized [19]. When the switch is off the energy accumulated in the coil is shedding the expense. In this analysis, we assume that the output capacitor is large enough that the output voltage can be considered constant.

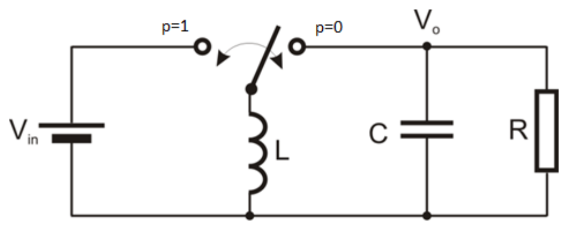

Figure 3. DC/DC converter

The mathematical formulas describing descending-ascending DC converter without loss in elements are given by the following equations [20]:

$$C\frac{dv_c}{dt} = (1-p)i_L - \frac{v_c}{R} - i_o \quad (1)$$

$$L\frac{di_L}{dt} = uv_{IN} - (1-p)v_c \quad (2)$$

When considering resistors and inductors:

$$C = \frac{dv_c}{dt} = (1-p)i_L - \frac{v_o}{R} - i_o \quad (3)$$

$$L = \frac{di_L}{dt} = pv_{IN} - (1-p)v_o - R_L i_L \quad (4)$$

$$v_o = \frac{Rv_C}{R+R_C} + \frac{RR_C}{R+R_C}((1-p)i_L - i_o) \quad (5)$$

For downlink (RL and RC), the mathematical formulas describing the DC direct current converter from Figure 3 are as [20]:

$$\frac{V_{out}}{V_{in}} = -\frac{D}{1-D} \quad (6)$$

Where D is the duty cycle.
In this work, the non-inverting DC converter had been used whose scheme is shown in Figure 4.

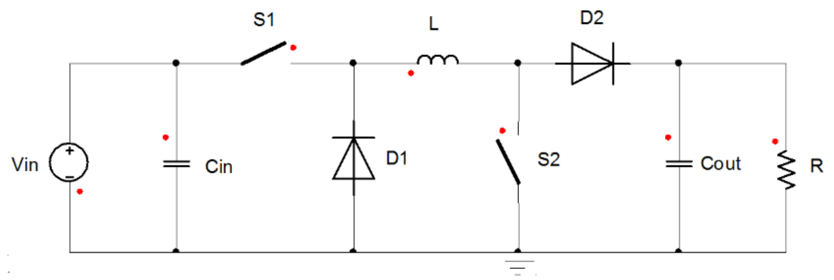

Figure 4. Non-inverting DC converter

In Table 2 the selected parameters are displayed for the needs of our DC converter. From the given parameters it is necessary to calculate the inductance L and the C-capacity. Output current and resistance we can calculate the load using the relation [21]:

$$I_{out} = \frac{P_{out}}{V_{out}} \quad (7)$$

$$R_{out} = \frac{V_{out}}{I_{out}} \quad (8)$$

Table 2. Calculation of DC inverter parameters

Parameter description	Symbol	Value
Output current	Iout	8.83 A
Load resistance	Rout	6.32 Ω
Input current	Iin	8.34 A
Conductor factor	D	0.45
Coil current	IL	15.7 A
Inductance	L	526 µH
Capacity	C	675 µF

Since the input voltage ranges from 60 V to 100 V, the following parameters are solved in 2 cases, when Vin=60 V and when Vin=100 V.

$$I_{in} = \frac{P_{out}}{V_{in}} \quad (9)$$

$$D = \frac{V_{out}}{V_{out}+V_{in}} \quad (10)$$

$$I_L = \frac{I_{in}}{D} \quad (11)$$

Inductance L and capacity C can be calculated using the following equations [21]:

$$L = \frac{V_{in}.D}{\Delta I_L.f} \quad (12)$$

$$C = \frac{I_{out}.D}{\Delta V_c.f} \quad (13)$$

Where ΔI_L is the permissible coil current wavelength (20%) and ΔV_C is the permitted voltage wavelength (0.5%)

3.2. MPPT controller

The goal of the maximum power point tracking (MPPT) controller is to bring the PV system to the maximum power point of the power and maintain it in the system regardless of the disturbance of the panel temperature changes, change the allowance or change the system load [22]. In Figure 5, the PU characteristic is shown with the point of maximum power. The maximum power point is at the extreme point where the derivation is . On the left side, the derivative characteristics are positive, while on the right side it is negative [23].

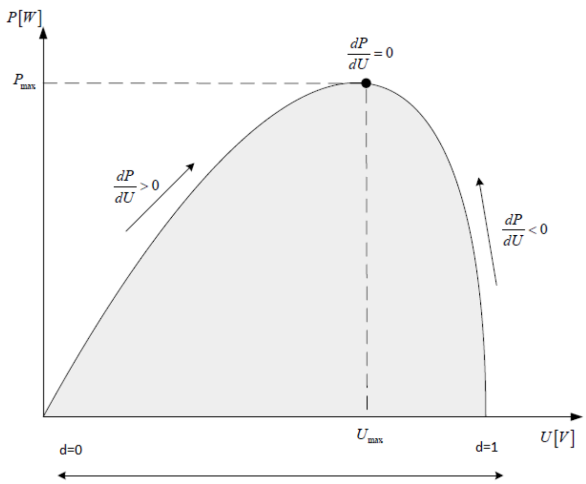

Figure 5. PU characteristic with the point of maximum power

Since the point of maximum power lies in the extreme point where it is valid [24]:

$$\frac{dP}{dU} = o \quad (14)$$

The expression (14) can be expressed as:

$$\frac{dP}{dU} = \frac{d(U.I)}{dU} = I.\frac{dU}{dU} + U.\frac{dI}{dU} = I + U\frac{dI}{dU} \quad (15)$$

$$\frac{dP}{dU} = 0 \Rightarrow -\frac{I}{U} = \frac{dI}{dU} \quad (16)$$

When the condition in (16) is met then the maximum power is achieved.

3.2.1. Realization of fuzzy controller for maximum power point

Monitoring regulator performance can be seen in Figure 6. The entry into the fuzzy regulator is a condition in (16), and output is a change of the driving factor. The condition in (16) tells us which side the characteristics are, and the point of maximum power regulates depending on the distance from the centre of the fuzzy logic [25]. The fuzzy controller for monitoring the maximum power point in MATLAB/Simulink is shown in Figure 6. When designing a fuzzy controller, 7 functions of membership function (triangular shape) were used. Affinity function is defined for how much of the current power point deviates from the maximum power point as shown in Figure 7.

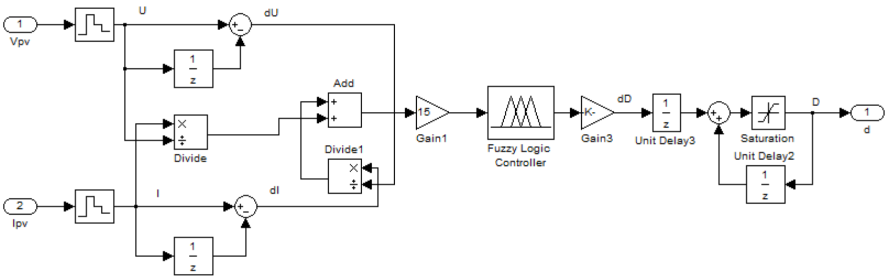

Figure 6. Fuzzy MPPT controller implemented in MATLAB/Simulink

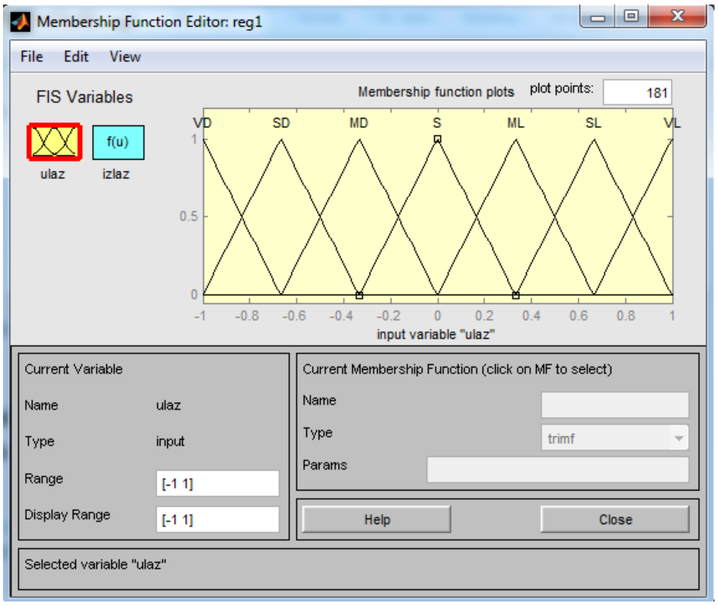

Figure 7. Functions of fuzzy MPPT controller

4. RESULTS AND DISCUSION

The following figures illustrates the responses obtained by simulating a fuzzy controller for monitoring the maximum power point:

a. In Figures 8 and 9, the responses to change of allowance are shown in the first case from 600 W/m^2 to 700 W/m^2 and in the second case from 600 W/m^2 to 500 W/m^2, in both cases the temperature Tc is constant and is equals to Tc=25 °C.
b. Figures 10 and 11 show changes in temperature, in the first case at 20 °C to 25 °C and in the other case at 30 °C to 25 °C, in both cases the allowance Gt is constant and is Gt=700 W/m^2. On the responses light blue is the maximum possible power that can be extracted from the PV system for the given amount and temperature.
c. On the responses, we see that the power of the PV panel and the output power from the DC converter do not achieve the maximum amount of power available, but achieve the amount of power that is very close to maximum power.
d. There is an uneven error in the input power, the regulator sometimes used to, and sometimes enter the area when it is. This depends on the workstation since the area is defined as a fuzzy set and the system is nonlinear.

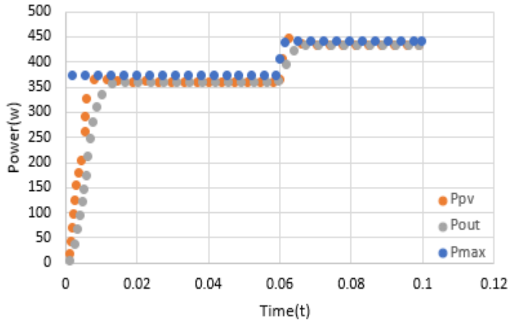

Figure. 8 Response to change of allowance from 600 W/m^2 to 700 W/m^2

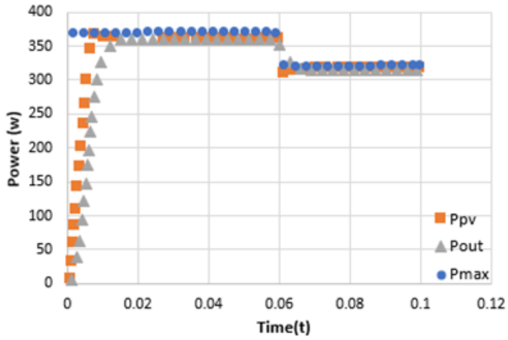

Figure 9. Response to change of allowance from 600 W/m^2 to 500 W/m^2

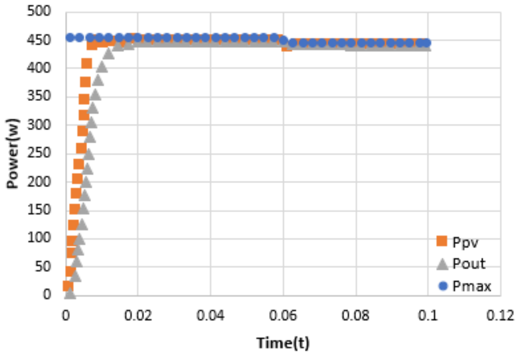

Figure 10. Response to change of allowance from 600 W/m^2 to 500 W/m^2

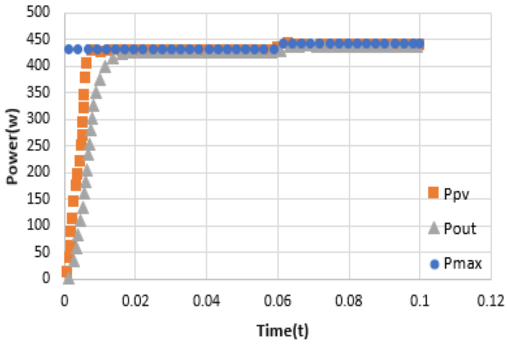

Figure 11. Response to temperature change with 30 °C at 25 °C 52 9

5. CONCLUSION

In this work a PV panel simulation and a controller for maximum power point monitoring at its current-voltage characteristics was conducted. It was designed to use the fuzzy logic controller to bring the PV system to the maximum power point of the power and maintain it in the system regardless of the disturbance of the panel temperature changes, change the allowance or change the system load. The operation of the PV model has been simulated by using the MATLAB/Simulink environment, which shows that the power of the PV panel and the output power of the inverter do not achieve the maximum amount of power available, but achieve the value of power that is very close to maximum power. The simulation results show the non-linearity of the output array. The IV characteristic shows an almost constant current to open a series of voltages and the characteristics of PV indicate that the power has increased relative to the voltage for certain environmental conditions. With changes in radiation cells, the actual changes are changing linearly because the voltage changes in the cells differ in the logarithmic, which is clear from the simulation equations. The proposed model can be used for research activities in the application of solar energy with a maximum power monitoring scheme for the PV system.

REFERENCES

[1] A. Rahimi, A. Kasaeipoor, E. H. Malekshah and L. Kolsi, “Natural convection analysis by entropy generation and heatline visualization using lattice Boltzmann method in nanofluid filled cavity included with internal heaters-Empirical thermo-physical properties,” *International Journal of Mechanical Sciences*, vol. 133, pp. 199–216, 2017, doi: 10.1016/j.ijmecsci.2017.08.044.

[2] R. Arshad, S. Tariq, M. U. Niaz and M. Jamil, "Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling," 2014 International Conference on Robotics and Emerging Allied Technologies in Engineering (iCREATE), 2014, pp. 292-295, doi: 10.1109/iCREATE.2014.6828382.

[3] K. Sukarno, Ag. S. Abd Hamid, J. Dayou, M. Z. H. Makmud, and M. S. Sarjadi, “MEASUREMENT OF GLOBAL SOLAR RADIATION IN KOTA KINABALU MALAYSIA,” *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 15, pp. 6467-6471, 2015.

[4] K. Sukarno, Ag. S. Abd Hamid, C. H. W. Jackson, C. F. Pien, and J. Dayou, “Comparison of Power Output Between Fixed and Perpendicular Solar Photovoltaic PV Panel in Tropical Climate Region,” *Advanced Science Letters*, vol. 23, no. 2, pp. 1259–1263, 2017, doi: 10.1166/asl.2017.8379.

[5] T. Nehari, M. Benlekkam, D. Nehari, and A. Youcefi, “The Effect of Inclination on the Passive cooling of the solar PV panel by using Phase change Material,” *International Journal of Renewable Energy Research (IJRER)*, vol. 6, no. 1, pp. 132–139, 2016.

[6] A. Pradhan, S. K. S. Parashar, S. M. Ali, and P. Paikray, “Water cooling method to improve efficiency of photovoltaic module,” in *2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES)*, 2016, pp. 1044–1047.

[7] A. K. Tripathi, M. Aruna, and C. S. N. Murthy, “Output power loss of photovoltaic panel due to dust and temperature,” *International Journal of Renewable Energy Research*, vol. 7, no. 1, pp. 439–442, 2017.

[8] G. Colț, "Performance evaluation of a PV panel by rear surface water active cooling," 2016 International Conference on Applied and Theoretical Electricity (ICATE), 2016, pp. 1-5, doi: 10.1109/ICATE.2016.7754634.

[9] A. Belhamadia, M. Mansor, and M. A. Younis, “A study on wind and solar energy potentials in Malaysia,” *International Journal of Renewable Energy Research (IJRER)*, vol. 4, no. 4, pp. 1042–1048, 2014.

[10] C. S. Sreejith, P. Rajesh and M. R. Unni, "Experimental study on efficiency enhancement of PV systems with combined effect of cooling and maximum power point tracking," *2016 International Conference on Inventive Computation Technologies (ICICT)*, 2016, pp. 1-5, doi: 10.1109/INVENTIVE.2016.7823185.

[11] Y. Ghiassi-Farrokhfal, F. Kazhamiaka, C. Rosenberg and S. Keshav, "Optimal Design of Solar PV Farms With Storage," in *IEEE Transactions on Sustainable Energy*, vol. 6, no. 4, pp. 1586-1593, Oct. 2015, doi: 10.1109/TSTE.2015.2456752.

[12] A. Sajimon and R. Chacko, "Design of reflectors for a canal top solar power plant," *2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS)*, 2017, pp. 1-4, doi: 10.1109/ITCOSP.2017.8303146.

[13] Y. Mizuno *et al*., "Improvement of solar radiation model based on physical parametrization," *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, 2015, pp. 789-792, doi: 10.1109/ICRERA.2015.7418519.

[14] A. Lekbir, C. K. Gan, M. R. Ab Ghani, and T. Sutikno, “The recovery of energy from a hybrid system to improve the performance of a photovoltaic cell,” *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 3, pp. 957-964, 2018, doi: 10.11591/ijpeds.v9.i3.pp957-964.

[15] M. Dhimish, V. Holmes, B. Mehrdadi, M. Dales and P. Mather, "Output-Power Enhancement for Hot Spotted Polycrystalline Photovoltaic Solar Cells," in *IEEE Transactions on Device and Materials Reliability*, vol. 18, no. 1, pp. 37-45, March 2018, doi: 10.1109/TDMR.2017.2780224.

[16] Y. Soufi, M. Bechouat, and S. Kahla, “Fuzzy-PSO controller design for maximum power point tracking in photovoltaic system,” *International Journal of Hydrogen Energy*, vol. 42, no. 13, pp. 8680–8688, 2017, doi: 10.1016/j.ijhydene.2016.07.212.

[17] C. Fant, C. A. Schlosser, and K. Strzepek, “The impact of climate change on wind and solar resources in southern Africa,” *Applied Energy*, vol. 161, pp. 556–564, 2016, doi: 10.1016/j.apenergy.2015.03.042.

[18] Z. Massaq, A. Abounada, and M. Ramzi, “Fuzzy and predictive control of a photovoltaic pumping system based on three-level boost converter,” *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 3, pp. 1183–1192, 2021, doi: 10.11591/eei.v10i3.2605.

[19] J. C. Y. Hui, “Adaptive Slope-Assist Maximum Power Point Tracking and Power Limit Search for Intelligent Power Management of Small Wind Energy Systems,” Ph.D. dissertation, Dept. ECE, Queen’s University, Kingston, Ontario, Canada, 2014, Available: https://central.bac-lac.gc.ca/.item?id=TC-OKQ-12627&op=pdf&app=Library&is_thesis=1&oclc_number=1033004244.

[20] M. I. Awad, A. A. Dehghani-Sanij, D. Moser and S. Zahedi, "Motor electrical damping for back-drivable prosthetic knee," *2016 11th France-Japan & 9th Europe-Asia Congress on Mechatronics (MECATRONICS) /17th International Conference on Research and Education in Mechatronics (REM)*, 2016, pp. 348-353, doi: 10.1109/MECATRONICS.2016.7547167.

[21] T. Ezzeddine, “Reactive power analysis and frequency control of autonomous wind induction generator using particle swarm optimization and fuzzy logic,” *Energy Exploration & Exploitation*, vol. 38, no. 3, pp. 755–782, 2020, doi: 10.1177/0144598719886373.

[22] M. A. M. Ramli, S. Twaha, K. Ishaque, and Y. A. Al-Turki, “A review on maximum power point tracking for photovoltaic systems with and without shading conditions,” *Renew. Sustain. Energy Rev.*, vol. 67, pp. 144–159, 2017.

[23] H. Abbes, K. Loukil, H. Abid, M. Abid and A. Toumi, "Implementation of a Maximum Power Point Tracking fuzzy controller on FPGA circuit for a photovoltaic system," *2015 15th International Conference on Intelligent Systems Design and Applications (ISDA)*, 2015, pp. 386-391, doi: 10.1109/ISDA.2015.7489260.

[24] B. Subudhi and R. Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," in *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 89-98, Jan. 2013, doi: 10.1109/TSTE.2012.2202294.

[25] M. Kermadi and E. M. Berkouk, “Artificial intelligence-based maximum power point tracking controllers for Photovoltaic systems: Comparative study,” *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 369–386, 2017, doi: 10.1016/j.rser.2016.11.125.

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