

Analysis of Temperature effect on Power Productivity of Solar Panels in Residence Area

Ramaz A. M.Alzubeer*,Elfadil Zakaria[†],Abusabah I. A. Ahmed*,Samah H. H. Mohammed Khir [‡]

*Karary University, University of Science and Technology, Khartoum, Sudan

[†] College of Engineering, Sudan University of Science and Technology, Khartoum, Sudan

[‡]College of Engineering and Architecture, Shendi University, Shendi, Sudan

barlida990@gmail.com

Abstract

Solar panel temperature coefficient varies according to it's industry, relates to the rate at which the panel will under-perform at each increase in degree Celsius ($^{\circ}C$). Majority of panels available here in Sudan for residential and agricultural usage are Polycrystalline Chinese origin like A star have a temperature coefficient $-0.4\% / ^{\circ}C$, when tested under standard laboratory conditions, where ambient temperature is set to $25^{\circ}C$. But in practical installations is found $-0.025\% / ^{\circ}C$. The lower temperature coefficient, the better panel performance when the temperature rises. It's important to chose the perfect solar panel technology for optimum performance at a given location considering the average temperature. This research study is proposed for performance variations evaluation of the solar panel during the day related to the temperature in Khartoum, Sudan. Field data of produced power of residence area A Star Chinese origin panel serve in designed Solar Panel system were collected. These data were analyzed and compared to the calculated results and with the installed solar panels ratings.

Key words-Solar Panel, Power Productivity (PP), Temperature Coefficient, Heat Effect, Field Data

I. INTRODUCTION

Temperature of Solar Panel (silicon one) negatively affects its power productivity, as the temperature increases, while the current increased slightly the cell voltage decreased intensely, and thus the power production affected negatively, as the effect of solar cells on heat varies according to the technology used (increasing temperature is inversely proportional to solar cell efficiency) [1], [2]. Solar panels in direct power generation convert sunlight into electricity, the photovoltaic effect appear in the electrical power generation is due to fact of doped semiconductor materials forming a P-N Junction. Thinking about renewable energy for residential or agricultural applications the first choice is the solar panels, especially in hot countries like Sudan [3], Also .Sudan Located in northeastern Africa, has unstable and complex weather varies from very hot, to hot, moderate cool and rainy. The principal climatic aspects affecting building construction and comfort are solar radiation, temperature, humidity, wind speed and direction and precipitation. Sudan is classified into three climatic zones (First Zone, warm desert climate, Second Zone, warm semi-arid weather and Third Zone, tropical savanna climate) as shown in Fig. 1. For the residential application the installer will position several solar panels on the house's roof in whats called a solar array. The pre-designed number of required solar panels depends on several factors, beside designed load including the size and position of the roof, the daily received amount of sunlight at home position, and the type of solar panels selected. Sudan is equipped with a fundamental necessity to cultivate its solar capability the important factor is that sunshine averages 8.5 to 11 hours daily [4].

Solar Panels (SPs) absorb the sun light and generate Direct Current (DC) power applying Photo Voltaic (PV) cells. Sunlight hits the solar panels, lead to generate a DC electricity [5]. Then an inverting procedures carried out for alternating

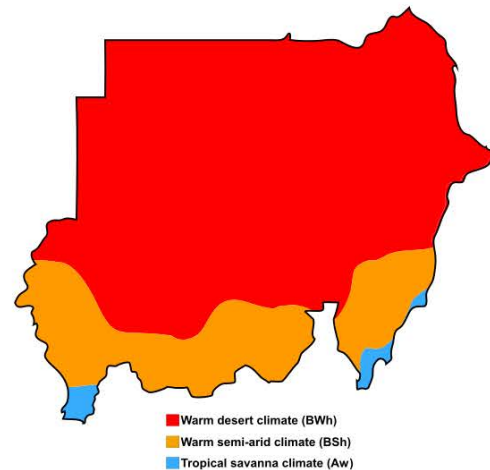


Fig. 1. Sudan map of Kppen climate classification depicted from [4]

current conversion [6]. For optimum power production several measures are taken such as recent control strategies for efficient tracking [7], [8].

Solar inverters are key factors of the solar power systems, because they convert the DC electricity in to AC. The AC power is more applicable for the majority of household electrical appliances [9], [10].

Photovoltaic cells absorb sunlight, then turn it into DC energy, through an inverter turns the DC energy into Alternating Current power to feed designed load which is equal to household electrical system [11], [12].

Photovoltaic modules when undergone a test at $25^{\circ}C$ temperature about $77^{\circ}F$ according to the Standard Test Condition (STC), and according to the installation area, Temperature can grave the output efficiency by 10 – 25%. As the surface

temperature of the solar panel increases, the output current increases exponentially, while the voltage is reduced linearly. In fact, the output voltage reduction is predictable, that it can be used to accurately measure temperature [13]. So, panel's heat can severely reduce the solar panels production of power. In the built environment, there are a number of ways to deal with this phenomenon [14], [15]. After the module technology is selected for installation, there are several ways to minimize the negative effects of high temperature :

- Rise up panels some considerable inches above the roof surface for coolness.
- Chose a good quality from the available panels with light-colored materials, to reduce heat absorption.
- The power system control units like inverters and combiners must be installed in shaded place.

II. SOLAR POWER SYSTEMS

Solar Power Systems (SPSs) are long lasting renewable energy sources which can be used almost anywhere subjected to the solar radiation. These systems are useful for rural areas as stand-alone source and also can be grid-tied for efficient power supply system. In Country like Sudan where there are big agricultural areas and no people live nearby Stand-alone SPSs are the best choice for irrigation. Such systems are capable of solving the irrigation problems beside lightening for big agricultural projects. The side effects of using SPSs in rural areas are dissertation fighting and economic issues by agricultural efficient production.

A. Types of Solar Panels (SPs)

The SPs are classified according to the production generation, applied technologies and performance abilities. The different types of solar panels made of mono-crystalline silicon or poly-silicon and are commonly used in traditional environments. According to the first generation of solar panels:

- Mono-crystalline Solar Panels (Mono-SI)
- Poly-crystalline Solar Panels (Poly-SI)

The different between two classes is clear as depicted in Fig. 2.

There are many factors that affect the power productivity SPs, despite the rating values provided by manufacturers listed according to the STC, including:

- Temperature.
- Amount of solar radiation reaching the surface of the solar cell.
- Objects that shade the parts of the solar cell.
- Dust.
- The angle of inclination of the sun (the angle of the suns fall line).

B. Solar Inverters

Solar inverters, convert the DC electricity produced by the solar PV panels to AC that can be used for both residential and agricultural applications. Solar inverters are very efficient electric equipment, 93-96% depending on the usage type and

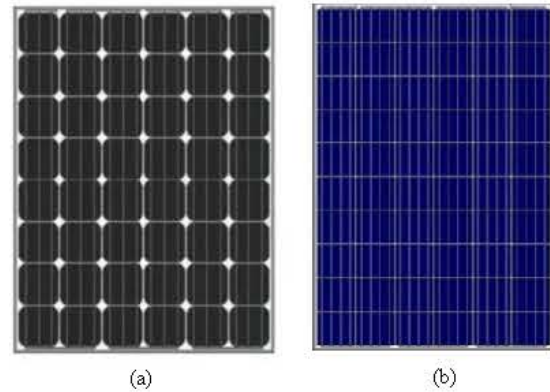


Fig. 2. First generation classification of solar panels: (a) Mono-crystalline; (b) Poly-crystalline.



Fig. 3. Copex Solar Power Inverter

power quantity. Solar inverters efficiency can be enhanced efficiently by Maximum Power Point Tracking (MPPT) [16]. Hybrid power systems include some other renewable source such as Wind Energy constant, step and variable wind speeds [17]. A dictation for optimum power generation can be achieved by a combination of current or voltage. Where it is will vary constantly according to light levels, shading, temperature and the characteristics of the solar PV panel. The Copex inverter used in this work is made by Copex Solar Energy Systems and Trading LLC, its depicted in in Fig. 3. The performance measures for inverters and inverting for residential loads are the efficiency and long life operation hours. The different types of solar inverters are String inverters, micro-inverters, hybrid inverters and power optimizers. Exploring the important characteristics of every type of solar inverter, to choose the right solar inverter for designed load.

C. Temperature Coefficient

The temperature coefficient of the SPs is one of the most important factor that affect the panel's efficiency. The main idea of manufactured country, it becomes clear to us that there are losses resulting from high temperature P_{max} . These losses due to high temperature is considered in this work to figure out the optimum power generation from the designed solar panels. SPs must pass the maximum power output test for practical application, they are tested at an industry standard temperature of $77^{\circ}F$. Generally, solar panels will begin to generate less power once the temperature rises above $77^{\circ}F$. The temperature coefficient value depends on the type and industrial proficiency of solar cell. There are a number of solar cells, including: Monocystic line and polycystic line cells have P_{max} from -0.35% to -0.50%. Digital cells have a classification from -0.20% to -0.25%. Halogen cells available in the international markets have a temperature equivalent P_{max} about -0.32%. That P_{max} depends on the temperature of the cell and not on the temperature of the air (you always find the temperature of the cell is greater than the temperature of the air as a result of the cells exposure to direct sunlight). The designer according to the SPS position and height must take in consideration the efficient conditions for Solar Panels. Fig. 4 shows the orientation of designed SPS in this work. A Star mono crystalline solar module SL550 - 120M, 3.8 meters height and 20° from horizontal.



Fig. 4. Solar Panels Orientation for optimum power generation (Khartoum, Sudan)

III. TEMPERATURE EFFECT ON SOLAR CELL

It is a change in efficiency to the bottom or higher when changing in degrees Celsius in the cell temperature, for example if maximum power -0.5% and the cell temperature is $25^{\circ}C$, this means that the solar panel decreases its efficiency proportionally to 5% when the temperature is $25^{\circ}C$. Example: location in Khartoum, Capital of Sudan, total energy needed 4150 wh, number of on-sun days per year 3, expected ambient temperature T_{Amb} is $20^{\circ}C$, available module SL 550-120m at $25^{\circ}C$, capacity of available batteries 200Ah, depth of discharge 0.8%, module power deficit to the rating at $25^{\circ}C$. Random day light readings are taken for the calculation, let's consider the following terms: solar radiation S_r in kilo watt

per square meter, if the daily solar radiation is $6.6 Kw/m^2$ what is solar radiation during noon time.

$$S_r = \text{daily}S_r * 4/L_h * 3.14 \quad (1)$$

where L_h is the light hours of the day.

The cell's temperature can be calculated as follows: defining the coefficients A and B,

$$A = CS_c - 20/0.8 \quad (2)$$

where CS_c is the cell specification constant, given for every cell type on the back.

$$B = 1 - (C_{eff}/0.9) \quad (3)$$

where C_{eff} is efficiency of the cell and its value is found in the specifications.

Lastly we can determine the SCT from Eq. 4.

$$SC_{temp} = 1 - (C_{eff}/0.9) \quad (4)$$

The calculated SCT, for the designed system where cells are exposed to a practical temperature and due to the lack of ventilation, we found that the effect of temperature deflection can be calculated as a power loss (P_{loss}) due to the deflection from standard as in Eq.5.

$$P_{loss} = \eta_T * (T_{Amb} - T_{real})/P_rmax \quad (5)$$

Where η_T is temperature coefficient, T_{Amb} is expected ambient temperature, T_{real} is real location temperature and P_rmax is the rated maximum power.

The number of modules for the designed load is equal to total energy needed per module's energy its (4150/538). 8 modules are needed as depicted in 4, the single plate capacity is 550W.

The required number of batteries for the designed load is equal to total energy needed times operating hours counter per battery capacity, $(4150*3/2400) = 6$ batteries (battery capacity is 200A).

To have an overview about the temperature effect on solar panels and the optimum power generation conditions, we conduct a trail of calculations during different day light levels and different days during one week. The captured cell temperature is depicted in Fig.5.

IV. COMPARISON BETWEEN STANDARD AND PRACTICAL VALUES OF SCT

Calculate ΔT the difference between the cell temperature and $25^{\circ}C$ (which is the temperature of choosing cells at work) achieved practically to evaluate the performance of chosen cell. The relation between temperature and solar radiation is determined by practical reading for performance evaluation and improvement. The registered values are depicted in Fig.6. The humidity in the area of installed stand-alone solar power system is proportional to the temperature. The designed and executed stand-alone solar power system shows excellent performance, full week of measuring shows the efficiency of the system. The system's main components are:

- Inverter 5kw.
- Number of modules 8 modules, 550w.
- Number of battery 6 battery, 200A @48volt.

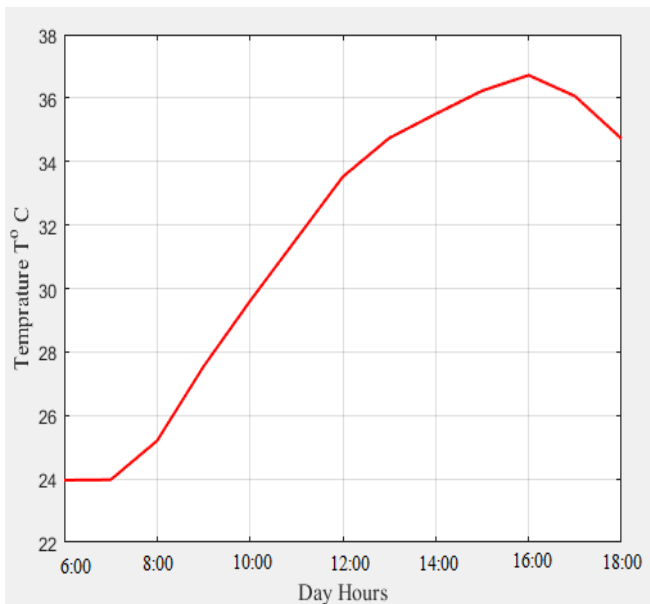


Fig. 5. Cell Temperature degree centigrade versus time (Khartoum, Sudan)

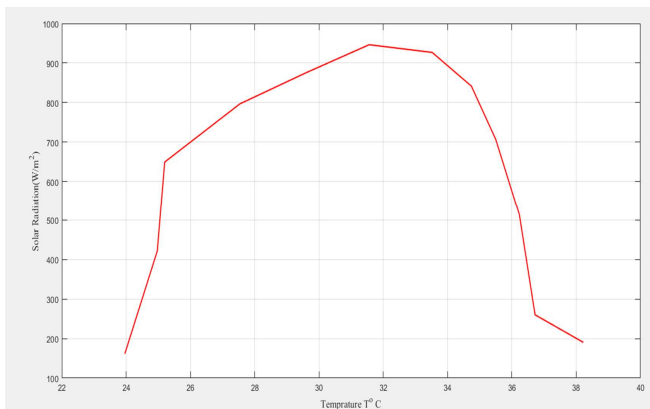


Fig. 6. Solar radiation versus Cell Temperature degree centigrade

V. CONCLUSIONS AND FUTURE WORK

This work executed to prove the variation of experimental solar panel data and the real practical values. The most important relationship for determining the specifications of solar panel approved by the manufacturer is practical operation observation. The data card that shows all the details of solar panel by manufacturer, or solar panel catalog for optimal operation conditions is always valid for practical operation. The deflection from the rating values is obtained and justified through practical trails of measurements for specified coordination in north Khartoum, Sudan.

The Performance of solar cells in different places is dependent on the difference of the environmental conditions and their output parameters in mother country and the working one. This performance parameters such as output voltage, current, power, and fill factor vary by temperature and environmental conditions. The executed experimental results proved that, the most significant changed by temperature is voltage which decreases with increasing temperature while output current

slightly increase by temperature. The designed power system is

- P(max) 550 w
- V (mp) 36.2V
- I (mp) 15.2A
- V(oc) 41.10V
- I (sc) 16.3A
- Maximum system voltag 100V
- Maximum series fuse rating 25A

Observing the average panel data parameter's deflection estimated throughout the day, it was observed that at the beginning and end of the day (6:00 AM and 7:00 PM) the highest values were found. On the other hand, the smallest deflections, on average, are between 1:00 PM and 3:00 PM, more precisely at 2:00 PM, when the smallest deflection is calculated for practically all the operation conditions.

ACKNOWLEDGMENT

This work was supported by karary University. The author would like to thank Staff of College of Graduate Studies and Scientific Research for such opportunity.

REFERENCES

- [1] Mohamed O. Babiker, "study on solar potential sudan- challenges and implementation approaches", The University of Warwick, 2020.
- [2] Ayat Y. Elshreef et al. "A Review in a Single-Stage Inverter Design for a PV Micro-grid Integration in Sudanese National Grid." 2021 31st Australasian Universities Power Engineering Conference (AUPEC), 2021.
- [3] A. M. Omer, "Renewable Energy Resources for Electricity Generation in Sudan", *Renew. Sustain. Energy Rev.* 11, 1481, 2007.
- [4] Kppen Climate Classification, Sudan map of Kppen climate classification, 2019.
- [5] S Vahedi et al., "Overcoming the Temperature Effect on a Single Junction and Intermediate Band Solar Cells Using Optical Filter and SECs", Research Square, 2021.
- [6] B. Almashary and Ahmed Telba, "Effect of High Temperature to Output Power of Solar Cell", *Proceedings of the World Congress on Engineering* 2018, 2018.
- [7] Abusabah I. A. Ahmed, H. Cheng, Z. Liangwei, M. Omer, X. Lin, "Online Walking Speed Control in Human-Powered Exoskeleton Systems Based on Dual Reaction Force Sensors", *Journal of Intelligent and Robotic Systems*, vol. 87, no. 1, pp. 59-80, 2017.
- [8] Abusabah I. A. AAhmed, Cheng Hong, Lin X., M. Omer and Atieno J. M., "Survey of On-line Control Strategies of Human-Powered Augmentation Exoskeleton Systems", *Advances in Robotics and Automation*, vol 5, no 3, pp pp. 34-44, 2016.
- [9] Renata L. Yang et al., "Photovoltaic Cell Temperature Estimation for a Grid-Connect Photovoltaic Systems in Curitiba", *Brazilian Archive for Biology and Technology*, vol. 62, 2019.
- [10] Qusay A. H. Al-Naser et al. "The Effect of Temperature Variations on Solar Cell Efficiency", *International Journal of Engineering, Business and Enterprise Applications (IJEBA)*, vol. 1, no 4, 2012.
- [11] Rafel Hekmat Hameed, "Mathematical Model to Investigate the Temperature Distribution for Photovoltaic Panels", *Journal of University of Babylon for Engineering Sciences*, Vol. (26), No. (8), 2018.
- [12] J. Adeeb, A. Farhan and A. Al-Salaymeh, "Temperature Effect on Performance of Different Solar Cell Technologies", *Journal of Ecological Engineering*, vol. 20, no 5, pp. 249254, 2019.
- [13] Osman W. Mohammed, Fathelrahman A. Elmahi "Prediction of Global Solar Radiation across the Region of Northern Sudan", *Journal of Karary University for Engineering and Science*, vol. 3, issue 1, 2023.
- [14] R. Eberle, S. T. Haag, I. Geisemeyer, M. Padilla, and M. C. Schubert, "Temperature coefficient imaging for silicon solar cells", *IEEE J. Photo-volt.*, Vol. 8, No. 4, pp. 930-936, 2018.
- [15] D. M. Tobnaghi, R. Madatov and D. Naderi, "The Effect of Temperature on Electrical Parameters of Solar Cells", *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 2, No. 12, 2013.

- [16] Sony V., Akshay S. A. and Raveendra R, "Maximum Power Point Tracking For Photovoltaic Systems", Proc. of Int. Conf. on Current Trends in Eng., Science and Technology, ICCTEST, 2017.
- [17] Zakieldean M. E. Elhassan, Abusabah I. A. Ahmed and Othman Hassen Abdalla, Approach Control of DFIG Rotor Side Converter Based on Grid Frequency Coordinated Control, Journal of Karary University for Engineering and Science, vol. 1, pp. 1-9, 2021.



Samah H. H. Mohammed Khir is a dean of college of Engineering and Architecture, Shendi University since 2020. She got her BSc. Degree from Nile Valley University in Electrical Power Engineering in 2017 and worked as teacher assistant at Shendi University. She got her master degree in Electrical Engineering, Power from Karary University in 2020. Her master research includes power system stability managing and control approach of doubly Fed Induction Machine for stable operation. Now she is a PhD student at Karary University. Her current research includes Hybrid Renewable Energy System Stability Investigation. Also, the application of Back- to Back Converters in both rotary side and Grid Side of Grid Tied Hybrid Renewable power system.



Ramaz A. M. Alziber got her B.S. degree in electrical Engineering (Power) from Engineering Science Academy, Khartoum, Sudan, in 2013, and M.S. degree in Electrical Power from Academy of Engineering and Medical Sciences, Khartoum, Sudan, in 2021. She worked for Sudanese airlines as Electrical Engineer from 2014 to 2015, for Sudanese railways company ltd from 2015 to 2016. she is a lecturer at Africa University, college of Engineering Since 2020. Eng. Ramaz is Executive Engineer in Solar and Modern Equipment Company. Now she

is a PhD student at Karary University, Her research interest is related to Renewable Energy and Solar Systems.



Elfadil Zakaria Yahia is an Associate Professor in the Department of Electrical Engineering, Sudan University of Science and Technology (SUST). He received the PhD, MSc and BSc degrees from Sudan University of Science and Technology (SUST). He is a member of Sudan Engineering Society Journal (SESJ), Sudan Engineering Council (SEC) and the Engineering Faculty Board (SUST). His research area includes Voltage Stability, Load flow analysis and Power System Stability and Control. Dr. Elfadil Zakaria Yahia has more than 15 academic publica-

tions and he is a reviewer for many journals and conferences. Now he is teaching Power System Analysis, Power System Stability and control, Electrical Circuits, Computer Application, Electric Power System and Electrical Machine.



Abusabah I. A. Ahmed is an Associate Professor in the College of Engineering at Karary University. He received the M.Sc. degree and Ph. D. degree in Electronic Engineering from University of Electronic Science and Technology of China in 2013 and 2017. His research area includes Robotics Control, Predictive and Adaptive Control and Neural Networks. Dr. Abusabah I. A. Ahmed has 15 academic publications and he is a reviewer for many journals and conferences. Now he is teaching Neural Networks and Systems Modelling and Simulation for

graduate students, and Control Theory, Automatic Control, Modern Control and Fuzzy Control for junior students at Karary University.