Performance analysis of photovoltaic panel using machine learning method

Ganesh S. Wahile[1,2], Srikant Londhe[1], Shivshankar Trikal[2], Chandrakant Kothare[3], Prateek D. Malwe[4,5], Nitin P. Sherje[4], Prasad D. Kulkarni[6], Uday Aswalekar[7], Chandrakant Sonawane[8], Mustak Maher Abdul Zahra[9], Abhinav Kumar[10]

[1]Department of Mechanical Engineering, Government College of Engineering, Amravati, India
[2]Department of Mechanical Engineering, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, India
[3]Department of Mechanical Engineering, Shri Shankar Prasad Agnihotri College of Engineering, Wardha, India
[4]Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology, Pimpri, India
[5]Department of Mechanical Engineering, Walchand College of Engineering, Sangli, India
[6]Department of Mechanical Engineering, Annasaheb Dange College of Engineering and Technology, Ashta, India
[7]Department of Mechanical Engineering, Vidyavardhini College of Engineering and Technology, Vasai, India
[8]Department of Mechanical Engineering, Symbiosis Institute of Technology, Symbiosis International University, Pune, India
[9]Department of Computer Techniques Engineering, Al-Mustaqbal University College, Hillah, Iraq
[10]Department of Nuclear and Renewable Energy, Ural Federal University, Yekaterinburg, Russia

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ABSTRACT

Demand for energy is increasing as the world’s population grows, fossil fuels deplete on a daily basis, and climate conditions change. Renewable energy is more important than ever. Solar energy is the most accessible and cost-effective renewable energy source available today. Photovoltaic (PV) cells are the most promising way to convert solar energy into electricity. Wind speed, ambient temperature, incident radiation rate, and dust deposition are some of the internal and external variables that affect photovoltaic panel performance. Unwanted heat from the sun’s rays raises panel temperatures, reduces the amount of energy that solar cells can produce, and lowers conversion efficiency. Solar panels must be adequately cooled. The current research is focused on improving photovoltaic panel performance. The experimental system includes a fully automated photovoltaic panel, a microcontroller (NodeMCU8266), a DC pump, voltage and temperature sensors. The experiment was carried out with and without cooling of the PV panel. The findings suggest that keeping PV panel temperatures close to ambient temperatures improves performance. The Wi-Fi module collects real-time data on PV panel temperature, irradiation, ambient temperature, water temperature, and PV panel power output. The collected data was analyzed using machine learning. The PV panel’s performance was analyzed using the linear regression method.

Corresponding Author:

Prateek D. Malwe
Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology
Pimpri, Pune, Maharashtra, India
Email: prateek0519@gmail.com

1. INTRODUCTION

The need for energy supply for industrial, commercial, and residential applications is increasing due to economic growth, facility expansion, and infrastructure develop-ment. As a result, solar energy could continuously meet all of the world’s energy needs, both present and future. Because of this, it is considered one of the most promising sources of unconventional energy [1]. Solar cells, also known as solar photovoltaic (PV) systems, are apparatuses that transform photons in sun rays into electrical energy. PV solar technology is a related field. The conventional silicon solar cell is made up of a thin wafer with a thicker layer of silicon doped with boron (p-type) on top of silicon doped with phosphorus (n-type). An electrical field is created where these two materials in contact form a p-n junction near the top surface of the solar cell. When sunlight hits the semiconductor surface, an electron emerges and is pulled to the n-type material. It will increase the quantity of electricity that can flow through n-type semiconductors and the amount of positives in p-type semiconductors. The term PV effect refers to this. Numerous factors may impact the effectiveness of solar PV systems, including filthy solar panels, cloud cover, sun intensity, relative humidity, and heat accumulation on the solar PV cell [2]. When a PV panel absorbs solar radiation, the temperature rises, Which reduces the energy production efficiency of PV cells. Under standard test conditions (STC), the efficiency of solar PV panels sold today ranges from 13% to 20%. The solar PV panel's operating temperature and the sunlight it receives impact how much energy is produced. As the temperature rises, the electrical efficiency of the cells declines. Standard flat panel PV modules' electrical output can be increased with cooling because it prevents the PV cells from heating up to a point where irreparable damage occurs. Passive and active cooling systems are the two categories into which the cooling systems have been divided. The active cooling system requires external electricity to operate the system's cooling mechanism. However, the passive cooling system doesn't require [3]. With reference to literature review it observed that the incident of solar radiation on PV panel raises the temperature of solar cells which effect degradation of performance. Active water-cooling technique is more significant. The present research on. To developed fully automatics system to maintain PV panel temperature nearer to ambient temperature, to check the performance of PV module with and without cooling and analyze that data using machine learning technique. The work involves constructing microcontroller internet of things (IoT) based water sprinkler cooling systems using temperature detection relay mechanisms, improving the performance of PV panels through active cooling approaches, and analyzing them using machine learning techniques.

In the present research work introduction section deals with summary of research conducted, in literature review section deals with various cooling methods were used to improve the performance of PV panel. In experimental methodology section gives brief description about specification of components required for experimentation and the complete procedure to conduct experimentation. In results and discussion section deals with using experimental data analyzed performance of PV panel and conclusion section gives the output of research for the usage of innovative technique percentage of electrical efficiency improved.

2. LITERATURE REVIEW

Laseinde and Ramere [4] focused on applying automatic water spray systems, which efficiently close the gap that solar panels in hot climates experience. Beginning with an Arduino board, solar panels, and other components in microcontroller-based thermal management of PV panel cooling control using a water spray system, performance was found to be improved. This work used a thermal control feedback system to build and create a solar collector cooling algorithm, boosting the solar panel array's efficiency by 16.65%. Rodríguez-Gómez *et al.* [5] discussed that installing solar panels for power generation in urban areas using open-source software to guide decision-making over prospective optimum locations is simpler. It also includes information from the light detection and ranging (LiDAR) images used to create height models of urban objects, as well as data from the meteorological department, such as temperature, radiation, and precipitation values.

The totals six main phases explain of the cross-industry process for data mining (CRISP-DM) approach of data mining projects are depicted in Figure 1. It helpful to developed software such as collection of data, process, modelling, and evaluation a modelling process explain briefly. Elias *et al.* [6] conducted experimentation to examine and assess the performance of four solar cooling systems. The mechanism developed a ground-mounted solar PV system for reducing temperature. According to this study's findings, cooling out of four technologies has been established, and active cooling systems work better overall than passive cooling systems installed with lower temperatures of up to 11.1%, increasing electrical power output by 4.9%.

Chuluunsaikhan *et al.* [7] discussed the environmental factors that affect PV panel power output, including weather, air pollution, humidity, moisture, and others. Six different machine learning techniques, including linear regression, k-nearest neighbour (KNN), gradient boosting (GB), support vector regression (SVR), random forest (RF), and multilayer perceptron (MLP), were used in this investigation. And the results showed that all models had the best accuracy, around 95%. Top linked traits and the weather have produced comparable positive results. Leary [8] conducted a study which specifically focused on PV cooling with an aluminum heat sink, incorporated heat pipes, heat pipe and heat sink cooling in tandem, and active cooling using water. The findings show that active water cooling is the most effective and should be employed. Active water cooling is frequently impractical, though. Thus, a consistent supply of cold water is required in chilly locations. To balance the pump's minimal power usage, cooling must be substantial. In many circumstances, cooling is demonstrated to be most feasible with embedded heat pipes and a medium-sized aluminum heat sink. This approach makes the most sense in desert environments with limited water supplies and strong winds. Choosing the appropriate PV cooling depends on various environmental factors, as is true for most technical decisions. Rakino *et al.* [9] it is dis-cussed those numerous researchers have tried to increase the effectiveness of cooling systems for solar panels. A passive cooling mechanism slightly lowers the surface temperature. Yet, it boosts effectiveness. This study suggests combining heat-sink and water-cooling technologies to increase the manufacturing performance of solar panels. The proposed system outperforms the other compared systems, according to experiments. Compared to a standard solar panel, a solar panel with a heat sink, and a solar panel with water, it decreases the average surface temperature by 12.66%, 10.13%, and 8.96%, respectively. The suggested method's output voltage is 21.49%, 4.66%, and 8.34% higher than the alternatives. The proposed cooled panel outperforms the conventional solar panel by 47.71%. Nasir *et al.* [10] water sprinkled on PV panel by force convection the degradation of PV temperature open circuit voltage was increased by 9%.

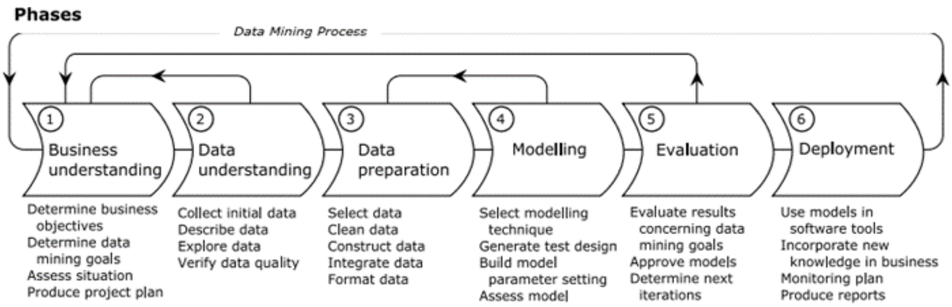

Figure 1. Outline of the CRISP-DM approach [5]

Pujotomo and Diantari [11] discuss the issues occurring in PV panels due to increases in the temperature of PV module. The re-search aimed to maintain the PV panel performance while minimizing the solar panel's temperature. The characteristics of the PV surface temperature, whether there are problems with the process of adjusting the surface temperature of the PV solar energy generator, are addressed in this research. Due to the temperature increase, a decrease in the voltage value but an increase and stability in the current value following an increase in temperature. As a result, the value of the output solar panel power will only reach its peak when the temperature is between 32°C and 50°C, more or lower than expected. Underestimate his force in the procession of the temperature rise brought on by an increase in solar intensity maximum power output at 11:00 on June 14, 2017, trial day.

Indugowda [12] thermal deterioration is the term used to describe the decline in a solar module's working surface temperature. The heat stored during the PV cell operation can be reduced by cooling the module. Crystalline silicon currently yields between 15% and 16%, and some studies predict that, under laboratory settings, it will eventually reach a limit of around 25%. Solar panel testing procedures in laboratories typically involve irradiation of 1,000 W/m^2 and a temperature of 25°C. When a PV module is overheated, its output power performance decreases by 0.4-0.5% in steps 1°C above its normal test condition. Thus, the concept of cooling off PV has taken on significant relevance. Milind *et al.* [13] the water flow over the surface of PV panel which degradation of temperature and improvement of electrical efficiency of PV panel. The comparison between PV panel cooling using natural and force convection shown in the research, it observed that force convection cooling reduced maximum temperature [14]. Ahmed and Mohammed [15] deposition of dust on PV panel with degradation of efficiency. Haurant *et al.* [16], Dimri *et al.* [17] enhancement of PV panel efficiency using coolant such as water, air and nanoparticles mix with water. Salih *et al.* [18], Luo *et al.* [19] heat sink as extended area for more dissipation of heat with air as coolant used to improve the electrical efficiency of PV panel [18], [19].

Emam *et al.* [20], Khanna *et al.* [21] the PV panel equipped with phase change materials which enhancement of performance. Kalogirou and Tripanagnostopoulos [22], Rabie *et al.* [23] with degradation of PV panel temperature the research shown that with increased in 1°C temperature, electrical efficiency decreased by 0.5%. Abolzadeh and Ameri [24], Nižetić *et al.* [25] PV panel cooling using water spray on front surface gives significant results. Jakhar *et al.* [26] water used as coolant to cool PV back side for the enhancement of performance. Vartak *et al.* [27] numerical analysis was done using CFD software of absorber tube to analyze the charging and discharging of phase change material (PCM). Wahile *et al.* [28] phase change materials were used for energy storage applications like, waste heat recovery from PV panel, internal combustion engine, condenser, and radiator.

3. EXPERIMENTAL METHOD

The experimental set-up photograph shown in Figure 2 consists of measuring instru-ments like pipes and sensors mounted on the panel. The experiment was performed for two days, from 23rd and 24th February 2023. The testing set-up was kept at an angle of 20° with the help of a stand and facing south, as shown in Figure 3. The measurement devices were temperature sensors (DS18b20), current sensors (ACS712), voltage sensors (AI0315) and solar power metres (KM-SPM-11) for the measurement of PV panel temperature, voltage, current, and surrounding solar radiation, respectively describe in Table 1. The Figure 4 shows voltage sensor (AI0315). The experimental set-up consists of an automated water spraying system that was conceived and developed to keep the minimum temperature of the PV panel using a combination of hardware components like microcontroller ESP-32, temperature sensor, relay module, DC pump and adafruit input-output (IO) software the complete set up mounted on pcb circuit shown in Figure 5. Monitoring the PV panel efficiency throughout the day while taking factors of the solar panel like current, voltage, temperature, and solar irradiance in measurement. The Figure 6 shows solar power meter (KM-SPM-11) respectively.

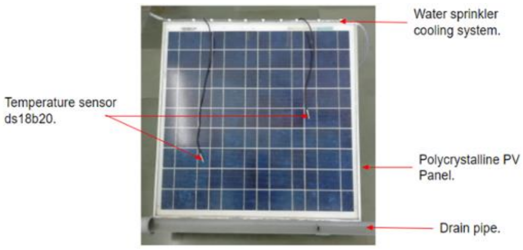

Figure 2. Actual photograph of the experimental setup

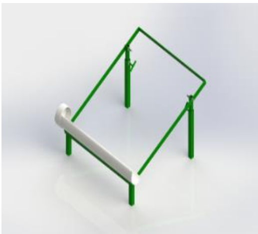

Figure 3. CAD model of stand

Figure 4. Voltage sensor (AI0315)

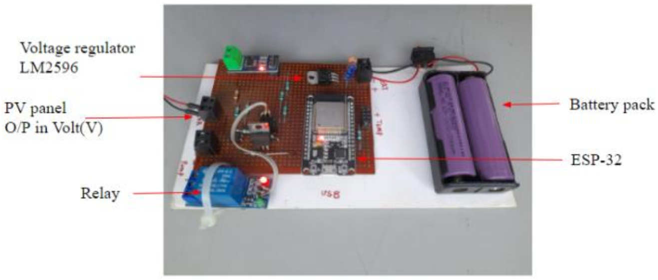

Figure 5. Circuit diagram

Figure 6. Solar power meter (KM-SPM-11)

Table 1. Detail specifications of the instruments/measurement devices used

Items	Model	Descriptions
Solar panel	Polycrystalline	Capacity: 60-Watt, voltage: 20 V, current: 3 A
Microcontroller	ESP 32	Operating voltage: 3.3 V; operating current; 80 mA
		Total pins: 38 Nos
Temperature sensor	DS18b20	Operating voltage: 5 V; temperature range: -55 to 145 °C
Relay module	5V single channel relay	Operating voltage: 5 V
DC pump	Micro submersible pump	Operating voltage: 5 V; flow rate: 80-120 L/h
		Maximum lift: 40-110 mm
Current sensor	ACS712	Operating voltage: 5 V; sensor output: analog
Voltage regulator IC	LM25796T	Operating voltage: 5 V; input voltage: Up to 40 V
Voltage sensor	AI0315	Operating voltage: 5 V; voltage detection range: Up to 25 V
Solar power meter	KM-SPM-11	Measuring range: 1,999 w/m^2
Battery	ICR-18650 25 C	Nominal voltage: 3.7 V; nominal capacity: 2,500 mAh

The temperature sensors were used to monitor the PV panel’s temperature. The algorithm sets the maximum and minimum temperatures of the PV panel to activate and deactivate the DC pump for cooling the PV panel. The set maximum temperature of 45°C begins cooling the PV panel by activating the submersible pump and water sprinkler system. The system is connected to Adafruit IoT software, where the live real-time data of the PV panel in terms of temperature and voltage gets fed continuously every 8 minutes. Temperature measuring equipment was used to double-check the solar panel’s temperature (Thermogun). A solar power metre is a device used to measure solar irradiance. A digital multi-meter, a testing instrument that measures current in amps, voltage in volts, and resistance in ohms, is used in this project. Table 1 shown detail specification of measuring instrument used in experimentation.

4. RESULTS AND DISCUSSIONS

The performance of PV panel without and with cooling compared in outdoor conditions for two days. The experiments were performed from 10:00 am to 4:30 pm for two days. Without a cooling system, the PV panel’s temperature and voltage readings were collected on day one. The results of the PV panel temperature against the time of day were plotted. Figure 7 shows the temperature readings fluctuating throughout the day. Figure 8 shows variation in solar irradiation with time in a full day. However, a noticeable peak occurred in the time interval of 11:30 am–11:47 am. It is deemed that these peaks are contributed by the high solar irradiance, due to which the PV panel temperature rises quickly.

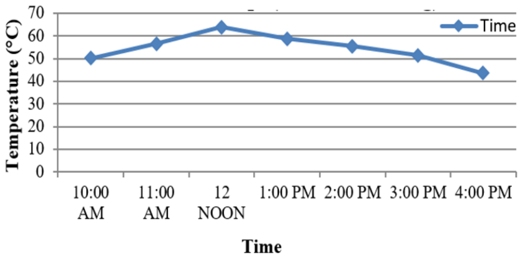

Figure 7. Variation in temperature of PV panel with time (without cooling)

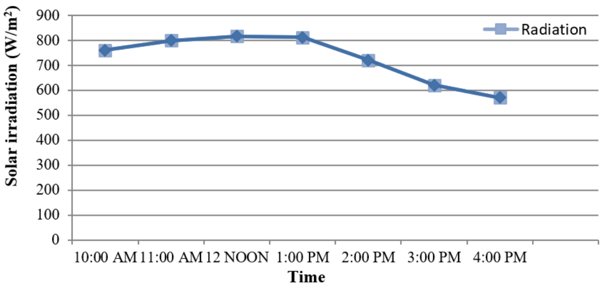

Figure 8. Variation in solar radiation with time (without cooling)

Figure 9 shows the variation in the output voltage of the PV panel concerning time without a cooling system. It observed that output voltage decreased with the increased temperature of the PV panel. According to the experimental findings, the PV panel temperature was 63.75°C and its output voltage was 19.03 V. Figure 10 shows the variation in the temperature and output voltage of the PV panel concerning time without a cooling system. It observed that with increasing temperature output voltage decreased. Figure 11 illustrates variation in temperature of PV panel with respect to time for PV panel with cooling system. It has been noted that as the PV panel temperature approaches ambient temperature, the output voltage increases.

Data from a PV panel’s first day of operation without a cooling system was analyzed, and the observation from data was observed that the PV panel showed its maximum output in the range between 45°C to 54°C. The water cool system is used to maintain the PV panel comfort temperature, which results in increased efficiency. In Figure 12, it was observed that when the solar panel cooling process was applied, the PV panel’s temperature was set to be maintained at 44°C, given its maximum voltage of 19.80 V.

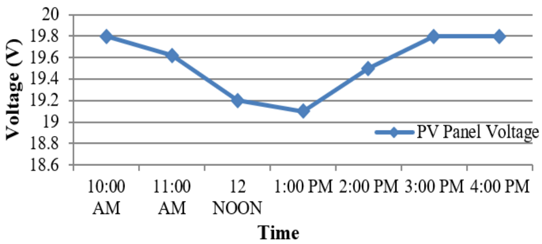

Figure 9. Variation in voltage of PV panel with time (without cooling)

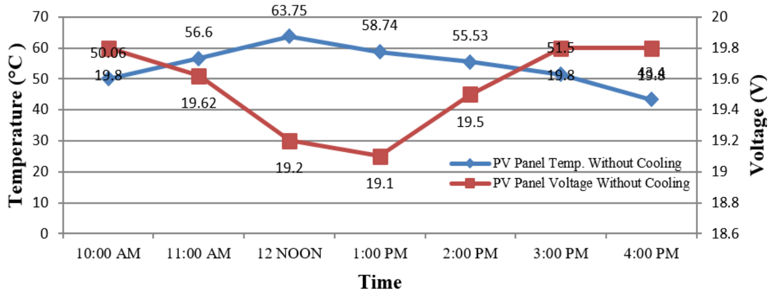

Figure 10. Variation in temperature and voltage of PV panel with time (without cooling)

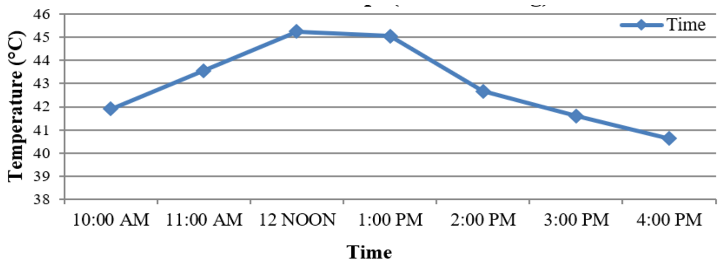

Figure 11. Variation in temperature of PV panel with time (with cooling)

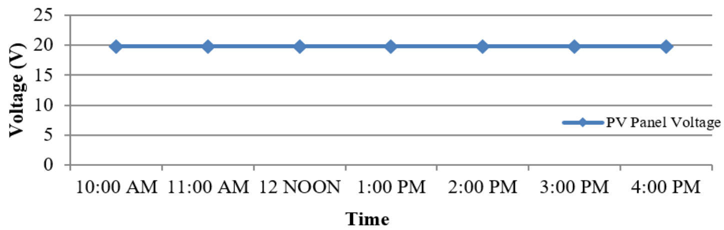

Figure 12. Variation in voltage of PV panel with time (with cooling)

Figures 13 and 14 shows a comparison between without and with cooling methods of PV panel with time, temperature, and voltage. It observed that the PV panel temperature rose during experimentation, which negatively impacted its output voltage. The water cool system is used to maintain the PV panel comfort temperature, which results in increased efficiency. The results observed that without cooling PV panel temperature reached 65°C with an output voltage of 19.03 V. With cooling PV panel temperature reached 44°C with an output voltage of 19.80 V. Fluctuation was observed in the voltage when the cooling system was not provided and constant voltage when cooling system was applied. It observed that with a cooling system, the panels produce higher output. It provides a dust-free environment for the panels to operate. The study's use of a water-cooling system helped it achieve its goal of lowering the solar panels' overall temperature.

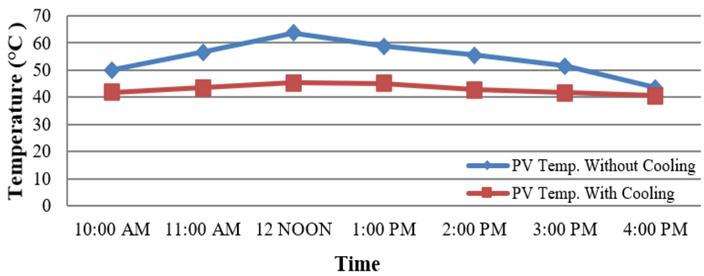

Figure 13. Variation in temperature with time comparative analysis of with and without cooling of PV panel

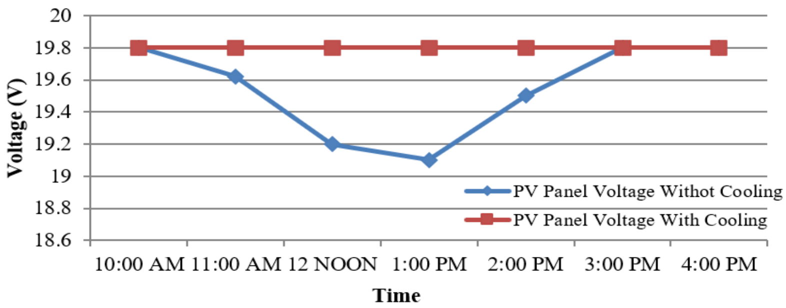

Figure 14. Variation in voltage with time comparative analysis of with and without cooling of PV panel

5. MACHINE LEARNING MODEL

In current research work, supervised machine learning, linear regression has been implemented in this prediction model. The experimental dataset was inserted in the algorithm as a CSV file. Split up the same dataset into train and test data sets in the ratio of 80:20 proportions. The dataset model must be trained in Jupiter's notebook. Input data collected from the PV panel regarding surface temperature in degrees Celsius. It shows predicted output of Volt (V) concerning PV panel surface temperature. The process flow chart of the execution of the machine learning algorithm is shown in Figure 15.

The observed dataset was analyzed using linear regression, and the graphs were plot-ted. Figure 16 shows that the regression line's slope was negative for the parameters of the PV panel without cooling systems and that the dependent variable (Y) and the independent variable (X) have a negative relationship. As the temperature rises, PV panel production declines. The process uses a statistical approach and machine learning algorithm, which works by analyzing the historical and current data given by user input and predicting the future outcomes related to it.

In Figure 17, the dataset of PV panel without a cooling system has been assigned to a machine learning algorithm, and the user input temperature was 58°C, and the predicted voltage is 19.51 V. Figure 18 shows that a zero-regression graph with a constant horizontal line without any slope lies on it, and all the predicted data points lie on it. The PV panel output has been preserved by employing the active cooling technique, and there is no variation in the predicted value, i.e., voltage. In Figure 19, the dataset of the PV panel with the cooling system has been assigned to a machine learning algorithm, the user input temperature was 58°C, and the predicted voltage is 19.8 V. At the same user-input temperature, it has been found that the maximum voltage of solar panels was predicted with cooling systems compared to the predicted voltage without cooling systems.

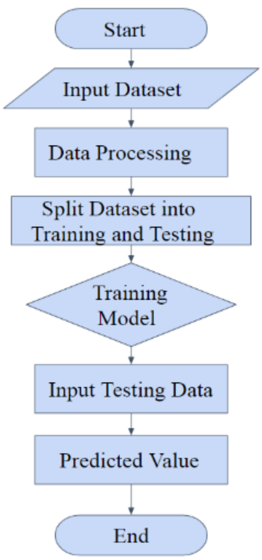

Figure 15. Machine learning algorithm flow chart

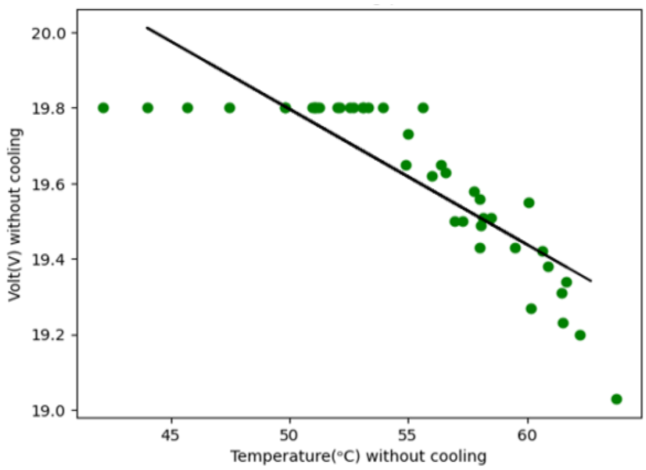

Figure 16. Variation in voltage with temperature of PV panel (without cooling)

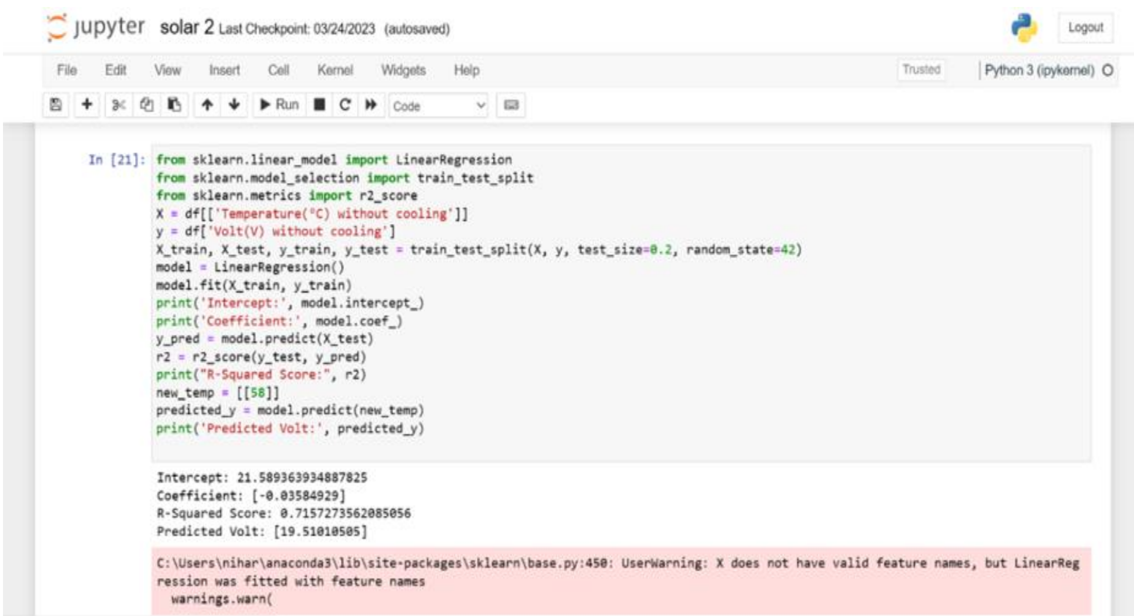

Figure 17. Prediction model for without cooling of PV panel

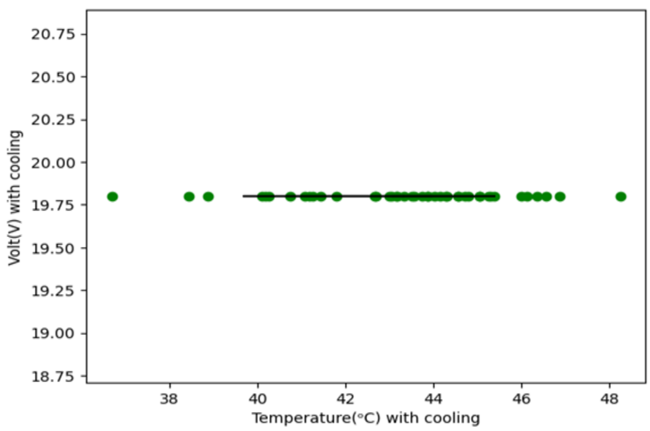

Figure 18. Variation in voltage with temperature of PV panel (with cooling)

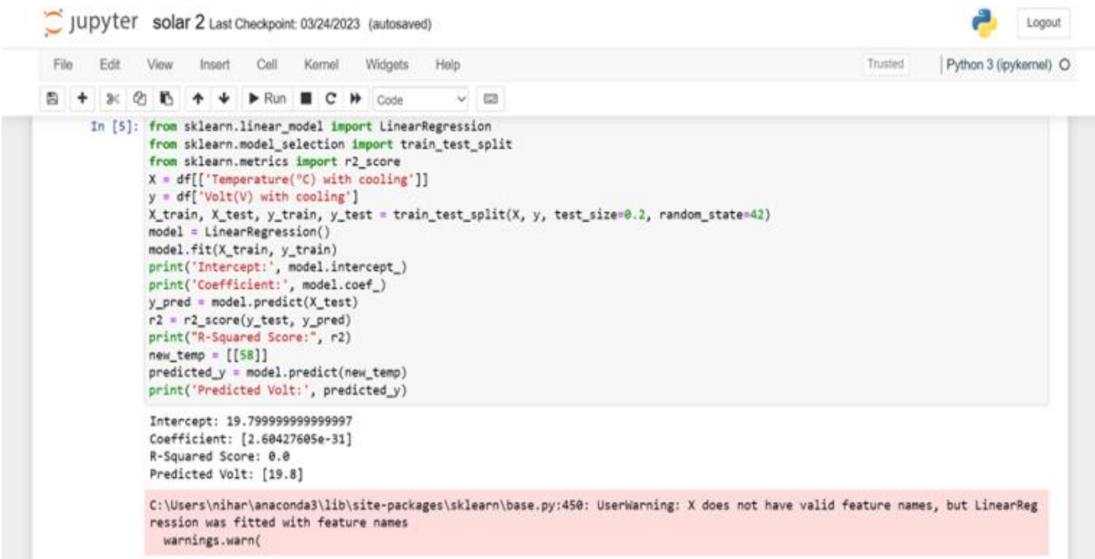

Figure 19. Prediction model for with cooling of PV panel

6. CONCLUSION

The PV panel with and without cooling was tested experimentally using a machine learning model. It has been designed and developed in the present research. The research on the water sprinkler forced convection cooling towards PV solar cells. It observed that with increased temperature of PV panel output voltage decreases. The conclusions of the present research work can be summarized as follows. When the photovoltaic panel was tested with and without cooling system. It observed that the output of PV panel was higher than without cooling. The experimental findings observed that when the cooling system was applied, the temperature of the PV panel was set to be maintained at 44°C, given its maximum voltage of 19.80 V. The machine learning model for PV panel with cooling has been observed as a zero-regression graph with a constant horizontal line without any slope, and all the predicted data points lie on it. As the temperature dropped, the PV panel output rose. According to the experimental findings, the PV panel without cooling the temperature was 63.75°C, and the output voltage was 19.03 V. The machine learning model for PV panel without cooling shows that the slope of the regression line is downward; this causes PV panels to produce less energy as the temperature rises. The research improves efficiency and provides a dust-free environment for the panels to operate at their maximum capacity.

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BIOGRAPHIES OF AUTHORS

Ganesh S. Wahile is a self-motivated and dedicated full-time Assistant Professor working in the Department of Mechanical Engineering at Shri Sant Gajanan Maharaj College of Engineering, Shehaon, Maharashtra, 444203 India. He is a Ph.D. research scholar in the Mechanical Engineering Department at Government College of Engineering, Amaravati, Maharashtra, India. His research focuses on photovoltaic panel, mechatronic, internet of things, waste heat recovery. Ganesh has worked as an Assistant Professor with a making teaching experience of 8 years and 6 months. Ganesh has published 18 research papers in various journals/conferences/book chapters on the international and national levels. He can be contacted at email: ganeshwahilemech@gmail.com.

Shrikant Londhe is a self-motivated and dedicated full-time Associate Professor working in the Department of Mechanical Engineering at Government College of Engineering, Amravati, Maharashtra, 444604 India. He has completed a Ph.D. in Thermal Engineering. His research focuses on CFD, photovoltaic panel, nano particles, heat transfer and fluid power. He has worked on many MoUs and consultees to the industry. He has worked as an Associate Professor with a making teaching experience of 30+ years. He has published 10 research papers in various journals/conferences/book chapters on the international and national levels. He has reviewed various manuscripts. He can be contacted at email: sdlondhe@gmail.com.

Shivshankar Trikal is a self-motivated and dedicated Head of Department (HOD) and full-time Professor working in the Department of Mechanical Engineering at Shri Sant Gajanan Maharaj College of Engineering, Shegaon, Maharashtra, 444203 India. He has complete Ph.D. in System Engineering from Sant Gadge Baba Amravati University, Amravati, Maharashtra, India. His research focuses on design and development of die, cavity, machine tools, and product development. He has done many MoUs and consultees to the industry. He has worked as a Professor with a making teaching experience of 25 years. He has published 19 research papers in various journals/conferences/book chapters on the international and national levels. He has reviewed various manuscripts. He can be contacted at email: trikalsp2020@gmail.com.

Chandrakant Kothare Ph.D. (Mechanical Engineering) is working as an Associate Professor and Head of Mechanical Engineering Department at Shri Shankar Prasad Agnihotri College of Engineering, Wardha, Maharashtra, India. He is an experienced academic dean with a demonstrated history of working in the education management industry. Strong education professional with a Ph.D. focused on mechanical engineering from Nagpur university. ANN, CFD and mathematical modelling are my assets. Spent near about 7 years researching future fuel of petrol engines to improve efficiency and reduce exhaust emissions. Software tester in energy conservation. Skilled in thermal analysis, CFD Analysis, project management, research and development (R&D), administration and leadership. He can be contacted at email: chandrakant.kothare@rediffmail.com.

Prateek D. Malwe is a self-motivated and dedicated full-time Assistant Professor working in the Department of Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, Maharashtra, 411018 India. He is a Ph.D. research scholar supported by the AICTE's National Doctoral Fellowship (NDF) program in the Mechanical Engineering Department at Walchand College of Engineering, Sangli, Maharashtra, India. His research focuses on waste heat recovery, the organic rankine cycle, energy and exergy analysis, refrigeration, and the cold chain. Prateek has worked as an Assistant Professor with a making teaching experience of 5 years & 11 months, research as 3 years and 4 months; thereby making a total experience of 9 years and 3 months. He has published 42 research papers in various journals/conferences/book chapters on the international and national levels. Till now, he has reviewed 100+ manuscripts since he is serving as an active reviewer for 30+ journals. He has also been awarded *"Silver Medal"* for acquiring 2nd rank amongst all the disciplines of M.Tech. students. He can be contacted at email: prateek0519@gmail.com.

Nitin P. Sherje is a dedicated professional currently serving as a full-time Professor and Head in the Department of Mechanical Engineering at Dr. D. Y. Patil Institute of Technology in Pimpri, Pune, Maharashtra, India (Pin code: 411018). With a comprehensive background spanning over 20 years, his specializes in research areas such as smart fluids, materials, vibration, semiactive controls, and more. His valuable expertise extends to seven years as the Head of the Mechanical Engineering Department, where he has demonstrated leadership and commitment to academic excellence. He has made significant contributions to the field, having authored 41 research papers published in various prestigious international and national journals, conferences, and book chapters. In addition to his research accomplishments, he has actively contributed to the academic community by organizing five international conferences in the role of convener. His influence doesn't stop there; he has also delivered keynote speeches at various conferences, showcasing his profound insights and expertise in the realm of mechanical engineering. He can be contacted at email: sherje.nitin@gmail.com.

Prasad D. Kulkarni is currently working as an Associate Professor in the Department of Mechanical Engineering of Annasaheb Dange College of Engineering and Technology (ADCET), Ashta, Sangli, Maharashtra.416301. He has been awarded his Ph.D. in Mechanical Engineering in 2019 from VTU, Belgaum University. He has a total of 25 years of experience including teaching, research, and industrial. He can be contacted at email: pdk_mech@adcet.in.

Uday Aswalekar is working as Professor in the Department of Mechanical Engineering at Vidyavardhini College of Engineering and Technology Vasai Road Palghar Maharashtra. He completed his Ph.D. in Ergonomics and Safety Management in 2018 from S.G.G.S. Institute of Technology Nanded Maharashtra. He was 25 years he had published more than 25 research papers in various journals/conferences. He had received the research grants from University of Mumbai and received 14 lacks fund from AICTE under MODROB scheme. He can be contacted at email: uday.aswalekar@vcet.edu.in.

Chandrakant Sonawane is Professor at Mechanical Engineering Department, Symbiosis Institute of Technology (SIT), Symbiosis International University, Pune, Maharashtra, India. He received his Ph.D. from Aerospace Engineering Department, Indian Institute of Technology Bombay (IITB), Mumbai, India, in 2013. He received a bachelor of engineering degree in mechanical engineering from North Maharashtra University, India, in 2001 and master of engineering degree in mechanical engineering (cryogenic engineering) from Gujarat University, India, in 2003. He has published 60+ research papers in various journals/conferences/book chapters on the international and national levels. He also received grant of 75 lacs from various funding agencies like SERB, and DRDO. His research activities mainly involve the development of a computational fluid dynamics (CFD) solver for fluid-structure interaction (FSI) problems, and moving boundary problems. We have also developed solution-dependent weighted least square algorithms for high-order accuracy on unstructured meshes. We are also developing high-performance computing–Parallel/MPI-based algorithm development using Open ACC and Open MP. We have successfully solved several problems of practical interest involving numerical heat and mass transfer for applications like helical heat exchanger systems, heat exchangers with fluid flowing with blended nano-material, solar desalination systems, solar dryers, wind turbines, cascaded cyclone separators for waste management of STP plants. He can be contacted at email: chandrakant.sonawane@sitpune.edu.in.

Mustak Maher Abdul Zahra has a Ph.D. in Communications and Electronics specialty at Electrical Engineering Department-College of Engineering-University of Babylon since 2023. He got his B.Sc. and M.Sc. in Electrical Engineering from the University of Babylon-Iraq in 2010 and 2017 respectively. His recent research interests include AI, neural networks, optical communications systems, wireless back haul 5G systems, mm waves, and massive MIMIO systems. He can be contacted at email: musaddaqmahir@mustaqbal-college.edu.iq.

Abhinav Kumar is affiliated with Ural Federal University (UrFU), Department of Nuclear and Renewable Energy. He has completed his Doctor of Philosophy in Mechanical Engineering. He is working on Renewable energy systems like Solar PV and PTSC systems, high temperature superconducting magnets and cables. He can be contacted at email: drabhinav@urfu.ru.