International Journal of Robotics and Control Systems
Vol. 2, No. 2, 2022, pp. 370-378
ISSN 2775-2658
http://pubs2.ascee.org/index.php/ijrcs

Techno-Economic Analysis of a 12-kW Photovoltaic System Using an Efficient Multiple Linear Regression Model Prediction

Pouya Pourmaleki [a,1,*], Willis Agutu [b,2], Ali Rezaei [c,3], Nima pourmaleki [d,4]

[a] Department of Electrical and Computer Engineering, University of Kermanshah, Kermanshah, Iran
[b] Department of Electrical and Computer Engineering, Texas Tech University, Texas, USA
[c] Department of Electrical and Computer Engineering, Quchan University of Technology, Quchan, Iran
[d] Department of Electrical and Computer Engineering, Sanandaj Azad University, Sanandaj, Iran
[1] poko99maeki@yahoo.com; [2] wiagutu@ttu.edu; [3] Rezaei.ila@gmail.com; [4] Nima.maleki.fc@gmail.com
* Corresponding Author

ARTICLE INFO

Article history
Received April 05, 2022
Revised May 29, 2022
Accepted June 12, 2022

Keywords
Machine learning;
SAM;
Solar energy;
Pollution-free;
Renewable energy

ABSTRACT

Renewable energy sources are expected to replace traditional energy sources such as oil and gas in the future. It goes without saying that solar energy has been demonstrated to be a key source of green energy. Solar energy is used because it is abundant, pollution-free, and easily available. However, the power utility market requires highly exact solar energy forecasts. These challenges need the creation of a device that can precisely predict solar energy output via processing the location's weather data, which is accomplished through the use of machine learning and multiple linear regression (MLR). Some elements, such as the number of cloudy days, humidity, temperature, wind condition, and precipitation, should be addressed while simulating solar power output. In this paper, a 12-kW photovoltaic (PV) system on the rooftop of a house in Isfahan was studied using the System Advisor Model (SAM). The most significant research contribution of the proposed paper is to predict the output power of a solar system with the lowest possible error. According to the simulation results, by using the MLR model, the predicted power has an error of 6 % with the actual power, which is a very good estimation. In addition, this system meets each household's energy needs plus an additional 8430 kWh per year, resulting in being paid by utility companies, a fewer number of outages, and lower air pollution levels.

1. Introduction

Green energy is the basic subject for quite a few researchers in the world [1]. Because of air pollution, a huge number of outages, and a scarcity of fossil fuels, renewable energy is in great demand presently [2-4]. Using a micro-grid or nano-grid system with an appropriate DC-DC converter is a suitable solution for implementing renewable energy sources [5]. Solar energy is the cheapest, cleanest, and most plentiful renewable energy source [6]. Solar energy, on the other hand, is affected by a variety of elements such as weather, wind, overcast days, dust, and so on [7]. Therefore, using regression models and machine learning is essential to predict the above factors [8-10].

There are quite a few regression models which are utilized to predict the possible output power, such as linear regression, logarithmic regression, artificial neural network (ANN), multiple linear regression, and so on [11-13]. In this paper, an efficient multiple regression model is used, which has some advantages over other methods, including using a lower number of weather factors [14-16]. Regarding the solar system, there are three types of tracking systems for installing solar panels, including a one-axis tracking system, a two-axis tracking system, and a fixed tracking system [17-19].

Several research has lately been undertaken to predict solar power based on weather forecasts. Using meteorological data supplied by weather agencies, the author [20] develops a model that forecasts the quantity of solar power output. This paper suggests a two-step modeling technique for connecting unexpected weather variables to weather predictions that have been made public. The empirical results reveal that, regardless of the types of machine learning algorithms used, this strategy outperforms a baseline approach by a large margin. The random forest regression approach likewise outperforms the others for this problem, with an R-squared value of 70.5 percent in the test data. In [21], power projection is estimated in the short term using real-time data from a 1 MW PV power plant in operation. The precision of the suggested technique is proved by comparing estimation power data with real-time data. Traditional artificial intelligence algorithms are applied in the initial step. The algorithm with the lowest error is chosen from all of the algorithms used. As a result, this research gives valuable information and approaches to scholars interested in planning and modeling PV power facilities.

The author in [22] mentions that energy forecasting can help to alleviate some of the problems that come with resource unpredictability. The research provides a solar power forecasting algorithm based on artificial neural networks. The model's performance is compared to that of multiple linear regression and persistence models, as well as a sensitivity analysis of numerous input variables for optimum selection. The impacts of different environmental conditions on the output of a PV system are discussed in [23]. Selective variables are assessed for prediction models based on Artificial Neural Networks (ANN) and regression models. The correlation-based feature selection (CSF) and Relief approaches are used to make the selection. All of the other strategies are outperformed by the ANN model. In [24], the performance of probabilistic predictions is evaluated using a number of indicators, most of which come from the weather forecasting community. The findings show that exogenous NWP inputs increase the quality of intraday probabilistic forecasts. The study looked at two regions with vastly different solar variability. It is obvious that by predicting the possible generated power, it is easier to convince people to invest their money in a PV system.

The two research contributions of the presented paper are predicting the extracted power by a solar system with the lowest error and doing the economic analysis of the mentioned PV system. The structure of the paper: The PV system is detailed in Section 2. In Section 3, the multiple linear regression is explained. In section 4, the simulation results are compared.

2. PV System

In order to extract solar energy, there is a need for a grid-tied inverter, DC-DC converter, maximum power point (MPPT) tracking system, batteries, and solar panels [25-27]. There are quite a few MPPT tracking techniques, including basic methods and optimized methods [28-30]. Fig. 1 depicts a photovoltaic (PV) system utilized and installed on a flat rooftop.

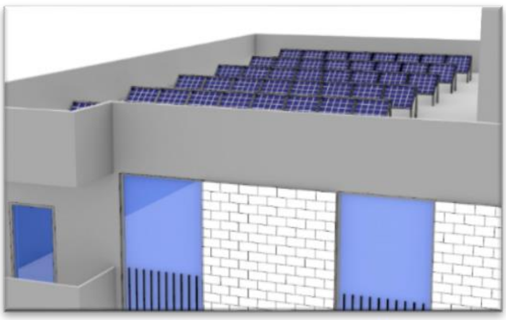

Fig. 1. PV installation design

International Journal of Robotics and Control Systems
Vol. 2, No. 2, 2022, pp. 370-378
ISSN 2775-2658

The system is made up of six rows of solar modules, each with eight modules connected in series. The initial stage in the design process is to select an appropriate solar panel. In this research, a module of 96 cells in series was used. The size and the angle of the roof should be considered for choosing a suitable module. Table 1 lists the PV modules utilized in this experiment. According to the table, each module weighs 23.23 kg, the system's efficiency is 17.87 percent, and the tilt angle is 32.6 degrees, which is precisely the same as Isfahan's latitude angle.

Table 1. Utilized PV module

Cells in series	96	**Latitude Isfahan**	32.6 °
Output DC power	250 W	**Tilt angle**	32.6 °
I (SC)	6.25 A	**Longitude**	51.68 °
I (MPP)	5.91 A	**Weight**	23.23 kg
V (MPP)	42.3 V	**Modules**	48
V(OC)	48.5 V	**Efficiency**	17.87 %

3. Multiple linear regression

The construction of multiple dependent and independent variables using weather sample data is referred to as multiple linear regression [15]. The theory and approach, which is a mature and quantifiable analysis method, is to investigate the relationship between a certain dependent variable and two or more independent variables [12, 31, 32]. The above construction of the characteristic engineering necessitates as many prediction points within a given interval as possible in order to predict humidity, dust, rainfall, and temperature using the multiple linear regression equation, which not only increases the accuracy of the temperature prediction trend but also increases the precision of the predicted contact temperature [33-35]. MLR (multiple linear regression) is a statistical method for predicting the result of a response variable by integrating a number of explanatory variables such as temperature, humidity, rainfall, and wind speed [36]. The technique of multiple linear regression (MLR) is used to model the relationship between explanatory and response variables [37]. Using MLR is necessary due to the high cost of installing a solar system such as the proposed system. Also, needless to mention that for feeding electric vehicles with a solar energy system, the efficiency of the solar system is so significant [38-40].

4. Results and Discussion

In this system, system advisor model software was utilized to simulate the power system. Temperature, of course, has a substantial impact on the output power of a PV system. The ambient and cell temperatures are shown in Fig. 2.

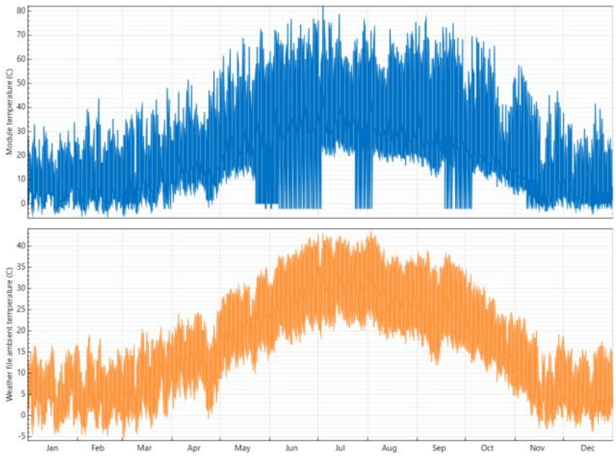

Fig. 2. Ambient temperature vs. cell temperature

Summer months have the highest cell temperature, as seen in Fig. 2. Furthermore, the highest cell temperature occurs throughout the summer months. Fig. 3 depicts a house's typical annual electricity use in Isfahan based on SAM. The use of air conditioners and other cooling equipment during the summer months increases the usage of electricity in the summer. The needed load for a house in Isfahan is shown in Fig. 3.

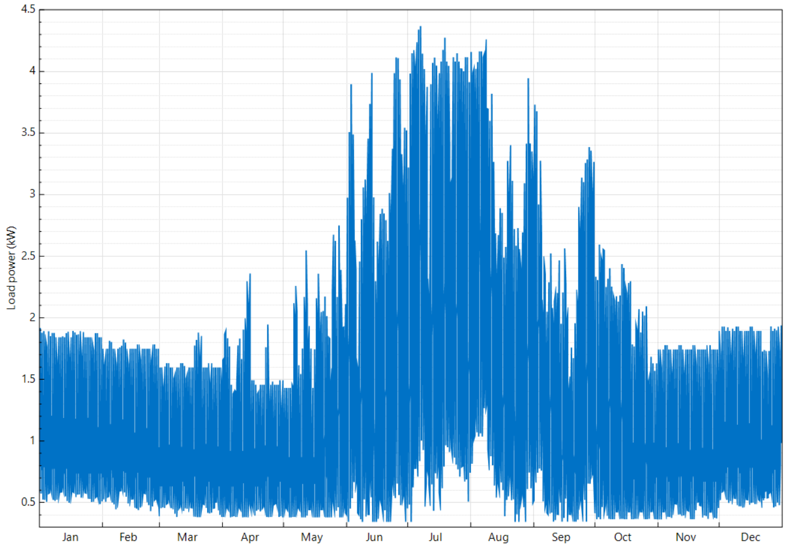

Fig. 3. The required energy for a house

Fig. 4 also shows daily and monthly generated energy. Due to increased daytime hours, the monthly energy output is higher during the summer months.

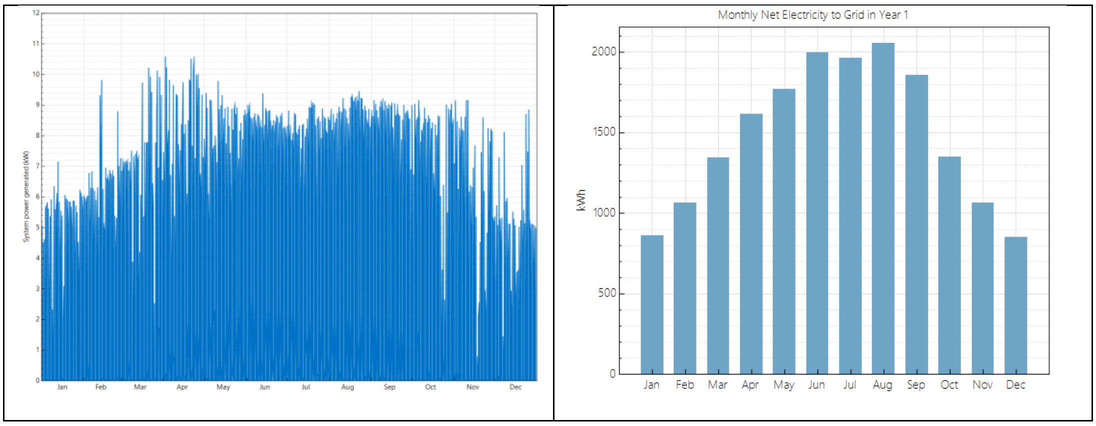

Fig. 4. Monthly and daily generated power

Furthermore, solar electricity created each day follows a regular distribution, increasing in the morning and decreasing in the afternoon. Fig. 5 shows the normal distribution of generated power in each month of the year. Fig. 6 shows that the electricity generation exceeds consumption throughout the course of the year. As a result, the owner does not have to pay for utilities and might instead be reimbursed by power companies. The final techno-economic analysis can be seen in Table 2.

Table 2. Techno economic analysis

Annual energy(kWh)	17784	**DC capacity factor**	16.9 %
Levelized COE (nominal)	8.85 cent/kWh	**Levelized COE (real)**	8.85 cent/kWh
Electricity bill with the system	$0	**Electricity bills without the system**	$1514
Simple payback period	14.7 years	**Net capital cost**	$32658

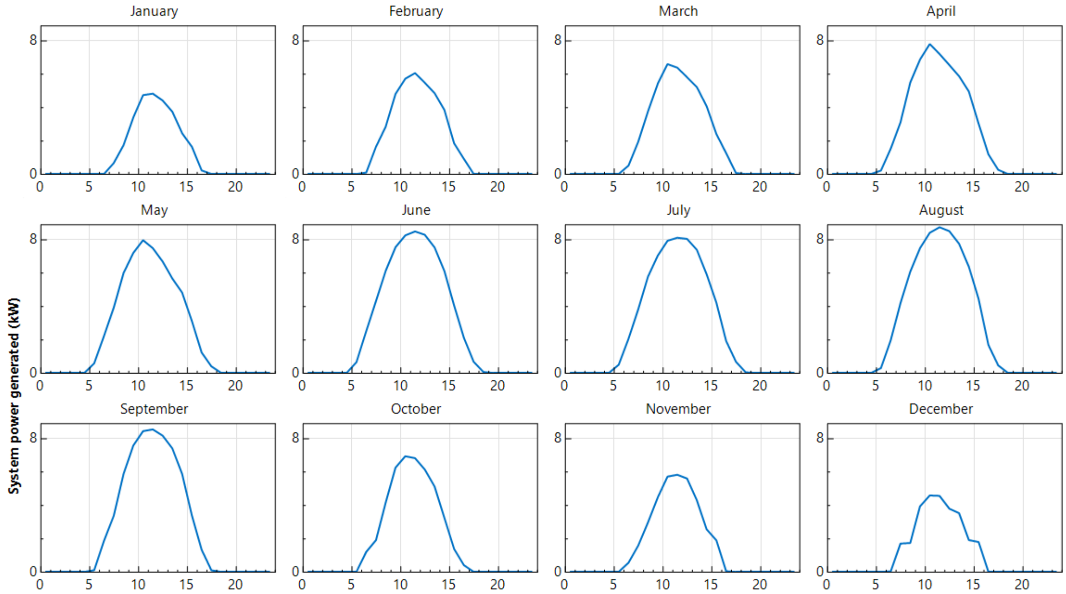

Fig. 5. Generated power each month

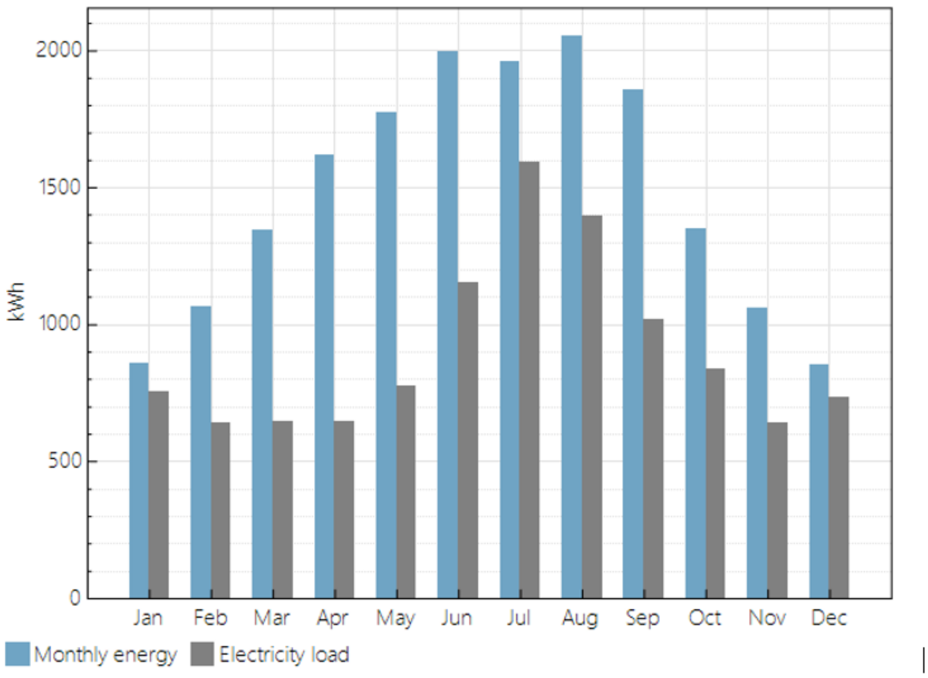

Fig. 6. Monthly generated power versus energy consumption

Fig. 6 shows the monthly energy use vs. the required load for a house in Isfahan. The system's power bill is $0 with the proposed system, as shown in the chart. The overall energy output for the year is 17784 kWh. In addition, the system's purchase and installation cost $32658, which will be returned in about 14 years. In addition, multiple linear regression is used in this work to forecast the system's output power. The actual and expected electricity output for the following year is depicted in Fig. 7. For forecasting weather data, a variety of regression models have been employed. In this research, however, multiple linear regression is used, with a prediction error of around 6% per 12 kWh. Table 3 shows the errors in some regression models and the proposed model.

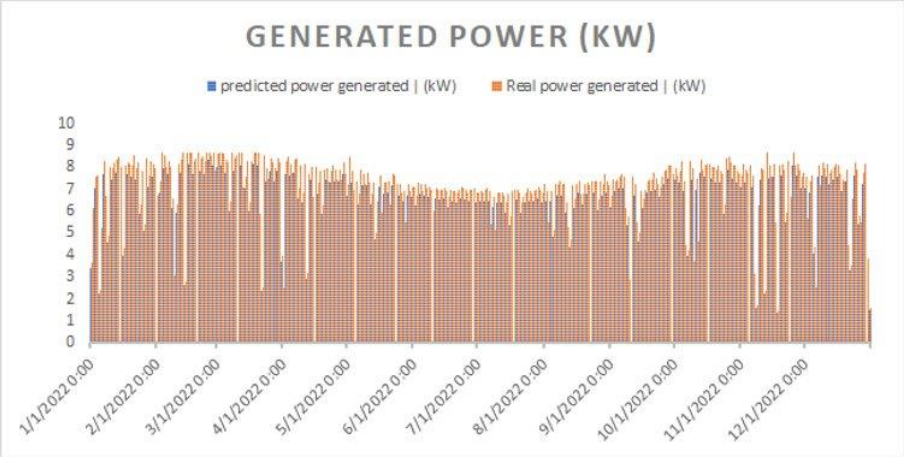

Fig. 7. The predicted and actual generated power

Table 3. Error in regression models

Model name	Error per 12 kWh
Logarithmic regression model	13 %
Simple linear regression	6.4 %
Proposed multiple linear regression	6 %

5. Conclusion

This research presents a rooftop solar PV system with 12-kW output power. Using the proposed multiple linear regression, the output power for the full year in the future was forecasted. The expected model, which is based on machine learning and multiple linear regression findings, has a 6% error rate per each 12-kWh output power. Furthermore, using the suggested PV system saves money while also helping the environment by eliminating a large number of hazardous gasses from the atmosphere. Future research will focus on comparing different regression models in order to obtain the lowest possible error for forecasting weather data and output power.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] F. Chien, M. Sadiq, M. A. Nawaz, M. S. Hussain, T. D. Tran, and T. L. Thanh, "A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes," *Journal of environmental management*, vol. 297, p. 113420, 2021, https://doi.org/10.1016/j.jenvman.2021.113420.

[2] G. Luderer, S. Madeddu, L. Merfort, F. Ueckerdt, M. Pehl, R. Pietzcker, M. Rottoli, F. Schreyer, N. Bauer, L. Baumstark, C. Bertram, A. Dirnaichner, F. Humpenöder, A. Levesque, A. Popp, R. Rodrigues, J. Strefler, and E. Kriegler, "Impact of declining renewable energy costs on electrification in low-emission scenarios," *Nature Energy*, vol. 7, no. 1, pp. 32-42, 2022, https://doi.org/10.1038/s41560-021-00937-z.

[3] Q. Wang, Z. Dong, R. Li, and L. Wang, "Renewable energy and economic growth: new insight from country risks," *Energy*, vol. 238, p. 122018, 2022, https://doi.org/10.1016/j.energy.2021.122018.

[4] B. Kroposki, B. Johnson, Y. Zhang, V. Gevorgian, P. Denholm, B.-M. Hodge, and B. Hannegan, "Achieving a 100% renewable grid: Operating electric power systems with extremely high levels of variable renewable energy," *IEEE Power and energy magazine*, vol. 15, no. 2, p. 61-73, 2017, https://doi.org/10.1109/MPE.2016.2637122.

[5] A. Balal and F. Shahabi, "Ltspice Analysis of Double-Inductor Quadratic Boost Converter in Comparison with Quadratic Boost and Double Cascaded Boost Converter," *2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, pp. 1-6, 2021, https://doi.org/10.1109/ICCCNT51525.2021.9579931.

[6] R. L. Fares and M. E. Webber, "The impacts of storing solar energy in the home to reduce reliance on the utility," *Nature Energy*, vol. 2, no. 2, pp. 1-10, 2017, https://doi.org/10.1038/nenergy.2017.1.

[7] U. Bulut and A. Menegaki, "Solar energy-economic growth nexus in top 10 countries with the highest installed capacity," *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 15, no. 5, pp. 297-310, 2020, https://doi.org/10.1080/15567249.2020.1788192.

[8] Z. Ramedani, M. Omid, A. Keyhani, B. Khoshnevisan, and Hadi Saboohi, "A comparative study between fuzzy linear regression and support vector regression for global solar radiation prediction in Iran," *Solar Energy*, vol. 109, pp. 135-143, 2014, https://doi.org/10.1016/j.solener.2014.08.023.

[9] H. Sarper, I. Melnykov, and L. A. Martínez, "Prediction of Daily Photovoltaic Energy Production Using Weather Data and Regression," *Journal of Solar Energy Engineering*, vol. 143, no. 6, 2021, https://doi.org/10.1115/1.4051262

[10] O. Abedinia, N. Amjady, and N. Ghadimi, "Solar energy forecasting based on hybrid neural network and improved metaheuristic algorithm," *Computational Intelligence*, vol. 34, no. 1, pp. 241-260, 2018, https://doi.org/10.1111/coin.12145.

[11] Z. Qadir, S. I. Khan, E. Khalaji, H. S. Munawar, F. Al-Turjman, M. A. P. Mahmud, A. Z. Kouzani, and K. Le, "Predicting the energy output of hybrid PV–wind renewable energy system using feature selection technique for smart grids," *Energy Reports*, vol. 7, pp. 8465-8475, 2021, https://doi.org/10.1016/j.egyr.2021.01.018.

[12] Y. S. Kim, H. Y. Joo, J. W. Kim, S. Y. Jeong, and J. H. Moon, "Use of a big data analysis in regression of solar power generation on meteorological variables for a Korean solar power plant," *Applied Sciences*, vol. 11, no. 4, p. 1776, 2021, https://doi.org/10.3390/app11041776.

[13] E. Paulescu and R. Blaga, "Regression models for hourly diffuse solar radiation," *Solar Energy*, vol. 125, pp. 111-124, 2016, https://doi.org/10.1016/j.solener.2015.11.044.

[14] K. Chiteka, R. Arora, and S. Sridhara, "A method to predict solar photovoltaic soiling using artificial neural networks and multiple linear regression models," *Energy Systems*, vol. 11, no. 4, pp. 981-1002, 2020, https://doi.org/10.1007/s12667-019-00348-w.

[15] H. Suyono, R. N. Hasanah, R. A. Setyawan, P. Mudjirahardjo, A. Wijoyo, and I. Musirin, "Comparison of solar radiation intensity forecasting using ANFIS and multiple linear regression methods," *Bulletin of Electrical Engineering and Informatics*, vol. 7, no. 2, pp. 191-198, 2018, https://doi.org/10.11591/eei.v7i2.1178.

[16] S. I. Bangdiwala, "Regression: multiple linear," *International journal of injury control and safety promotion*, vol. 25, no. 2, pp. 232-236, 2018 https://doi.org/10.1080/17457300.2018.1452336.

[17] A. Balal, M. Herrera, E. Johnson, and T. Dallas, "Design and Simulation of a Solar PV System for a University Building," *2021 IEEE 4th International Conference on Power and Energy Applications (ICPEA)*, 2021, https://doi.org/10.1109/ICPEA52760.2021.9639361.

[18] M. Alam, M. A. Dewan, S. S. Bashar, M. S. Miah, and A. Ghosh, "A Microcontroller Based Dual Axis Tracking System for Solar Panel," *2019 3rd International Conference on Electrical, Computer & Telecommunication Engineering (ICECTE)*, 2019, https://doi.org/10.1109/ICECTE48615.2019.9303534.

[19] S. Aziz and S. Hassan, "On improving the efficiency of a solar panel tracking system," *Procedia Manufacturing*, vol. 7, pp. 218-224, 2017, https://doi.org/10.1016/j.promfg.2016.12.053.

[20] S.-G. Kim, J.-Y. Jung, and M. K. Sim, "A two-step approach to solar power generation prediction based on weather data using machine learning," *Sustainability*, vol. 11, no. 5, p. 1501, 2019, https://doi.org/10.3390/su11051501.

[21] T. Demirdelen, I. O. Aksu, B. Esenboga, K. Aygul, F. Ekinci, and M. Bilgili, "A new method for generating short-term power forecasting based on artificial neural networks and optimization methods for solar photovoltaic power plants," *Solar photovoltaic power plants*, pp. 165-189, 2019, https://doi.org/10.1007/978-981-13-6151-7_8.

[22] M. Abuella and B. Chowdhury, "Solar power forecasting using artificial neural networks," *2015 North American Power Symposium (NAPS)*, 2015, https://doi.org/10.1109/NAPS.2015.7335176.

[23] D. Van Tai, "Solar photovoltaic power output forecasting using machine learning technique," *Journal of Physics: Conference Series*, 2019, https://doi.org/10.1088/1742-6596/1327/1/012051.

[24] P. Lauret, M. David, and H.T. Pedro, "Probabilistic solar forecasting using quantile regression models," *energies*, vol. 10, no. 10, p. 1591, 2017 https://doi.org/10.3390/en10101591.

[25] A. Balal, S. Dinkhah, F. Shahabi, M. Herrera, and Y. L. Chuang, "A Review on Multilevel Inverter Topologies," *Emerging Science Journal*, vol. 6, no. 1, pp. 185-200, 2022, https://doi.org/10.28991/ESJ-2022-06-01-014.

[26] S. A. Lopa, S. Hossain, M. K. Hasan, and T. K. Chakraborty, "Design and simulation of DC-DC converters," *International Research Journal of Engineering and Technology (IRJET)*, vol. 3, no. 1, p. 63-70, 2016.

[27] A. Balal and M. Giesselmann, "Demand Side Management and Economic Analysis Using Battery Storage System (BSS) and Solar Energy," *2021 IEEE 4th International Conference on Power and Energy Applications (ICPEA)*, 2021, https://doi.org/10.1109/ICPEA52760.2021.9639359.

[28] A. Balal, M. Abedi, and F. Shahabi, "Optimized generated power of a solar PV system using an intelligent tracking technique," *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 4, p. 2580, 2021, https://doi.org/10.11591/ijpeds.v12.i4.pp2580-2592.

[29] M. A. Eltawil and Z. Zhao, "MPPT techniques for photovoltaic applications," *Renewable and sustainable energy reviews*, vol. 25, p. 793-813, 2013, https://doi.org/10.1016/j.rser.2013.05.022.

[30] A. Ali, K. Almutairi, M. Z. Malik, K. Irshad, V. Tirth, S. Algarni, Md. H. Zahir, S. Islam, Md Shafiullah, and N. K. Shukla, "Review of online and soft computing maximum power point tracking techniques under non-uniform solar irradiation conditions," *Energies*, vol. 13, no. 12, p. 3256, 2020, https://doi.org/10.3390/en13123256

[31] S. Aslam, H. Herodotou, S. M. Mohsin, N. Javaid, N. Ashraf, and S. Aslam, "A survey on deep learning methods for power load and renewable energy forecasting in smart microgrids," *Renewable and Sustainable Energy Reviews*, vol. 144, p. 110992, 2021, https://doi.org/10.1016/j.rser.2021.110992

[32] G. Muhammed and N. Tekbiyik-Ersoy, "Development of renewable energy in China, USA, and Brazil: A comparative study on renewable energy policies," *Sustainability*, vol. 12, no. 21, p. 9136, 2020, https://doi.org/10.3390/su12219136.

[33] H. Salem, "Predictive modelling for solar power-driven hybrid desalination system using artificial neural network regression with Adam optimization," *Desalination*, vol. 522, p. 115411, 2022, https://doi.org/10.1016/j.desal.2021.115411.

[34] S. Barhmi, O. Elfatni, and I. Belhaj, "Forecasting of wind speed using multiple linear regression and artificial neural networks," *Energy Systems*, vol. 11, no. 4, pp. 935-946, 2020, https://doi.org/10.1007/s12667-019-00338-y.

[35] D. Maulud and A. M. Abdulazeez, "A review on linear regression comprehensive in machine learning," *Journal of Applied Science and Technology Trends*, vol. 1, no. 4, pp. 140-147, 2020, https://doi.org/10.38094/jastt1457.

[36] S. A. Kalogirou, E. Mathioulakis, and V. Belessiotis, "Artificial neural networks for the performance prediction of large solar systems," *Renewable Energy*, vol. 63, pp. 90-97, 2014, https://doi.org/10.1016/j.renene.2013.08.049.

[37] M. Abuella and B. Chowdhury, "Solar power probabilistic forecasting by using multiple linear regression analysis," *SoutheastCon 2015*, 2015, https://doi.org/10.1109/SECON.2015.7132869.

[38] A. Balal and M. Herrera, "Design a Power Converter to Charge a Hybrid Electric Vehicle," *2021 IEEE 18th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET)*, 2021, https://doi.org/10.1109/HONET53078.2021.9615492.

[39] A. Palomino and M. Parvania, "Data-driven risk analysis of joint electric vehicle and solar operation in distribution networks," *IEEE Open Access Journal of Power and Energy*, vol. 7, pp. 141-150, 2020, https://doi.org/10.1109/OAJPE.2020.2984696.

[40] F. He and H. Fathabadi, "Novel standalone plug-in hybrid electric vehicle charging station fed by solar energy in presence of a fuel cell system used as supporting power source," *Renewable Energy*, vol. 156, pp. 964-974, 2020, https://doi.org/10.1016/j.renene.2020.04.141.