Indonesian Journal of Electrical Engineering and Computer Science
Vol. 29, No. 2, February 2023, pp. 635~643
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v29.i2.pp635-643

Perturb and observe maximum power point tracking approach for microgrid linked photovoltaic system

Kshirod Kumar Rout[1], Debani Prasad Mishra[1], Sivkumar Mishra[2], Suman Patra[1], Surender Reddy Salkuti[3]
[1]Department of Electrical and Electronics Engineering, International Institute of Information Technology Bhubaneswar, Bhubaneswar, India
[2]Department of Electrical Engineering, Biju Patnaik University of Technology, Rourkela, India
[3]Department of Railroad and Electrical Engineering, Woosong University, Daejeon, Republic of South Korea

Article Info

Article history:

Received Mar 9, 2022
Revised Oct 4, 2022
Accepted Oct 12, 2022

Keywords:

Boost converter
Perturb and observe
PV array
Utility grid
Voltage source converter

ABSTRACT

This paper develops a maximum power point tracking (MPPT) approach for a microgrid-linked solar photovoltaic (PV) system based on the concept of a perturb and observe (P&O) approach. It is an iterative algorithm that requires a starting point to trace the maximum power point tracking. This study proposes the P&O MPPT algorithm for a 3-ϕ grid-connected PV system. In this work, the PV system is modeled as a DC grid-connected PV system, and the MPPT algorithm is applied to that model. An MPPT application is used in this proposal to amplify the effectiveness of the PV array in face of any unsteady climatic circumstances. Hence, the highest energy could be secured out of the solar PV array and interfaced with the grid. The voltage source converter will empower defining of boundaries and greatest degrees of force from sunlight-based chargers in an efficient way. A few outcomes like the current, voltage and result power for each different mix have been noted.

Corresponding Author:

Surender Reddy Salkuti
Department of Railroad and Electrical Engineering, Woosong University
17-2, Jayang-Dong, Dong-Gu, Daejeon-34606, Republic of Korea
Email: surender@wsu.ac.kr

1. INTRODUCTION

A lot of power is created from sustainable power sources over the last ten years. Among the expected sustainable power sources, photovoltaic (PV) has encountered colossal development in the power age [1]. A financially savvy answer for understanding the energy hold for 2 different network-associated photovoltaic frameworks is given. The suggested arrangement regularly utilizes a most extreme energy direct following control toward gauging the accessible photo energy and a constant power generation (CPG) mode to attain energy savings [2]. To carry out a thorough investigation and assessment of model predictive control (MPC)-based maximum power point tracking algorithm (MPPT) approaches in several typical power converter settings. MPC-based MPPT presentation is intrinsically tied to converter geography, and it is impacted by the accurate assurance of the converter boundaries; aversion to the converter boundary fluctuations is examined [3]. The suggested calculation's key peculiarity is its suitability for both single and 2-stage PVPPs, as well as its adaptability to transfer the activity highlight to the right side or left side of MPPT. Further, the calculation execution recurrence and voltage rise between continuous working focuses are regulated in light of a hysteresis band regulator to obtain rapid unique reaction under homeless individuals and low-power swaying throughout consistent state operation [4]. A 3-level push ahead converter and a 3-level inverter are remembered for the proposed two-stage inverter. The three-level push ahead converter not just further develops power-change proficiency by bringing down voltage stress, however, it additionally guarantees that the dc-interface capacitor voltages are changed utilizing a straightforward control computation [5]. The temperature regulator guarantees the ideal temperature of the sunlight-powered charger. A variable advance measured incremental conductance largest power point following computation is performed to ensure the cell works at its most extreme power point [6]. Photovoltaic frameworks have made significant progress in recent years. Because the greatest power point of a solar framework varies with the adjustment of natural circumstances, the most extreme power point following innovation is critical to gather the most extreme power from photovoltaic frameworks [7]. The dangers indicate a broad range of frequencies ranging from 10s to 1000s of Hertz. In light of the writing review, potential causes for the dangers are discussed [8].

The investigation uncovers that the annoyance from the MPPT calculation is one of the beginnings of inter harmonics showing up in the framework current [9], [10]. The essential objective of every MPPT method is to upgrade the result of concealed PV clusters under steady and transient weather patterns [11]-[15]. Due to the lower number of info signals accessible in single-stage frameworks contrasted with three-stage frameworks, PI-based dq regulators can't be utilized straightforwardly. The standard methodology in single-stage frameworks is to blend a stage signal symmetrical to the single-gradually ease framework's fundamental sign to procure dc values through (αβ to dq) interpretation [16]. To regulate the power flow of a 4 inverter with such a predetermined operating frequency, a high-performance system management controller (SMC) system is presented. Not only is the chattering problem greatly minimized in the proposed SMC system, but the resilience, control, and static responsiveness of the SMC system are also unaffected [17]-[18]. Whenever the lattice power is accessible for the extreme price during high electrical tax, the privately produced power from sun oriented is used for purchaser stacks or even overabundance power can be taken care of back to the matrix to procure monetary advantages [19]-[21].

To manage the dc-interface voltage, an altered voltage regulator utilizing a criticism linearization plot with a feedforward PV current sign is introduced. The genuine and receptive powers are constrained by utilizing dq parts of the network current. A little sign solidness/eigenvalue examination of a matrix-associated PV framework with the total linearized model is performed to survey the vigor of the regulator and the decoupling character of the network-associated PV framework [22]. The adaptable AC transmission framework incorporates different remunerating gadgets. This paper manages the use of a sun-powered PV ranch inverter as a static compensator (STATCOM) to control voltage at the place of association which further develops the security during the constant time [23]. PV power yield is still low, ceaseless endeavors are taken to foster the PV converter and regulator for most extreme power extricating productivity and diminished expense factor [24].

One of the arrangements being proposed to work on the unwavering quality and execution of these frameworks is to incorporate energy stockpiling gadgets into the power framework organization [25]. Examination of the powerful attributes of Lithium-ion batteries was helped out, through recreations of the normalized systems [26]. Under the trapezoidal light change, a logical perturb and observe (P&O) calculation is proven to differentiate shortfall courses following regular P&O calculation [27]. A two-level voltage source inverter (VSI) was used in SAPF architecture, and P-Q hypothesis computation is used to extract referential consonant fluxes [28]. The most basic problem with running a breeze ranch or a sun-oriented PV plant is that these RERs can't be planned like conventional generators since they contain environmental parameters like breeze speed and solar-powered lighting [29]. To make up for the low transformation productivity, different MPPT calculations are fostered that give robotized command over power points of interaction to create ideal power effectiveness [30].

2. RESEARCH METHOD

This paper focuses on perturb and observe (P&O) based MPPT approach for microgrid-linked photovoltaic systems. The workflow diagram of the study approach used in this research report is shown in Figure 1. This method is based on the synchronous reference frame theory.

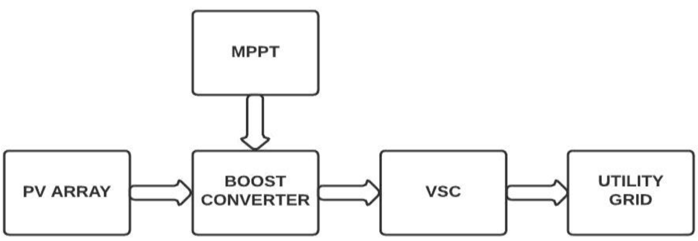

Figure 1. Workflow diagram of the proposed method

2.1. PV array

PV cells are the building blocks of solar modules. Electricity is produced by solar cells which turn the energy in the photons of sunlight by using the phenomenon of photoelectric. Each solar cell generates electric power but in a very small amount. PV arrays are arranged in such a way that solar cells are connected in parallel or series to raise the output power. Output voltage and current of a PV array can be studied as nonlinear and exponential relationships, and exactly at one point PV array gains maximum power. Photovoltaic generators are normally compared to current generators with neither dependent voltage sources. While night time, the solar cell becomes a passive device. Due to its passive nature, it neither produces voltage nor current. A solar cell contains p-n junction-like semiconductor devices. A current is generated when exposed to light. With regard to sun irradiation, the produced current will fluctuate linearly.

$$\mathrm{I} = I_{ph} - I_o\left[e^{\left(\frac{V+R_sI}{V_ta}\right)} - 1\right] - \frac{V+R_sI}{R_p} \quad (1)$$

Where I_{ph} is solar-generated current, I_o is the diode saturation current, $V_t = N_sKT/q$ is the thermal voltage of the array, N_s is the number of cells connected in series, a is the diode ideality constant, R_s is series resistance, and R_p is parallel resistance.

2.2. MPPT control

An array is a string of panels where its output power reaches the maximum value at a point. The array of the MPPT has to be followed to confirm the efficient operation of the solar array. A PV system lifetime booster is fixed to raise the delivery power of the PV module. There are several control schemes and controller kinds to choose from. Different properties can be used to categorize these approaches. MPPT may be divided into two categories: offline techniques and online approaches, with the first relying on solar cell models and the latter, referred to as model-free methods. In the simplest form, the P&O algorithm is widely used and simple to execute strategy. If the operating voltage (v_0) of the photovoltaic array is unsettled in a specific direction, then P>0, and the arrangement travels towards the array's operation point to acquire maximum value. The PV array voltage will then be arranged in a similar direction using the P&O method. If P is less than zero, the Photovoltaic array arrangement moves far from the MPPT, and the P&O method reverses the perturbation's direction. The P&O method of MPPT is shown in Figure 2. The P&O depends on the principle of change in the voltage level in comparison to the recent power with previous power.

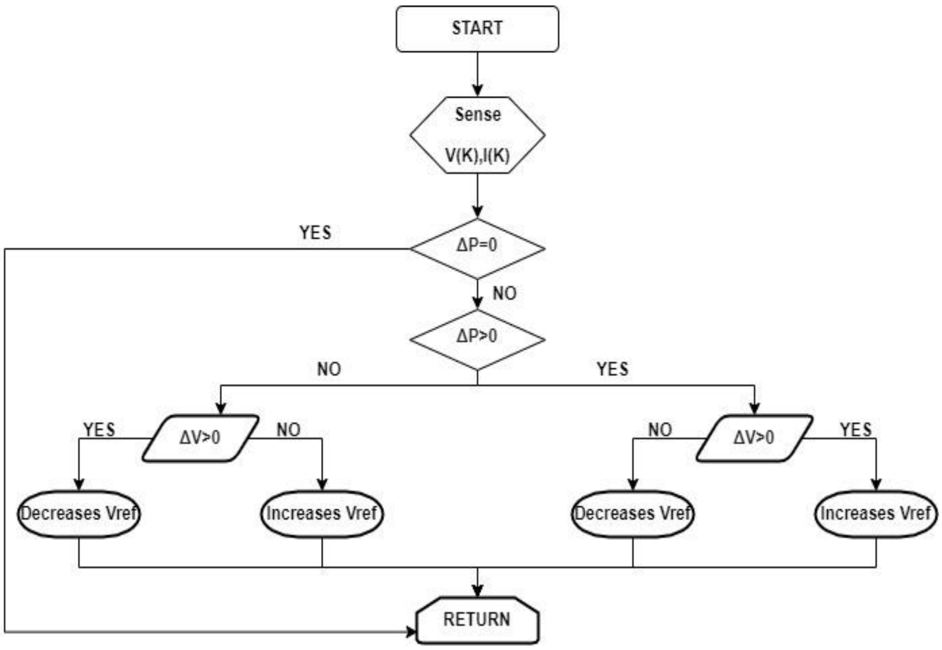

Figure 2. Perturb and observe (P&O) MPPT algorithm

2.3. DC-DC boost converter

The converter that has its input voltage less than its output voltage is called a boost converter. Periodical opening and closing of an electronic switch make it function as a switching converter. To increase the Photovoltaic voltage to point level a boost converter happens to be used. PV array temperature and irradiance impact the input of boost converter remains unchecked. All this process is controlled in continuous conduction mode. MPPT controller causes pulses for maximum power point. The capacitor value in a boost converter is usually chosen in such a way that a controlled voltage is achieved and the inductor value is chosen for maximum permissible ripple current at a low duty cycle.

2.4. VSC

VSC is really called voltage source converters, these are self-commutated converters that associate with HVDC, and this framework uses gadgets fit for high-power electronic applications like insulated-gate bipolar transistor (IGBTs). They produce alternating current (AC) voltages that are delivered with no assistance or depending on an AC framework. It enables us to have more freedom in view of active power regulation and also reactive power regulation, and even black start capabilities. VSCs, also known as modules in an modular multilevel converter (MMC), maintain consistent polarity at the terminals of voltage direct current (DC), like a two-level or a three-level converter. The reversal of the power flow direction causes a shift in the current direction. VSCs are more obviously coupled in DC systems with multiple terminals. In contrast with the more mature VSC-based high voltage direct current (HVDC) frameworks, critical security controls (CSC)-HVDC gives speedier dynamic power stream guidelines while likewise giving greater adaptability and responsive power steadiness at the 2 converter nodes.

3. RESULTS AND DISCUSSION

All of the calculations in this work were done in MATLAB. Figure 3 shows the simulation of the grid-connected photovoltaic system. In order to achieve desired results, a P&O kind of MPPT method has been implemented, along with a direct current to direct current boost converter.

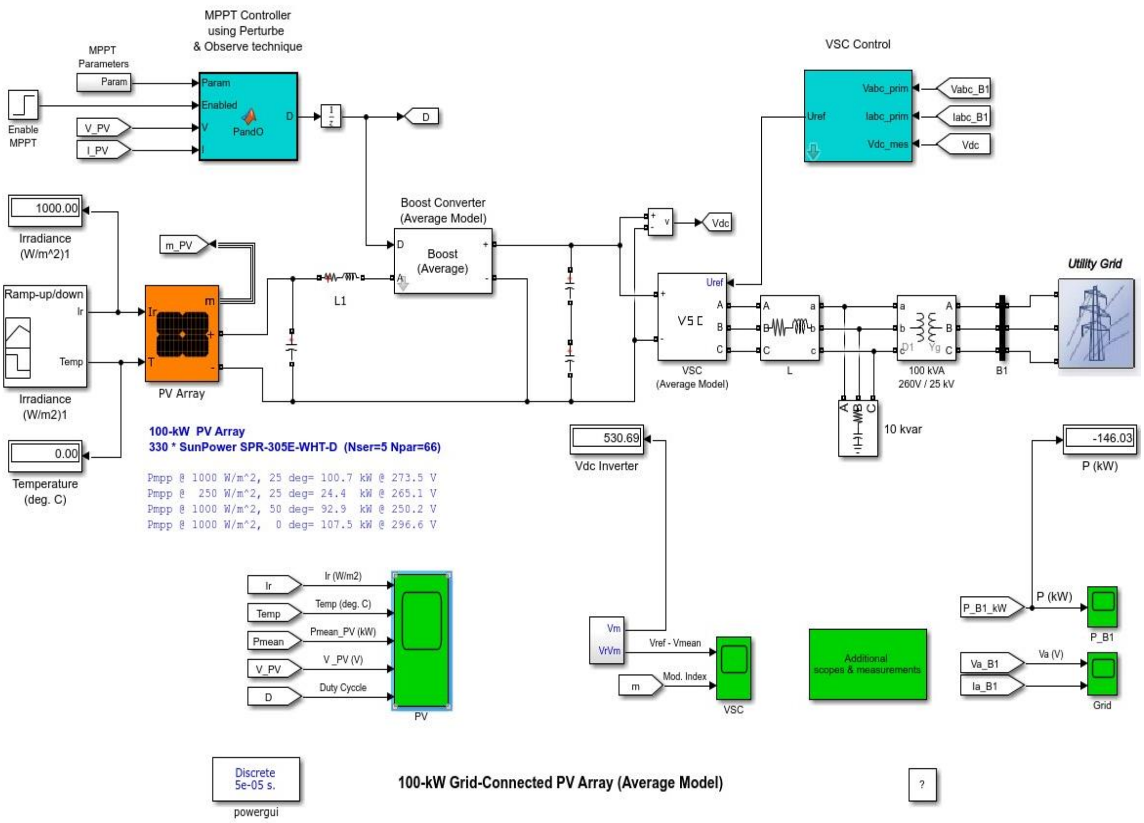

Figure 3. The photovoltaic system is simulated with a grid type of connection

The I-V and P-V properties of the solar cell are shown in Figure 4. The 5 series modules and 66 parallel threads make up a solar cell. The parameters were acquired at a temperature of 25 °C with irradiances of 1 kW/m^2 and 0.25k W/m^2. The graph of irradiance vs. time and temperature vs. time is shown in Figure 5. In the irradiance–time graph, it starts off constant at 1,000 and then drops to 250 owing to the use of MPPT, before increasing and remaining constant at 1,000. When it comes to temperature-time graphs, it starts at 25 and rises to 50 when using MPPT, then drops to 20 and remains constant. The plot shows power versus time as already shown in Figure 6. Output power has a dynamic temporal response, which is shown. The characteristics of temporal response for system output power in the case of P&O method-based MPPT imply that the P&O-based MPPT follows non-spiky peaks but with occasional oscillations, particularly at changing intervals.

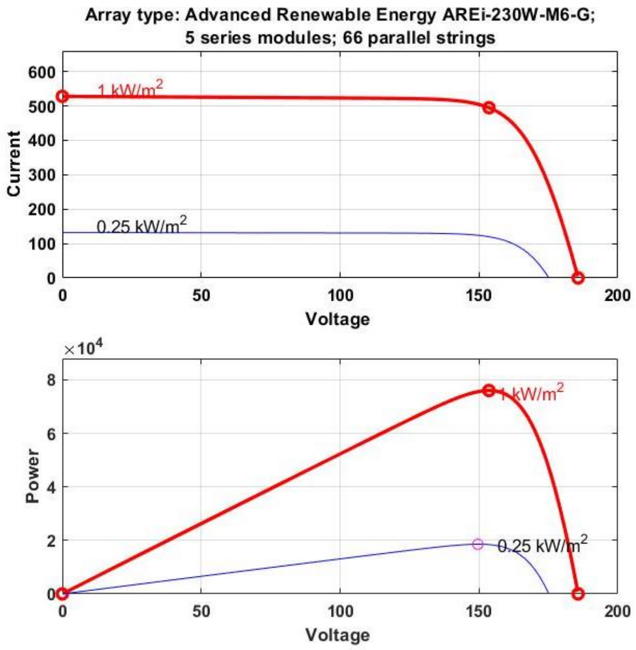

Figure 4. Solar cell's P-V and I-V characteristic plot

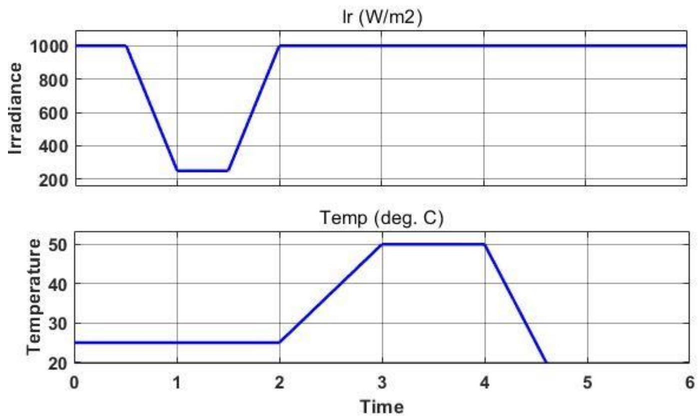

Figure 5. The output of irradiance and temperature of the PV array

Figure 7 depicts a graph of voltage versus time as well as duty cycle versus time. The non-static response of v_0 is shown in a voltage-time graph. During fast variations in irradiance and temperature, the output voltage's temporal response shows tiny voltage waves. Due to the enablement of MPPT, the duty cycle in the duty cycle–time graph remains constant for 0.3s before increasing to 0.6. We can extract the maximum power, which is 100.7 kw at 0.453 duty cycle, by adjusting the duty cycle. Figure 8 shows the graph between $V_{ref} -$

V_{mean} vs time and modulation index vs time. In the voltage-time graph, it first increases and oscillates at 500 and then reaches its peak value at 750 and decreases and remains constant. In the modulation index–time graph it first increases and constant and forms ripples due to MPPT. When connected to the grid, Figure 9 depicts the output V and I. At the utility grid end, the current and voltage waveforms are strictly sinusoidal.

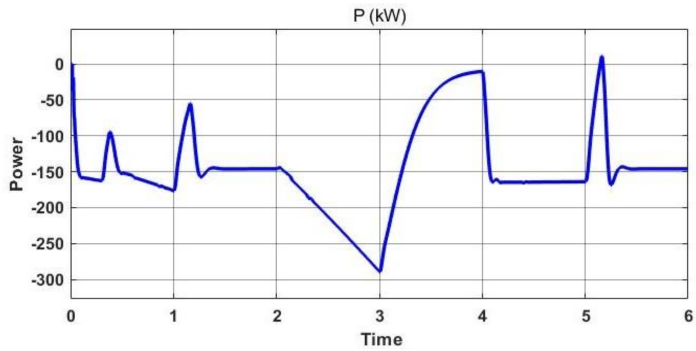

Figure 6. The output of power of the PV array

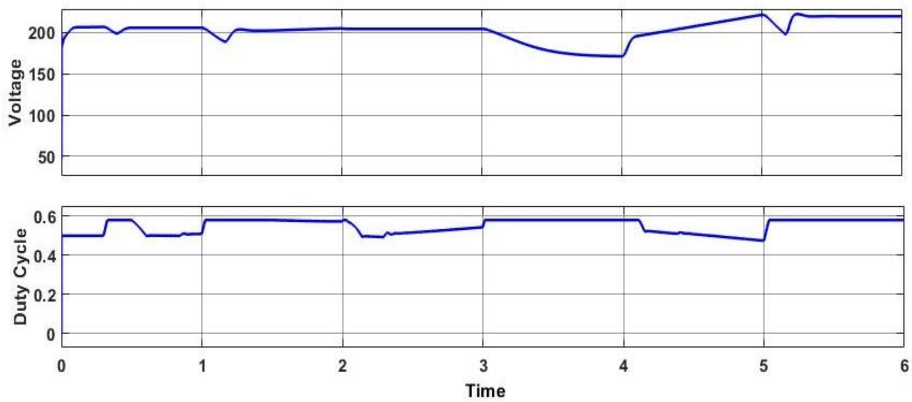

Figure 7. The output of voltage and duty cycle of PV array

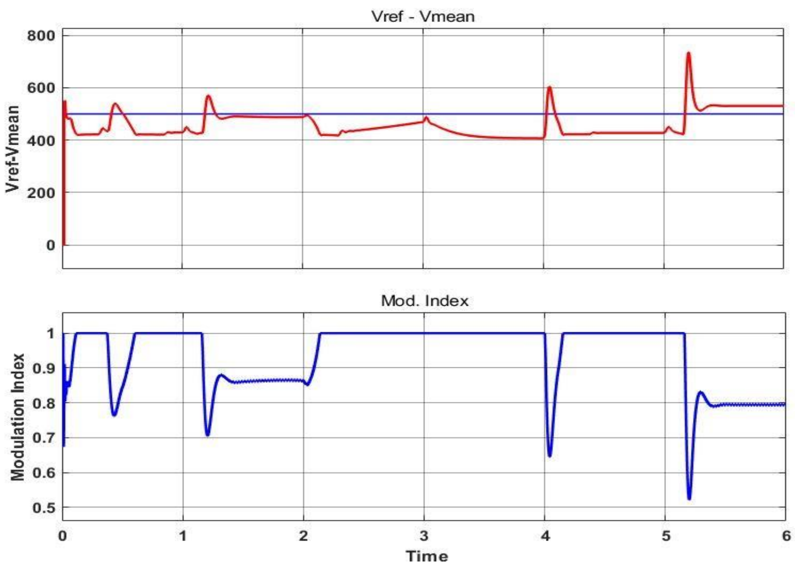

Figure 8. The output of the voltage source controller (VSC)

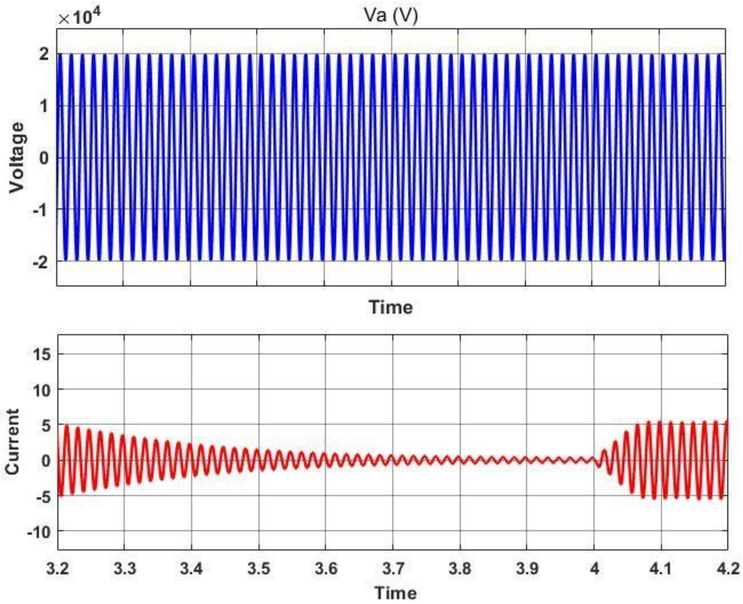

Figure 9. The output of the utility grid

4. CONCLUSION

This study documents the development of a grid-connected PV system simulation model based on complete circuits. MATLAB/Simulink was used to create all of the simulations. P-V and I-V curves are obtained for a variety of temperatures and solar irradiance output circumstances. The report also includes a PV array using MPPT. With the use of MPPT, one of the results in MATLAB reveals the highest position of the photovoltaic array. MPPT is attained and enhanced utilizing a DC-to-DC boost converter using the P&O method. This has a maximum power of 100.7 kW and a duty cycle of 0.453.

ACKNOWLEDGEMENTS

This research work was funded by “Woosong University’s Academic Research Funding - 2022”.

REFERENCES

[1] U. K. Das *et al.*, “Forecasting of photovoltaic power generation and model optimization: A review,” *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 912–928, Jan. 2018, doi: 10.1016/j.rser.2017.08.017.

[2] A. Sangwongwanich, Y. Yang, and F. Blaabjerg, “A sensorless power reserve control strategy for two-stage grid-connected PV systems,” *IEEE Transactions on Power Electronics*, vol. 32, no. 11, pp. 8559–8569, Nov. 2017, doi: 10.1109/TPEL.2017.2648890.

[3] A. Lashab, D. Sera, J. M. Guerrero, L. Mathe, and A. Bouzid, “Discrete model-predictive-control-based maximum power point tracking for PV systems: overview and evaluation,” *IEEE Transactions on Power Electronics*, vol. 33, no. 8, pp. 7273–7287, Aug. 2018, doi: 10.1109/TPEL.2017.2764321.

[4] H. D. Tafti, A. I. Maswood, G. Konstantinou, J. Pou, and F. Blaabjerg, “A general constant power generation algorithm for photovoltaic systems,” *IEEE Transactions on Power Electronics*, vol. 33, no. 5, pp. 4088–4101, May 2018, doi: 10.1109/TPEL.2017.2724544.

[5] J.-S. Kim, J.-M. Kwon, and B.-H. Kwon, “High-efficiency two-stage three-level grid-connected photovoltaic inverter,” *IEEE Transactions on Industrial Electronics*, vol. 65, no. 3, pp. 2368–2377, Mar. 2018, doi: 10.1109/TIE.2017.2740835.

[6] H. Shahid, M. Kamran, Z. Mehmood, M. Y. Saleem, M. Mudassar, and K. Haider, “Implementation of the novel temperature controller and incremental conductance MPPT algorithm for indoor photovoltaic system,” *Solar Energy*, vol. 163, pp. 235–242, Mar. 2018, doi: 10.1016/j.solener.2018.02.018.

[7] G. Li, Y. Jin, M. W. Akram, X. Chen, and J. Ji, “Application of bio-inspired algorithms in maximum power point tracking for PV systems under partial shading conditions – A review,” *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 840–873, Jan. 2018, doi: 10.1016/j.rser.2017.08.034.

[8] C. Li, “Unstable operation of photovoltaic inverter from field experiences,” in *2018 IEEE Power & Energy Society General Meeting (PESGM)*, Aug. 2018, pp. 1–1, doi: 10.1109/PESGM.2018.8586409.

[9] A. Sangwongwanich, Y. Yang, D. Sera, H. Soltani, and F. Blaabjerg, “Analysis and modeling of interharmonics from grid-connected photovoltaic systems,” *IEEE Transactions on Power Electronics*, vol. 33, no. 10, pp. 8353–8364, Oct. 2018, doi: 10.1109/TPEL.2017.2778025.

[10] A. Sangwongwanich and F. Blaabjerg, “Mitigation of interharmonics in PV systems with maximum power point tracking modification,” *IEEE Transactions on Power Electronics*, vol. 34, no. 9, pp. 8279–8282, Sep. 2019, doi: 10.1109/TPEL.2019.2902880.

[11] R. Ahmad, A. F. Murtaza, and H. A. Sher, "Power tracking techniques for efficient operation of photovoltaic array in solar applications – A review," *Renewable and Sustainable Energy Reviews*, vol. 101, pp. 82–102, Mar. 2019, doi: 10.1016/j.rser.2018.10.015.

[12] S. Selvakumar, M. Madhusmita, C. Koodalsamy, S. P. Simon, and Y. R. Sood, "High-speed maximum power point tracking module for PV Systems," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 2, pp. 1119–1129, Feb. 2019, doi: 10.1109/TIE.2018.2833036.

[13] S. Ouchen, A. Betka, J. P. Gaubert, S. Abdeddaim, and F. Mazouz, "Fuzzy-direct power control of a grid connected photovoltaic system associate with shunt active power filter," in *Lecture Notes in Networks and Systems*, vol. 35, 2018, pp. 164–172, doi: 10.1007/978-3-319-73192-6_17.

[14] E. Heydari and A. Y. Varjani, "Combined modified P&O algorithm with improved direct power control method applied to single-stage three-phase grid-connected PV system," in *2018 9th Annual Power Electronics, Drives Systems and Technologies Conference (PEDSTC)*, Feb. 2018, vol. 2018-Janua, pp. 347–351, doi: 10.1109/PEDSTC.2018.8343821.

[15] D. Verma, J. Mishra, and M. Pattnaik, "Output voltage based adaptive step size MPPT controller with improved dynamics for stand-alone photovoltaic system," *Journal of Renewable and Sustainable Energy*, vol. 10, no. 4, p. 043505, Jul. 2018, doi: 10.1063/1.5035109.

[16] A. M. Mnider, D. J. Atkinson, M. Dahidah, and M. Armstrong, "A simplified DQ controller for single-phase grid-connected PV inverters," in *2016 7th International Renewable Energy Congress (IREC)*, Mar. 2016, pp. 1–6, doi: 10.1109/IREC.2016.7478941.

[17] M. Pichan and H. Rastegar, "Sliding-Mode control of four-leg inverter with fixed switching frequency for uninterruptible power supply applications," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 8, pp. 6805–6814, Aug. 2017, doi: 10.1109/TIE.2017.2686346.

[18] H. Komurcugil, S. Ozdemir, I. Sefa, N. Altin, and O. Kukrer, "Sliding-Mode Control for Single-Phase Grid-Connected LCL-Filtered VSI With Double-Band Hysteresis Scheme," *IEEE Transactions on Industrial Electronics*, vol. 63, no. 2, pp. 864–873, Feb. 2016, doi: 10.1109/TIE.2015.2477486.

[19] S. Paghdar, U. Sipai, K. Ambasana, and P. J. Chauhan, "Active and reactive power control of grid connected distributed generation system," in *2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, Feb. 2017, pp. 1–7, doi: 10.1109/ICECCT.2017.8118019.

[20] H. Jafarian, N. Kim, and B. Parkhideh, "A distributed active and reactive power control strategy for balancing grid-Tied cascaded h-bridge pv inverter system," *2017 IEEE Energy Conversion Congress and Exposition, ECCE 2017*, vol. 2017-January, pp. 1667–1672, 2017, doi: 10.1109/ECCE.2017.8095993.

[21] B. Boukezata, A. Chaoui, J.-P. Gaubert, and M. Hachemi, "Power Quality Improvement by an Active Power Filter in Grid-connected Photovoltaic Systems with Optimized Direct Power Control Strategy," *Electric Power Components and Systems*, vol. 44, no. 18, pp. 2036–2047, Nov. 2016, doi: 10.1080/15325008.2016.1210698.

[22] V. N. Lal and S. N. Singh, "Control and performance analysis of a single-stage utility-scale grid-connected PV system," *IEEE Systems Journal*, vol. 11, no. 3, pp. 1601–1611, Sep. 2017, doi: 10.1109/JSYST.2015.2408055.

[23] M. Azharuddin and S. R. Gaigowal, "Voltage regulation by grid connected PV-STATCOM," in *2017 International Conference on Power and Embedded Drive Control (ICPEDC)*, Mar. 2017, pp. 472–477, doi: 10.1109/ICPEDC.2017.8081136.

[24] S. Neupane and A. Kumar, "Modeling and Simulation of PV array in MATLAB/Simulink for comparison of perturb and observe & incremental conductance algorithms using buck converter," *International Research Journal of Engineering and Technology(IRJET)*, vol. 4, no. 7, pp. 2479–2486, 2017, [Online]. Available: https://irjet.net/archives/V4/i7/IRJET-V4I7506.pdf.

[25] M. Upasani and S. Patil, "Grid connected solar photovoltaic system with battery storage for energy management," in *2018 2nd International Conference on Inventive Systems and Control (ICISC)*, Jan. 2018, pp. 438–443, doi: 10.1109/ICISC.2018.8399111.

[26] I. Baboselac, T. Benšić, and Ž. Hederić, "MATLAB simulation model for dynamic mode of the Lithium-Ion batteries to power the EV," *Tehnički glasnik*, vol. 11, no. 1–2, pp. 7–13, 2017.

[27] B. Boukezata, A. Chaoui, J. P. Gaubert, and M. Hachemi, "An improved fuzzy logic control MPPT based P&O method to solve fast irradiation change problem," *Journal of Renewable and Sustainable Energy*, vol. 8, no. 4, p. 043505, Jul. 2016, doi: 10.1063/1.4960409.

[28] R. Belaidi, A. Haddouche, M. Fathi, M. M. Larafi, and G. M. Kaci, "Performance of grid-connected PV system based on SAPF for power quality improvement," in *2016 International Renewable and Sustainable Energy Conference (IRSEC)*, Nov. 2016, pp. 542–545, doi: 10.1109/IRSEC.2016.7984050.

[29] S. S. Reddy, "Optimal scheduling of thermal-wind-solar power system with storage," *Renewable Energy*, vol. 101, pp. 1357–1368, Feb. 2017, doi: 10.1016/j.renene.2016.10.022.

[30] D. P. Mishra and S. Chakraborty, "Application of soft computing in simulation of solar power tracking," in *2018 Technologies for Smart-City Energy Security and Power (ICSESP)*, Mar. 2018, vol. 2018-Janua, pp. 1–5, doi: 10.1109/ICSESP.2018.8376679.

BIOGRAPHIES OF AUTHORS

Kshirod Kumar Rout received B Tech degree in electrical engg. from VSSUT burla in 2000, Received M Tech degree in power electronics from KIIT University in 2011 and continuing PhD degree in IIIT Bhubaneswar. He is currently serving as Assistant Professor in the Dept of Electrical Engg, International Institute of Information Technology Bhubaneswar, Odisha. He can be contacted at email: kshirod@iiit-bh.ac.in.

Debani Prasad Mishra received the B.Tech. in electrical engineering from the Biju Patnaik University of Technology, Odisha, India, in 2006 and the M.Tech in power systems from IIT, Delhi, India in 2010. He has been awarded the Ph.D. degree in power systems from Veer Surendra Sai University of Technology, Odisha, India, in 2019. He is currently serving as Assistant Professor in the Dept of Electrical Engg, International Institute of Information Technology Bhubaneswar, Odisha. His research interests include soft Computing techniques application in power system, signal processing and power quality. He can be contacted at email: debani@iiit-bh.ac.in.

Sivkumar Mishra his higher studies in MS Food Engineering by coursework at the at the department of Food Science, University of Leeds from 1981-1982. He is attached to the Faculty of Biotechnology and Biomolecular Sciences. His research area then was on spray drying of food. With a small research grant provided by UPM, he developed the process for producing spry-dried coconut milk which made the national headlines. His vast experience and expertise in the field of biotechnology and biomolecular sciences have enabled him to become a national point of reference in the area of biomass, renewable energy and waste utilization. He has also served as a consultant to The Science Advisor Office, Prime Minister's Department, on the national project on biomass utilisation and is the national representative for the Asia Biomass Association headquartered in Tokyo, Japan. He can be contacted at email: capgs.smishra@bput.ac.in.

Suman Patra received the B-Tech (Bachelor of Technology) in the stream of Electrical and Electronics Engineering from International Institute of Information Technology Bhubaneswar (IIIT-BH), Odisha, India, in 2022. He is currently serving as Software Engineer in MNC. His research interests include renewable energy, power electronics, web development, and microgrid development with the integration of wind and solar photovoltaic energy sources. He can be contacted by email: patrasuman612@gmail.com.

Surender Reddy Salkuti received the Ph.D. degree in electrical engineering from the Indian Institute of Technology, New Delhi, India, in 2013. He was a Postdoctoral Researcher with Howard University, Washington, DC, USA, from 2013 to 2014. He is currently an Associate Professor with the Department of Railroad and Electrical Engineering, Woosong University, Daejeon, South Korea. His current research interests include market clearing, including renewable energy sources, demand response, smart grid development with the integration of wind and solar photovoltaic energy sources. He can be contacted at email: surender@wsu.ac.kr.