International Journal of Applied Engineering & Technology

A NOVEL AND HYBRID MPPT ALGORITHM FOR PHOTOVOLTAIC ELECTRONIC SYSTEM

Muhammad Kamran[1*], Inam Ullah[2], Sanaul Haq[3], Imtiaz Rasool[4], Faiz Ullah[5] and Aman Khan[6]
[1, 2,3,4,6] Department of Electronics, University of Peshawar, Peshawar 25120, Pakistan
[5]Department of Electronics, Islamia College Peshawar, Peshawar 25120, Pakistan
[1]kamranmu@uop.edu.pk, [2]Inam1991@uop.edu.pk, [3]sanaulhaq@uop.edu.pk, [4]imtiazrasoolkhan@uop.edu.pk, [5]faiz@icp.edu.pk and [6]khanaman3214@uop.edu.pk
Corresponding Author, Dr. Muhammad Kamran

ABSTRACT
In the contemporary era, solar energy serves as a crucial source for generating electric power across various applications. However, its drawback lies in the conversion of only 30 to 40 percent of incident solar energy into electrical power. To enhance efficiency and power generation capabilities, the application of maximum power point (MPPT) is instrumental. In this research article, we propose a novel hybrid MPPT technique that amalgamates the strengths of incremental conductance (IncCond) and fractional open circuit voltage (FOCV) methods. The FOCV approach, while swift, lacks precision, whereas the IncCond method boasts accuracy but suffers from a slow response. The FOCV method attains the maximum power point (MPP) rapidly albeit with some deviations. Conversely, the IncCond method achieves the MPP without oscillations but at a slower pace. Our hybridized technique leverages the advantages of both methods by initially using the FOCV to swiftly reach the approximate MPP. Subsequently, this value is refined by the IncCond method to precisely ascertain the MPP. The results obtained from this proposed approach are satisfactory, as the swift attainment of the MPP from the FOCV method is complemented by the accuracy achieved through the IncCond method. In comparison to other MPP techniques, our proposed algorithm exhibits a superior response.

Keywords: Fractional open circuit voltage, IncCond, Renewable energy, Maximum PowerPoint tracking, Hybridized MPP techniques.

INTRODUCTION
Renewable energy sources, like solar and wind energy, have garnered significant attention as sustainable alternatives to traditional fossil fuels [1][2][3]. One key challenge in harnessing the full potential of renewable energy lies in optimizing the conversion of natural resources into usable electrical power. MPPT techniques play a crucial role in this optimization process by ensuring that renewable energy systems operate at their peak efficiency levels [4]. Among the various MPPT methods, FOCV and IncCond are prominent approaches with distinct advantages and limitations. The FOCV method offers rapid attainment of the MPP, making it well-suited for applications requiring quick response times [5]. However, its accuracy may be compromised due to inherent deviations. On the other hand, the IncCond method excels in precision, ensuring accurate determination of the MPP [6]. Nonetheless, it suffers from slower response rates compared to FOCV. Recognizing the strengths and weaknesses of these individual techniques, researchers have proposed hybridized MPPT approaches to leverage the benefits of both methods. This research aims to hybridize two MPPT methods FOCV and IncCond to achieve a balance between speed and accuracy in tracking the MPP. By combining the rapid response of FOCV with the precise adjustment capability of IncCond, these hybrid approaches aim to optimize energy harvesting from renewable sources more effectively. In this hybrid system, FOCV initially identifies the approximate MPP swiftly, while IncCond fine-tunes this value to ensure optimal power extraction without oscillations. This synergistic integration results in improved overall performance and enhanced energy yield from renewable sources. The development and refinement of techniques signify a significant advancement in renewable energy technology, paving the way for more efficient and reliable energy systems [7]. As the demand for clean energy solutions continues to grow, these innovative approaches hold immense promise for maximizing the utilization of renewable resources and accelerating the transition towards a sustainable energy future.

According to [8], solar power generation is highly dependent on irradiance and temperature, requiring complicated electronic systems for further efficient energy consumption. In this study, to obtain the maximum electricity from the sun for solar systems the Moving Averaging Filter (MAF) is paired with the boosted P&O . The research also shows how to charge a photovoltaic system's battery using a buck converter controlled by a customized algorithm. The proposed system is computer-simulated and implemented. The improved approach performs well in simulations and experiments, indicating that it is more suitable for photovoltaic applications. The original P & O algorithm was upgraded with the MAF algorithm to increase the PV system's performance and overcome power drift. MAF entirely reduced the drift and oscillations that existed in the basic P & O algorithm, as evidenced by experimental findings. The fact that the maximum point is near the peak of the curve further indicates that the proposed technique works well. To extract the required output, a buck converter developed and created, was capable of giving the intended performance. Moreover, the converter's output was used to charge the battery and drive the load. The results of the experiments show that the P & O, along with the MAF technique, performs better for solar system MPPT. Future work is under consideration to test the system under different temperature and irradiance conditions.

In [9] Uday G. Khadodra et al. suggested that, renewable energy system sizing or design for a Canadian home. All design considerations are made in this case based on the physical location of St. John's. The strong wind intensity at this location might cause major problems to wind turbine functioning. An additional challenge is that the strategy is for home usage, and wind turbines emit excessive noise, which might be a concern for residents in the area. Considering the challenges connected with wind-based power generation, solar-based power generation is the best option for this site location. Canadian houses have been considered to design a solar energy system in this work. It is made up of the house's annual energy use, solar PV sizing, and system control, which is handled by PI controller. The process for determining the best solar array size is presented. This is a useful way of designing a renewable energy system for homes and determining the system's performance and cost before it is implemented.

In [10], the authors suggested to evaluate the power generated under conventional climatic conditions by comparing alternative approaches to the MPPT algorithms. The performance of all of these algorithms is compared under a variety of operational situations. In considerations of normalization, Fuzzy Logic Control (FLC) is the quickest, undergone by the FSCC, FOCV, P&O, IncCond and Hill Climbing (HC) methods. The FLC method, along with the P&O INC, HC, FSCC, and FOCV techniques, gives the best calculating outcomes. A new FLC approach is developed in this paper. Two fundamental questions are addressed by the suggested design. To begin with, while traditional MPPT approaches are adequate for a PV system with a moderate change in irradiation, they encounter significant hurdles when the irradiation changes quickly. The other issue is that when there are few functions defined for members, the challenging engineering issues of a fuzzy system are decreased. The fuzzy rules of the proposed technique are generated from an enhanced conventional MPPT technique. The suggested method ensures that the highest PowerPoint is precisely measured. In [11] E. P. Sarika et al., developed a new hybrid Zero Oscillation (ZO) MPPT method for an independent Solar system with a boost converter to reduce output power oscillations due to rapid variations in the solar irradiance and ambient temperature on the operation of solar module's output power. In addition, when compared to previous MPPT approaches, the suggested MPPT is simpler and less expensive to implement. MPPT algorithms are divided into two types: classical and intelligent. G and T are required as inputs for LUT MPPT, and all relevant data is stored beforehand. These facts are obtained immediately during running, which reduces completion time and eliminates the need for discovery in the case of a disruption. More stored data is required for increased precision, which raises the memory need. The FLC MPPT is proposed, which increases the system's tracking efficiency. FLC MPPT has the advantage of not requiring a precise scientific model of the Photovoltaic system.

In (Palanisamy, Vijayakumar, Venkatachalam, Mano Narayanan, et al., 2019) R. Palanisamy et al, claimed that, for high and medium power applications, high input sources from renewable systems such as solar and wind energy systems become difficult, increasing the cost of installation. As a result, depending on the uses, the generated voltage from the PV system is increased using various boost converters. In [14] A. Chandramouli, V. Sivachidambaranathan, et al., investigated the extraction of maximum power from a photovoltaic (PV) system using a fuzzy logic controller (FLC) based MPPT technique. Fuzzy is a supervisory control algorithm method that offers PV with satisfied and acceptable results. Different techniques are used to acquire the most output power from the PV module, regardless of the input source change (Solar irradiation and temperature). For various conditions, the performance results were investigated in the MATLAB/Simulink software.

REVIEW OF THE INCCOND AND FOCV MPPT METHODS

In this section, both the IncCond and FOCV methods have been reviewed for a better understanding of the hybrid MPPT.

Inccond MPPT Algorithm

The IncCond method determines the cessation of perturbing the operating point once the MPPT achieves the MPP. If this condition is not met, the relationship between -I/V and dI/dV is utilized to ascertain the path in which the MPPT operational point may need tuning. The IncCond method consistently operates on the MPP voltage, relying on both IncCond and instant conductance of the PV module [15][16]. The MPP point exhibits a zero slope with numerous curves at the MPP, increasing on the left for maximum power point tracking and decreasing on the right side to achieve MPP. Through the differentiation of the power of the PV array, the IncCond method determines the voltage until the result equals zero, indicating the desired MPP.

$$\frac{dP}{dV}=\frac{d(VI)}{V}=I+V\frac{dI}{dV}=0 \quad at\ MPP \qquad (1)$$

$$-IV=\frac{dI}{dV} \qquad (2)$$

As depicted in equation 2, the left side illustrates the immediate conductance of the PV array, while the right side denotes its IncCond. Therefore, to track the MPP, two essential conditions must be met: firstly, both quantities must become equal to each other in magnitude but have opposite signs. Secondly, if equation (2) displays any derived set of inequalities, we can readily deduce, at any given moment, whether the MPP voltage lies above or below. Figure 1 shows the IncCond MPPT curve.

$$\frac{\Delta I}{\Delta V}=-\frac{I}{V}; \qquad \left(\frac{dP}{dV}=0\right) \qquad (3)$$

$$\frac{\Delta I}{\Delta V}>-\frac{I}{V}; \qquad \left(\frac{dP}{dV}>0\right) \qquad (4)$$

$$\frac{\Delta I}{\Delta V}<-\frac{I}{V}; \qquad \left(\frac{dP}{dV}<0\right) \qquad (5)$$

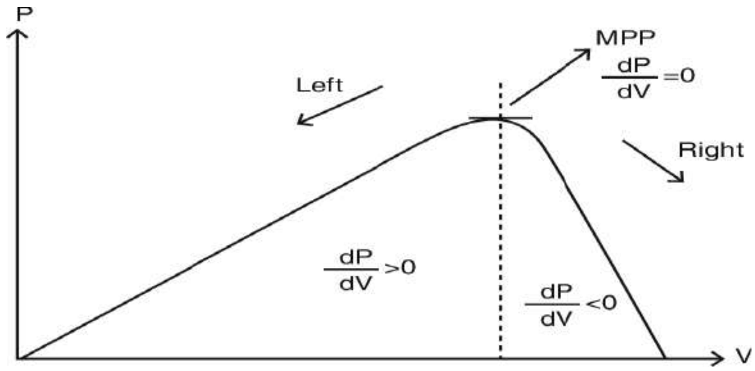

Figure 1 *(IncCond MPPT curve)*

Inccond Flow Chart

Figure 2 shows the the flowchart of the IncCond method. The initial step in elucidating the flowchart of IncCond involves sampling current and voltage. Subsequently, these samples are stored in memory, followed by the determination of the change in current and voltage by subtracting present samples from previous ones. Upon assessing the change in voltage, if it equals zero, IncCond is not regulated due to the resulting infinity ratio. Conversely, if the change in voltage is nonzero, IncCond is computed. In essence, it is established that IncCond equals the negative value of instantaneous conductance when it reaches the MPP [17]. If this condition persists, MPP is attained without the need to agitate any parameter. Conversely, if the result is negative, it becomes necessary to examine whether the MPP lies on the right or the left side. Decreasing the duty cycle on the right-hand side aids in reaching MPP while increasing it on the left side serves the same purpose. MPP is achieved when the change in current equals zero; otherwise, adjustments to the current are required to align with the MPP.

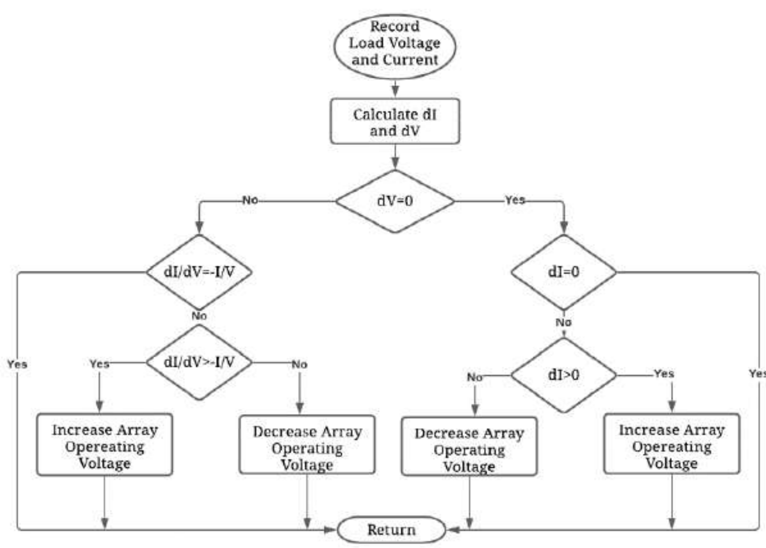

Figure 2 *(Flowchart of IncCond)*

Fractional Open Circuit Voltage MPPT Algorithm

This method employs a direct approach to achieve the Maximum PowerPoint. Rapid attainment of MPP characterizes this technique [7][18]. It involves interrupting the usual process of the system in a stated timeframe to measure the open-circuit voltage of the solar panel, denoted as Voc. These measurements are stored, and subsequently, the reference voltage, Vmpp, is adjusted to approximately 60 to 80% of Voc. Then the Vmpp is checked with the actual working voltage, Vpv, of the solar panel. Numerically, this can be expressed as follows:

$$Vmpp = K * Voc \quad (6)$$

The value of parameter K can be adjusted between 0.76 and 0.82. If the difference between the output DC voltage of the PV panel and this parameter is positive, then the value of K is incremented by a specified step size of the voltage, otherwise, it is decremented by a similar step size of the voltage.

Focv Flowchart

Figure 3 displays the flowchart of the FOCV method. The initial step in the flowchart of FOCV involves measuring the open circuit voltage (V_{OC}) of the Photovoltaic array. Subsequently, the Open Circuit Voltage value is multiplied by a constant K to attain the MPP [19]. In the subsequent step, if the voltage value of the PV array is lower than the MPP voltage, it is incremented. Conversely, if the MPP voltage exceeds the voltage of the PV array, the PV module voltage is reduced to achieve equilibrium between the maximum voltage and MPP voltage of the PV array. The entirety of this process is visually depicted in the accompanying figure.

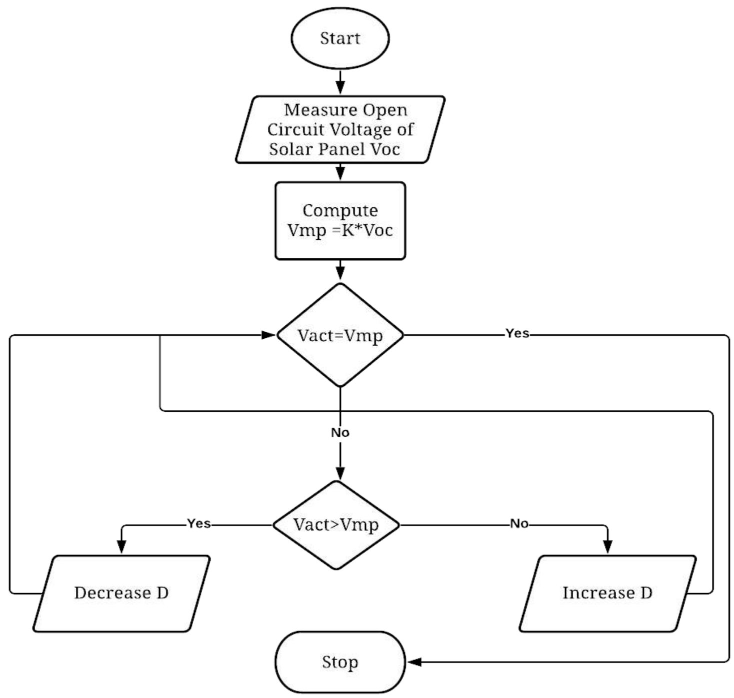

***Figure 3** (Flowchart for FOCV MPPT)*

SYSTEM DESIGN

Figure 4 illustrates the comprehensive Simulink design of the proposed system. This hybridized model combines two MPPT techniques, IncCond and FOCV. The boost converter utilized in our model operates at its maximum point determined by the duty cycle. Initially, the FOCV MPPT is executed to swiftly reach the maximum power point despite discrepancies at the MPP. Then the IncCond starts its working and it fine-tunes the MPP. After acquiring the MPP the system waits for 10 minutes and after that, the process is repeated. During this time, the voltage of the PV module across the open circuit points is measured and then multiplied by a constant to quickly achieve the MPP. This MPP voltage is then compared to the actual value of the PV array's voltage. Once both voltages align, MPP is achieved as per the FOCV method. IncCond is subsequently employed to minimize variations in the fractional open circuit voltage. This involves monitoring changes in current and voltage, comparing IncCond with instantaneous conductance, and achieving MPP when they coincide. If not, the operating voltage of the array is adjusted accordingly to attain MPP. Similarly, if the change in current equals zero, adjustments to the array's operating voltage are made as necessary. Consequently, the obtained final results ensure efficient MPP completion with minimal variations.

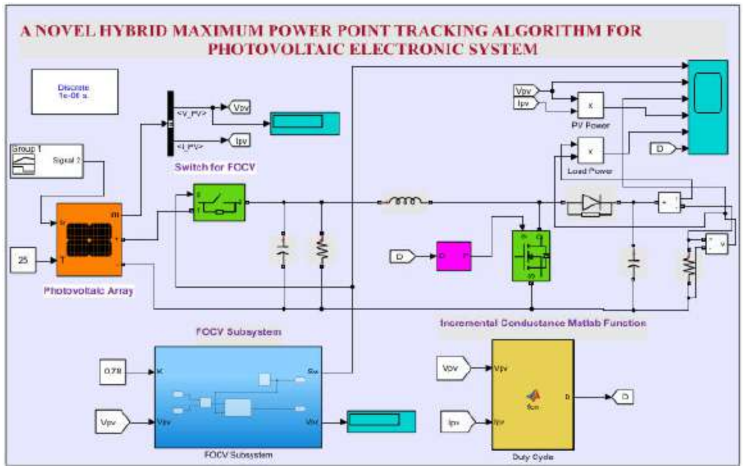

Figure 4 *(Overall system design)*

RESULTS AND DISCUSSION

This section covers the MPPT curves for IncCond, FOCV, modified FOCV and the proposed hybrid MPPT methods. The reference MPPT curve serves as a benchmark for assessing different MPPT approaches. Approaches that exhibit rapid convergence and minimal variance when compared to others are considered precise. The IncCond method is accurate and the FOCV is fast. That's why they are hybridized in this research. The results obtained are satisfactory and meet the desired fast and accurate MPPT. The following are the results that were obtained after this research.

REFERENCE MPPT CURVE.

The reference MPPT curve stands out for its exceptional accuracy and the swiftest convergence speed. Notably, it exhibits no fluctuations and achieves rapid convergence [20][21]. All other MPPT approaches are evaluated against this standard MPPT curve, emphasizing its pivotal role in the comparison process. Essentially, the Reference MPPT curve serves as a benchmark for assessing other MPPT techniques, serving as a model for comparison. The effectiveness of various MPPT techniques is gauged by their ability to converge quickly with minimal alteration when related to the reference MPPT curve. Figure 5 displays the curve of the reference MPPT, depicting the initial power output of 40 watts recorded up to 100 seconds, followed by an increment to 85 watts over the subsequent 100 seconds, up to 200 seconds.

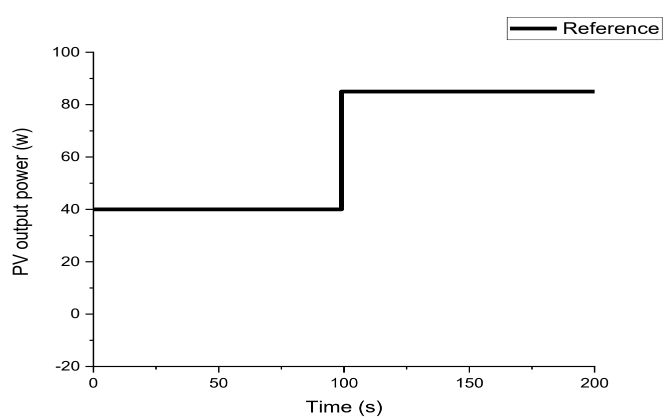

Figure 5 *(Reference MPPT Curve)*

Inccond MPPT Curve

Illustrated in Figure 6, the IncCond curve aligns with the reference MPPT curve after a significant delay, suggesting a lower convergence speed. The IncCond curve converges with the reference curve approximately 75 seconds later. Despite this delay, the variations are minimal, indicating the accuracy of the IncCond method. The IncCond curve follows the reference curve with minor deviations up to approximately 100 seconds. Subsequently, it deviates from the reference MPPT curve until approximately 155 seconds, attributable to the step taken by the reference curve. However, from 155 seconds onwards until 200 seconds, the IncCond curve follows the reference curve with fewer variations, indicating its accuracy.

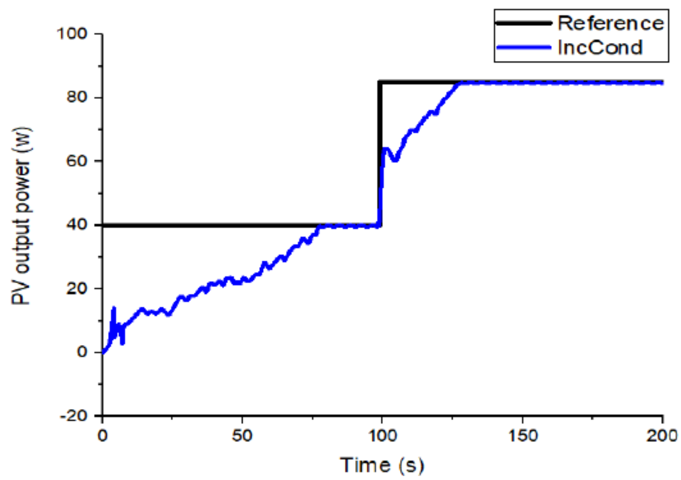

Figure 6 *(Comparison of IncCond with the reference MPPT curve)*

FOCV MPPT curve.

The FOCV method rapidly approaches the MPP point, albeit with significant variations. This implies that while the FOCV technique exhibits fast convergence speed, it lacks precision. In Figure 7, the FOCV method curve is juxtaposed with the benchmark MPPT curve. Initially, the FOCV curve closely follows the reference curve, but as time progresses, it displays considerable fluctuations towards the end, indicating its lesser precision despite its swiftness. The FOCV technique achieves alignment with the reference MPPT curve at the 25-second mark, demonstrating its accuracy. However, when the reference curve increases to 85 watts, the FOCV curve swiftly realigns with it at 120 seconds. Subsequently, there is a significant variation in the curve until the 200-second mark, underscoring the lesser accuracy of the FOCV MPPT technique.

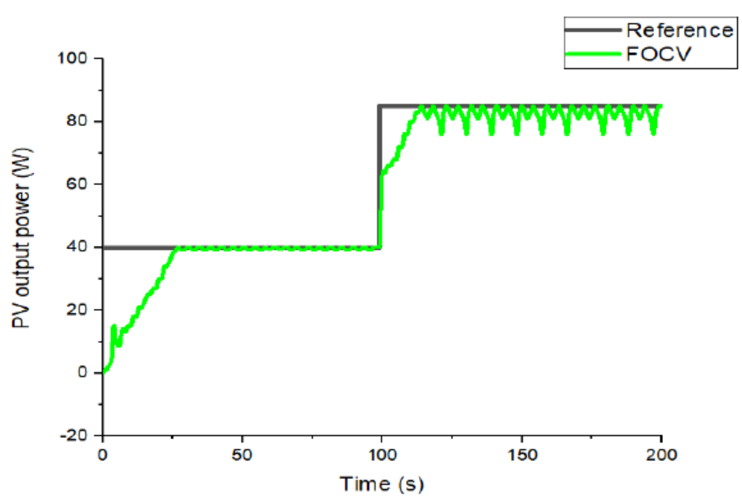

Figure 7 *(Comparison of FOCV and reference MPPT Curve)*

Modified FOCV MPPT curve

An improved version of the FOCV curve has been developed through several adjustments to the original FOCV MPPT. When compared to the standard MPPT curve, the Modified FOCV approach swiftly reaches the MPP with fewer fluctuations in the curve. Figure 8 illustrates that the MPPT point is achieved promptly, typically within 22 seconds, in contrast to the reference MPPT curve. Subsequently, minimal variations are observed up to 100 seconds. Furthermore, when accounting for a step change, the reference MPPT curve aligns more rapidly with fewer fluctuations. Overall, the modified FOCV MPPT technique demonstrates expeditious behavior and exhibits less variation up to a certain extent.

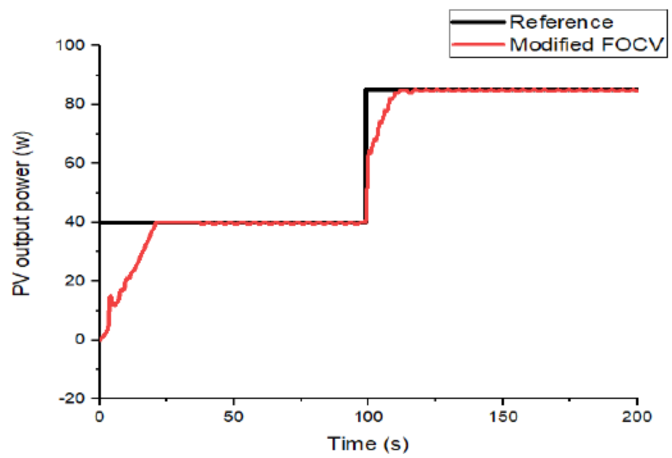

Figure 8 *(Comparison of Modified FOCV with the Reference curve)*

Proposed Hybrid MPPT curve

In the proposed hybrid system, the IncCond and FOCV MPPT approaches are integrated. The FOCV initiates the rapid establishment of the reference MPPT curve. Subsequently, the deviations in the curve are relatively minimal due to the inclusion of the IncCond curve. Consequently, our suggested hybrid system exhibits exceptional precision and boasts a swift convergence rate. As illustrated in Figure 9, the MPP is achieved in approximately 15 seconds, with the FOCV technique facilitating a rapid alignment with the reference MPPT curve. Moreover, the hybrid system swiftly traces the MPP during adjustments made by the reference curve. The result of this proposed method is very close to the benchmark MPPT curve as it is evident from the curve that it is touching the standard curve just in the first 10 seconds. Another improvement is in the value of MPP, as there are minimum fluctuations after reaching the MPP. Thus, this novel and hybrid approach combines the advantages of the swiftest convergence speed and highest accuracy.

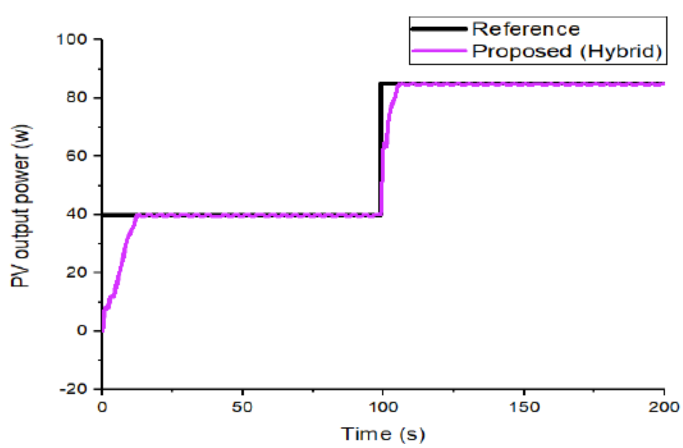

Figure 9 *(Comparison of the Proposed Hybrid MPPT with the reference curve)*

Comparison of all MPPT curves

Figure 10 displays the comparison of all the MPPT methods. Among them, the IncCond curve exhibits the slowest convergence speed compared to others. However, its accuracy is notably higher if compared to the reference MPPT method and other MPPT techniques. Conversely, the FOCV method establishes a higher convergence speed than other MPPT techniques but is less accurate. Another technique discussed is the modified FOCV MPPT approach, which outperforms the simple FOCV MPPT approach. The modifications in the FOCV method lead to superior results, resulting in faster attainment of the MPP and higher efficiency compared to the basic FOCV MPPT curve. Additionally, the variations in the Modified FOCV MPPT curve are minimal towards the end, indicating increased accuracy. Our proposed hybrid technique combines FOCV and IncCond MPPT, which proves to be the most effective among other MPPT techniques. The FOCV contributes to faster MPP achievement, while the accuracy is enhanced by the inclusion of the IncCond technique.

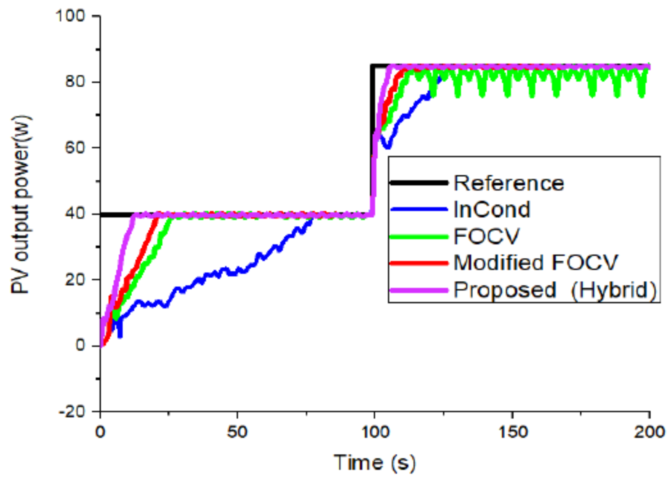

Figure 10 *(Comparison of all MPPT curves)*

CONCLUSION

The objective of this study was to utilize a hybrid MPPT approach to maximize electrical energy extraction from photovoltaic panels. Two distinct MPPT methods, IncCond and FOCV, were combined for this purpose. The optimal MPPT method is characterized by its ability to reach the MPP in the shortest time with high accuracy. To achieve this goal, this research work combined the FOCV method, which achieves rapid MPP attainment, with the IncCond method, known for its high accuracy. The FOCV technique facilitates swift MPP acquisition, and the implementation of IncCond ensures precision. The results obtained from simulations are considered satisfactory, as they have led to the development of a novel, accurate, and efficient MPPT technique.

REFERENCES

[1] L. S. Paraschiv and S. Paraschiv, "Contribution of renewable energy (hydro, wind, solar and biomass) to decarbonization and transformation of the electricity generation sector for sustainable development," *Energy Reports*, vol. 9, pp. 535–544, Sep. 2023, doi: 10.1016/J.EGYR.2023.07.024.

[2] R. H. Inman, H. T. C. Pedro, and C. F. M. Coimbra, "Solar forecasting methods for renewable energy integration," *Prog Energy Combust Sci*, vol. 39, no. 6, pp. 535–576, 2013, doi: 10.1016/j.pecs.2013.06.002.

[3] R. Al Badwawi, M. Abusara, and T. Mallick, "A Review of Hybrid Solar PV and Wind Energy System," *Smart Science*, vol. 3, no. 3, pp. 127–138, 2015, doi: 10.1080/23080477.2015.11665647.

[4] Z. M. S. Elbarbary and M. A. Alranini, "Review of maximum power point tracking algorithms of PV system," *Frontiers in Engineering and Built Environment*, vol. 1, no. 1, pp. 68–80, 2021, doi: 10.1108/febe-03-2021-0019.

[5] J. Ahmad, “A fractional open circuit voltage based maximum power point tracker for photovoltaic arrays,” in *2010 2nd International Conference on Software Technology and Engineering*, IEEE, Oct. 2010. doi: 10.1109/ICSTE.2010.5608868.

[6] D. Choudhary and A. Ratna Saxena, “Incremental Conductance MPPT Algorithm for PV System Implemented Using DC-DC Buck and Boost Converter,” 2014. [Online]. Available: www.ijera.com

[7] M. Mithun Krishnan and K. R. Bharath, “A Novel Sensorless Hybrid MPPT Method Based on FOCV Measurement and P &O MPPT Technique for Solar PV Applications,” in *International Conference on Advances in Computing and Communication Engineering, ICACCE*, 2019.

[8] A. Ballaji, B. P. Divakar, N. Hediyal, R. P. Mandi, and K. N. Swamy, “Energy efficient perturb and observe maximum power point algorithm with moving average filter for photovoltaic systems,” *International Journal of Renewable Energy Research*, vol. 9, no. 1, pp. 207–214, 2019.

[9] U. Khadodra, M. H. Rahaman, and M. Jamil, “Design of Renewable Energy System for a House in St. John’s, Canada,” *European Journal of Electrical Engineering and Computer Science*, vol. 4, no. 3, 2020, doi: 10.24018/ejece.2020.4.3.213.

[10] C. Bertin *et al.*, “A comprehensive assessment of MPPT algorithms to optimal power extraction of a PV panel,” *Journal of Solar Energy Research*, vol. 4, no. 3, pp. 172–179, 2019.

[11] P. E. SARIKA, J. Jacob, S. Mohammed, and S. Paul, “A Novel Hybrid Maximum Power Point Tracking Technique With Zero Oscillation Based On P&O Algorithm,” *International Journal of Renewable Energy Research (IJRER)*, vol. 10, no. 4, pp. 1960–1971, 2020.

[12] R. Palanisamy, K. Vijayakumar, V. Venkatachalam, R. M. Narayanan, D. Saravanakumar, and K. Saravanan, “Simulation of various DC-DC converters for photovoltaic system,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 2, p. 917, 2019, doi: 10.11591/ijece.v9i2.pp917-925.

[13] R. Palanisamy, K. Vijayakumar, V. Venkatachalam, R. Mano Narayanan, D. Saravanakumar, and K. Saravanan, “Simulation of various DC-DC converters for photovoltaic system,” *International Journal of Electrical and Computer Engineering*, vol. 9, no. 2, pp. 917–925, 2019, doi: 10.11591/ijece.v9i2.pp.917-925.

[14] C. A, “Extract Maximum Power From Pv System Employing Mppt With Flc Controller,” *Journal of Electrical Engineering and Automation*, vol. 1, no. 02, pp. 58–71, 2019, doi: 10.36548/jeea.2019.2.001.

[15] P. K. Mishra and P. Tiwari, “Incremental conductance MPPT in grid connected PV system,” *International Journal of Engineering, Science and Technology*, vol. 13, no. 1, pp. 138–145, 2021, doi: 10.4314/ijest.v13i1.21s.

[16] L. Shang, H. Guo, and W. Zhu, “An improved MPPT control strategy based on incremental conductance algorithm,” *Protection and Control of Modern Power Systems*, vol. 5, no. 1, 2020, doi: 10.1186/s41601-020-00161-z.

[17] I. Owusu-Nyarko, M. A. Elgenedy, I. Abdelsalam, and K. H. Ahmed, “Modified variable step-size incremental conductance mppt technique for photovoltaic systems,” *Electronics (Switzerland)*, vol. 10, no. 19, 2021, doi: 10.3390/electronics10192331.

[18] Y. C. Im, S. S. Kwak, J. Park, and Y. S. Kim, “Intermittent FOCV using an I-V curve tracer for minimizing energy loss,” *Applied Sciences*, vol. 11, no. 19, 2021, doi: 10.3390/app11199006.

[19] D. Baimel, S. Tapuchi, Y. Levron, and J. Belikov, "Improved fractional open circuit voltage MPPT methods for PV systems," *Electronics (Switzerland)*, vol. 8, no. 3, Mar. 2019, doi: 10.3390/electronics8030321.

[20] D. Y. Raval, P. J. Munjani, and N. R. Mansoori, "Reference based Maximum Power Point Tracking Algorithm for photo-voltaic power generation," *International Conference on Electrical Power and Energy Systems, ICEPES 2016*, pp. 438–443, May 2017, doi: 10.1109/ICEPES.2016.7915971.

[21] A. O. Baba, G. Liu, and X. Chen, "Classification and Evaluation Review of Maximum Power Point Tracking Methods," *Sustainable Futures*, vol. 2, p. 100020, Jan. 2020, doi: 10.1016/J.SFTR.2020.100020.