SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

A Study on Maximum Power Point Tracking (MPPT) Converters for Solar Energy Harvesting

Muhammad Aniq Shahmi Bimazlim[1,*], Chanuri Charin[1], Baharuddin Ismail[1], Yessi Jusman[2]

[1] Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia
[2] Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, Daerah Istimewa Yogyakarta 55183, Indonesia

ABSTRACT

This research paper presents a brief comparative analysis review paper on Maximum Power Point Tracking (MPPT) converters utilized in the process of solar energy harvesting. The primary focus of this paper is on conventional MPPT converters such as buck, boost, and buck-boost converters. Applications of MPPT controllers have also been analysed in this review paper. The controllers or algorithms nowadays are rapidly evolving as more new algorithms are developed and applied to MPPT converters. Thus, the benefits and drawbacks of the MPPT converters and controllers have been properly discussed and analysed based on tracking efficiency, convergence speeds, and steady-state oscillation. Appropriate research reviews are used to properly study and analyse the findings. Artificial Bee Algorithm (ABC) has been deemed as a good MPPT controller as ABC outperforms the other MPPT controllers. This research review is considered to be a guidance resource for new researchers working in the MPPT research.

Keywords:

MPPT converters; MPPT controllers; Soft computing

1. Introduction

Global warming has become a worldwide environmental crisis that dominates the international agenda and is one of humanity's most difficult challenges. Many individuals will be impacted by the difficulties posed by this extremely complex issue both now and in the future, especially those who are most vulnerable yet have a limited ability to adapt to and respond to climate hazards. Malaysia aimed to cut greenhouse gas emissions intensity, one of the causes of global warming by launching a low-carbon economy as one of its primary strategies to combat global warming and climate change. The solar energy is one of the natural energies applicable to reduce greenhouse gas emissions intensity. Due to its clean and sustainable nature, solar energy has gained popularity as a source of renewable energy as well as can be considered the best among the available renewable energy technologies [1].

* *Corresponding author.*
E-mail address: aniq12@gmail.com

https://doi.org/10.37934/araset.60.1.278289

A Photovoltaic (PV) system is used to harvest the aforementioned energy. Despite of many advantages of PV systems, obtaining the highest or optimum power output still remain a challenge to PV systems. This is especially true for partial shading conditions (PSC), in which the solar panels are partially obstructed by objects that disturb the non-linear parameters such as temperature and irradiance. These disturbances on the non-linear parameters caused changes in the characteristics of the I-V and P-V curves of solar PV and reduced the power output of the systems [2]. Once the PV system is under shading conditions, multiple peaks are presented in the I-V and P-V characteristics. The highest peak is known as the global maximum power point (GMPP) or maximum power point (MPP), while the rest is known as local peak [3]. However, if compared with uniform conditions, only one optimum peak is shown in the I-V and P-V characteristics. Nonetheless, MPP is the only power point needed to obtain maximum PV power.

Maximum power point tracking (MPPT) techniques are applied to solar-powered systems to harvest the optimum point [4]. There are various MPPT controllers were introduced into MPPT research to utilize the solar-powered systems output, such as Perturb & Observe (P&O), Artificial Neural Network (ANN) and Particle Swarm Algorithm (PSO). The MPPT controller will tracking the GMPP throughout the cycle to harvest the optimum power. Once the MPPT has tracked the GMPP, the systems will maintain the optimum output by controlling the PWM signal from the controller. Thus, the MPPT controller can track and maintain the optimum output from the PV systems.

The DC-DC converters also important to produce the best quality of output power from PV system. However, MPPT DC-DC converter cannot be the same as any normal DC-DC converter. Normal converter only step-up or step-down the input DC into new value of DC output. Meanwhile, MPPT converter used for boosting or reducing the DC output while maintaining the MPP output with the help of the controller. The MPPT controller search for the MPP of the PV power, produces PWM duty cycle to control the input of PV systems as well as maintaining the MPP of the output. So, the MPPT converter is a complex system compared to conventional DC-DC converter. Thus, a reliable MPPT converter is required for obtaining and maintaining the MPP of PV systems output during PSC as well as during UIC.

This paper is divided into five sections, the Introduction, MPPT controller, MPPT controller, Results and discussion, and the Conclusion. This information is vitally important to researcher and industrial to start exploring on the solar MPPT system.

2. MPPT Converter

The PV systems mainly consist of solar panel, the MPPT converter and the DC output load as shown in Figure 1. The main focus of this paper is the available MPPT DC-DC converters. Variable DC-DC converter exist for MPPT. The common DC-DC converters that are widely used in MPPT research are buck [5], boost [6], buck-boost [7], Cuk [8], Single-ended primary inductor (SEPIC) [9] and flyback converter [10]. Each converters have different configuration and purposed including different efficiency and power outputs.

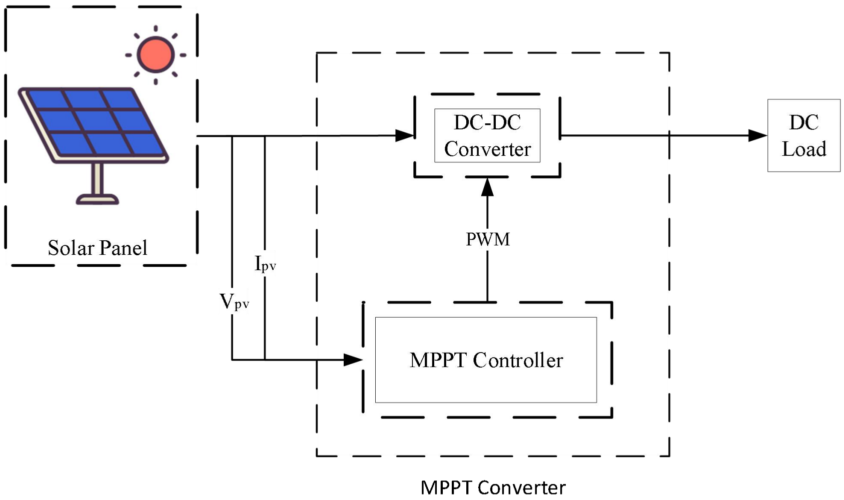

Fig. 1. Standalone PV systems

2.1 Buck Converter

The buck converter, also known as the step-down DC-DC converter, is frequently employed in PV systems when it is necessary to reduce the voltage of the PV module to match the load or battery voltage. The MPPT buck converter is utilized to connect a PV array and DC load, with the objective of guaranteeing optimal performance of both MPPT and power control functions [11]. The buck converter also has drawn interest for industrial applications because of its simple design and reasonable cost [5,6].

MPPT buck converter operates when optimum resistance, R_{mpp} is equal or lower than load resistance, R_{load}, $R_{load} \geq R_{mpp}$. Figure 2 depicts that the converter does not operates or tracing MPP of I-V curve regions that is near to short circuit current, I_{SC}. Thus, changing duty cycle, D, value to control the input resistance, R_i, to match with R_{mpp} and operates the buck converter tracking MPP restricted within operational regions.

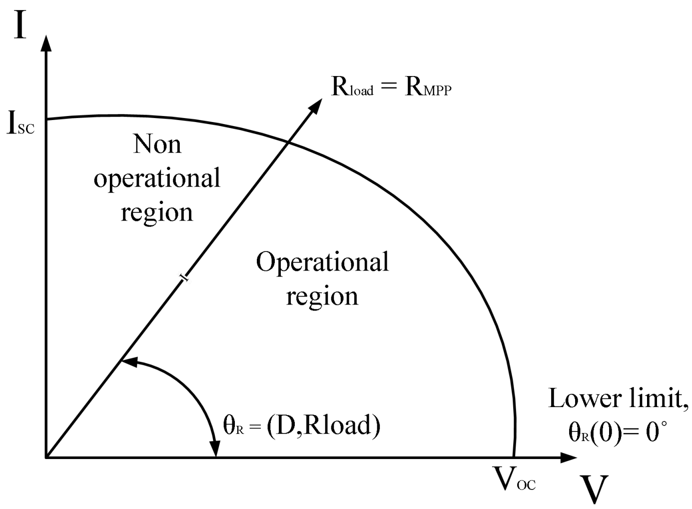

Fig. 2. Operational and non-operational regions of I-V curve in MPPT buck converter [12]

Based on paper by Ayob *et al.,* [13], proper sizing of the MPPT buck converter is imperative to guarantee the persistence of the continuous current mode (CCM) operation as well as a tolerable degree of output voltage ripple. The results by Ayob *et al.,* [13] shows that MPPT buck converter requires high duty cycle to maintain best efficiency. Proper size of resistive loads is important to maintain the duty cycle within limits, 0 < D < 1, and avoid the MPPT controller from failing. However, proper sizing of capacitor and inductor can be found in this study. Figure 3 shows the MPPT buck converter.

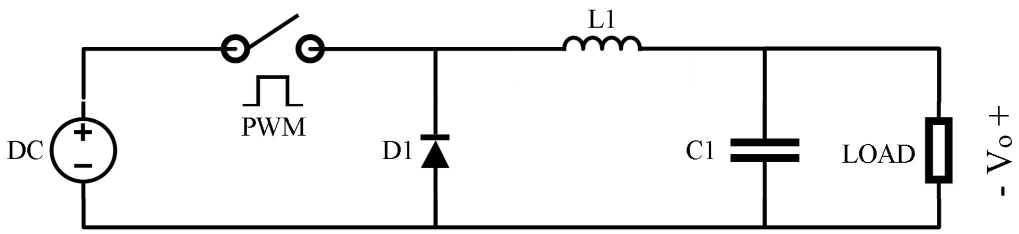

Fig. 3. Buck converter

2.2 Boost Converter

The output voltage from PV modules is low and must be increased for high power usage [14]. So, the boost converter or the step-up DC-DC converter, also a conventional converter is use to increase the voltage output higher than input voltage from the PV module. Unfortunately, the boost converter have issues including high switch voltage stress, limited gain, high duty cycle for high gain, and poor efficiency during high duty ratio [15].

MPPT boost converter operates when optimum resistance, R_{mpp} is equal or greater than load resistance, R_{load}, $R_{load} \leq R_{mpp}$. Figure 4 shows that the converter does not operates or tracing MPP of I-V curve regions that is near to open circuit voltage, V_{OC}. Thus, changing duty cycle, D, value to control the input resistance, R_i, to match with R_{mpp} and operates the boost converter tracking MPP restricted within operational regions. Thus, during low irradiance, the boost converter is inoperable as the R_i is within non-operational region.

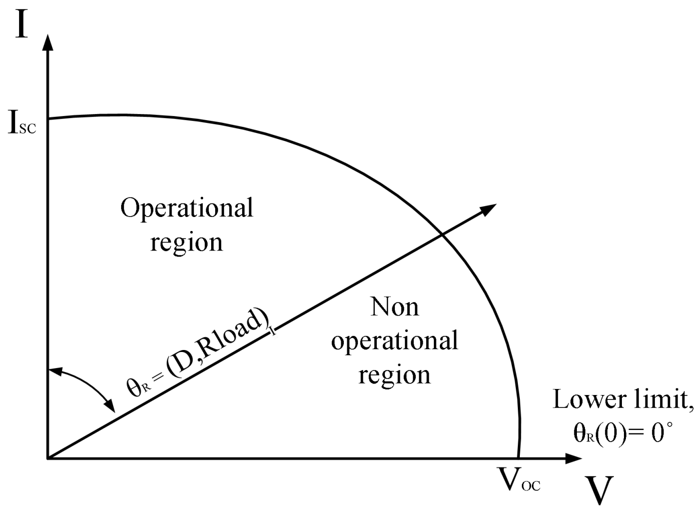

Fig. 4. Operational and non-operational regions of I-V curve in MPPT buck converter [12]

According in the paper by Ayop and Tan [2], proper sizing and developed MPPT boost converter are able to operate as desired and allow the ripple factor and duty cycle of MPPT boost converter to be control as required. The results by Ayop and Tan [2], shows that the proper sizing MPPT boost converter can reduce the cost and the total size of the converter. However, to achieve optimal performance despite the presence of non-ideal components such as inductor and capacitor internal resistance, it becomes necessary to meticulously adjust the sizing and undertake various steps to obtain the appropriate derivation of requirements. Figure 5 depicts a MPPT boost converter.

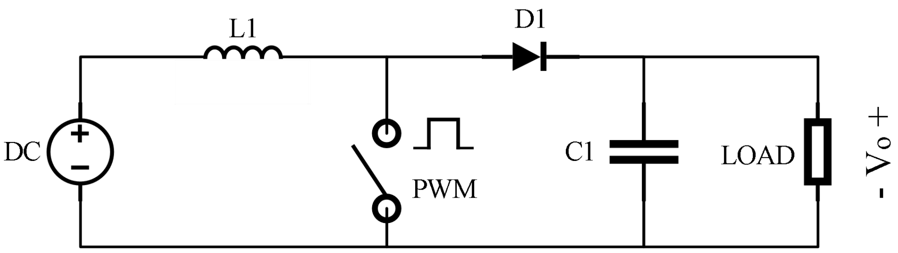

Fig. 5. Boost converter

2.3 Buck-Boost Converter

A buck-boost converter amalgamates the architectural features of both a buck converter and a boost converter, thereby facilitating voltage amplification and attenuation capabilities from the PV input to the MPP output [8]. It is imperative to acknowledge that buck-boost converters will encounter heightened requisites in terms of power density, physical footprint, mass, voltage amplification range, efficiency, stability, cost implications, and other pertinent aspects. However, the topology of buck–boost converters is different for different applications. By regulating the active switch in the buck-boost converter, the circuit is capable of effectuating the operation of escalating and reducing voltage by means of directing the D during the process of forward or reverse power induction. During buck-boost converter operational, when D increases, the R_{Load} decreases and the converter operates in left side region. Meanwhile, as D decreasing, the R_{Load} increasing and the converter operates in left side of I-V region [12]. This can be referred in Figure 6, as the buck-boost converter have no non-operational region in the I-V curve.

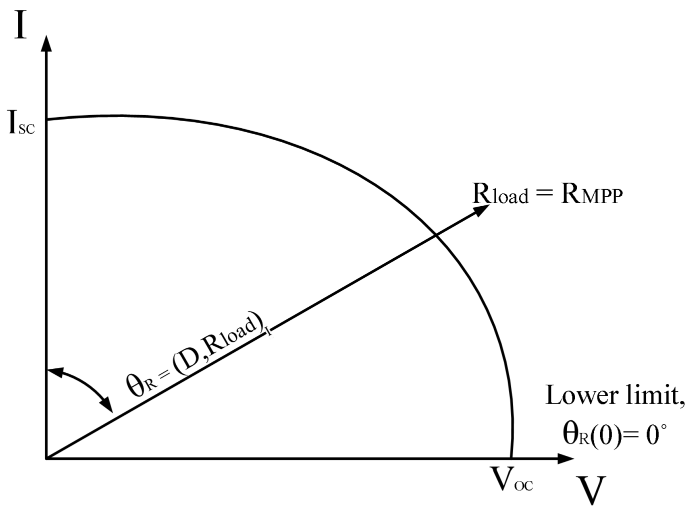

Fig. 6. Operational and non-operational regions of I-V curve in MPPT buck-boost converter [12]

By referring to Mishra and Singh [16], the conventional MPPT buck-boost converter is isolated from PV source during switch-off, which reduces the efficiency of the system. Also, to reduces the high ripple in PV current, the converter required more DC link capacitors and deviation controlled

MPPT controller which increasing the cost of the converter. Figure 7 depicts a common boost converter.

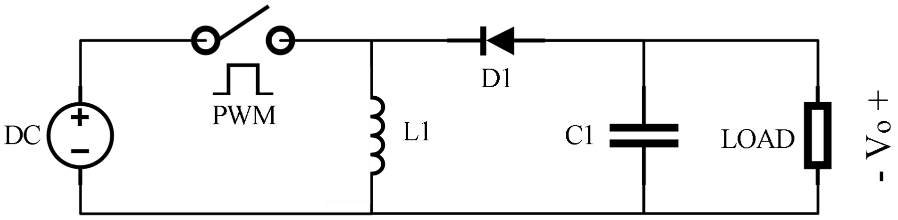

Fig. 7. Buck-boost converter

Table 1 provide the output voltage, current, load, the boundary limit of R_{mpp}, relationship between R_o and D, inductance and capacitance equations related to MPPT buck, boost, and buck-boost converter respectively.

Table 1
Equations related to MPPT buck, boost and buck-boost converter

	Buck Converter [13]	Boost Converter [2]	Buck-Boost converter [12]
Output Voltage, V_0	$V_o = D * V_{mpp}$	$V_o = \frac{V_{mpp}}{1-D}$	$V_o = \frac{D}{(1-D)} * V_{mpp}$
Output Current, I_0	$I_o = \frac{I_{mpp}}{D}$	$I_o = I_{mpp}(1-D)$	$I_o = \frac{(1-D)}{D} * I_{mpp}$
Resistive load, R_o	$R_o = R_{mpp} * D^2$	$R_o = \frac{R_{mpp}}{(1-D)^2}$	$R_o = \frac{R_{mpp} * D^2}{(1-D)^2}$
Boundary condition to determine limit of R_{mpp}, at minimum irradiance, G_{min}	$R_{mpp\_max} = \frac{V_{mpp\_Gmin}}{I_{mpp\_Gmin}}$	$R_{o\_\min} = \frac{R_{mpp\_\max}}{(1-D_{\min})^2}$ $R_{o\_\max} = \frac{R_{mpp\_\max}}{(1-D_{\max})^2}$	Not stated
Boundary condition to determine limit of R_{mpp}, at maximum irradiance, G_{max}	$R_{mpp\_min} = \frac{V_{mpp\_Gmax}}{I_{mpp\_Gmax}}$	$R_{o\_\min} = \frac{R_{mpp\_\min}}{(1-D_{\min})^2}$ $R_{o\_\max} = \frac{R_{mpp\_\min}}{(1-D_{\max})^2}$	Not stated
Relationship between duty ratio, D and resistive load, R_o	$R_{mpp\_\max} \le R_{mpp\_min}\left(\frac{D_{\max}}{D_{\min}}\right)^2$	$\frac{R_{mpp\_\max}}{(1-D_{\min})^2} \le R_{0(opt)} \le \frac{R_{mpp\_\min}}{(1-D_{\max})^2}$	Not stated
Inductance	$L_{CCM} = \frac{(1-D)R_o}{2f_s}$	$L = \frac{R_{mpp}}{\gamma_{i_L} f_s}\left(1-\sqrt{\frac{R_{mpp}}{R_o}}\right)$	$L_i = \frac{V_{mpp} * D}{\gamma_{i_L} f_s}$

			$L_o = \frac{D * I_{ph}}{8C\gamma_{I_{ph}} f_s^2}$
Capacitance	$C_o = \frac{1-D}{8L_{ccm}\gamma_{Vo} f_s^2}$	$C_i = \frac{D}{8L\gamma_{V_{mpp}} f_s^2}$ $C_o = \frac{D}{R_o \gamma_{Vo} f_s}$	$C = \frac{I_{mpp}(1-D)}{\gamma_{V_C} f_s}$

3. MPPT Controller

Every MPPT converter required a controller to maximize the MPP of the PV system. The MPPT controller control the output of the MPPT converter by controlling the duty cycle, D through the PWM signal generated into the converter. Various controllers were introduced for the MPPT. Basically, it divides into three categories which are, conventional, soft computing and bio-inspired algorithm. Figure 8 shows some algorithms related to MPPT controller. Each algorithms have its own special methods for searching the MPP of the PV systems.

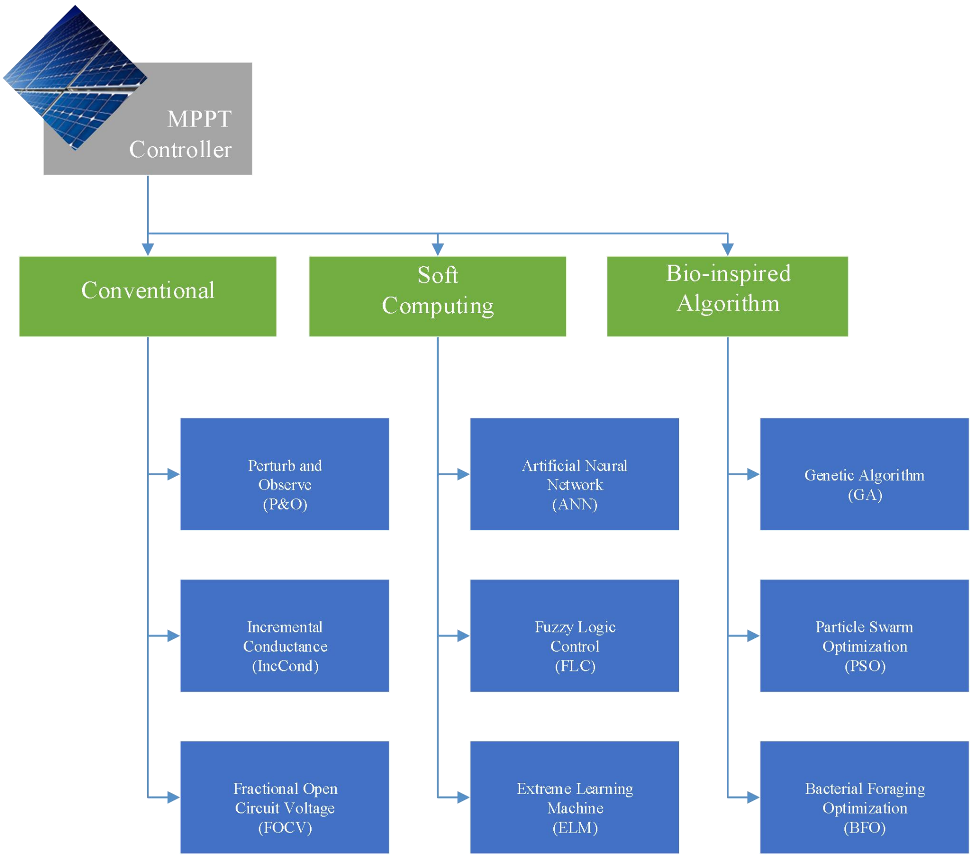

Fig. 8. MPPT controller

Table 2 shows the brief pros and cons for MPPT controllers.

Table 2

Advantages and disadvantages of MPPT controller

Algorithm	Type	Advantages	Disadvantages
Perturb and Observe (P&O) [11]	Conventional	Simple implementation	Oscillations around the maximum power point and slow tracking speed during an abrupt weather change.
Incremental Conductance (INC) [11]	Conventional	Faster tracking, avoids oscillations	Requires more computational resources and low tracking speed during an abrupt weather change.
Fractional Open Circuit Voltage (FOCV) [17]	Conventional	Simple implementation, works well in stable conditions	Less accurate under varying environmental conditions
Artificial Neural Network (ANN) [17]	AI-Based	Adaptability to changing conditions, handles nonlinear relationships	Requires training data and computational resources
Fuzzy Logic Control (FLC) [17]	AI-Based	Handles uncertainties, linguistic rules	Requires tuning and may have limited accuracy
Extreme Learning Machine (ELM) [18]	AI-Based	Fast training, good generalization ability	Limited interpretability, may require tuning of parameters
Genetic Algorithm (GA) [19]	Optimization-Based	Global optimization, handles complex problems	Longer computation time, may require tuning parameters
Particle Swarm Optimization (PSO) [20]	Optimization-Based	Fast convergence, explores search space effectively	Prone to getting stuck in local optima, requires tuning
Artificial Bee Colony (ABC) [19]	Optimization-Based	Efficient global optimization, handles dynamic conditions	Parameter tuning, sensitivity to initial conditions

4. Result and Discussion

This section discusses the results obtain from previous researcher for the MPPT converter regarding of any controller used in the research. The result is briefly explained in the Table 3. The performances of the MPPT algorithms are studied in term of tracking efficiency, steady-state oscillation, and convergence speed also shown in Figure 9.

From the results in Table 3 and Figure 9, all the MPPT controllers shown promising results as all of the converters were able to achieved tracking more than 90% of the tracking efficiency. These results shows that the controllers, P&O, INC, ANN, FLC, PSO and ABC were able to properly tracking the MPP of the PV systems. The MPPT controller, ABC shows the best result in tracking efficiency as it able to achieve 99.79 % of tracking efficiency which helps in producing and maintaining the MPP output power. ABC exhibits superior performance when compared to other algorithms. This can be attributed to its ability to efficiently track high power levels with a high degree of accuracy. The ABC's success is further enhanced by its capacity to identify the most optimal solution for the MPP. Compared to ABC, ANN and FLC falls much worst in tracking efficiency as the recorded results are 96.48% and 96.10% respectively. For ANN, the power loss occurs at steady-state phase due to oscillation at MPP cause the efficiency of power tracking drop significantly. The FLC buck-boost converter reason for low power tracking efficiency is due to its low accuracy to track MPP as the GMPP tracked by the FLC buck-boost converter is lower than the ideal GMPP thus reduce its power tracking efficiency. However, FLC results for boost converter is much better than FLC results for buck-boost converter in term of power tracking efficiency. These FLC results can be a good example of the compatibility between the MPPT controller and converter as some algorithm perform the best with suitable converter.

The steady state oscillation results also show that FLC and ABC controller have low oscillation at MPP. These results show that these algorithms, FLC and ABC are able to accurately track the MPP and maintain the GMPP at the optimum point. This also boost up the efficiency of power tracking and the power output. However, the result for ANN steady-state oscillation is high which cause the power output efficiency drop and unstable. This is probably due to ANN were lack of accuracy to properly track the GMPP, lost at local optima and cause the oscillation become higher and reduces the efficiency.

Lastly, convergence speed of an algorithm is important for MPPT system as it is the time taken for the controller to completely track the GMPP. This convergence speed become much more important during PSC, since in real time, the irradiance is always changing and the MPPT converter must be able to track MPP as quick as possible at all time. Thus, the convergence speed results shows that FLC and ABC shows the fast convergence speed followed by INC and PSO while P&O and ANN is the slowest. ABC and FLC were able to converge towards global optima or GMPP due to its capability to quickly and accurately track the GMPP. PSO and INC also were able to track MPP quickly, however they always trap at local optima which cause they a bit delay to converge towards GMPP. Unfortunately for P&O and ANN, due to their characteristic to track the GMPP step by step cause these two controllers to slowly converge towards the GMPP for better accuracy.

Overall, as shown in Table 3 and Figure 9, the converter with the controller has its pros and cons in term of tracking efficiency, steady-state oscillation and convergence speed. The overall best results shown is the ABC boost MPPT converter while the ANN boost MPPT converter is the worst results obtained.

Table 3
Result for MPPT converter in previous research

Reference	MPPT converter	MPPT Controller	Tracking Efficiency (%)	Steady-state oscillation	Convergence speed	Remarks
[11]	Buck	P&O	98.37	Medium	Slow	Resulting power waste due to oscillation at MPP
[21]	Boost	INC	98.51	Medium	Medium	Resulting power waste due to oscillation at MPP
[22]	Boost	ANN	96.48	High	Slow	Low tracking speed and accuracy
[9]	Boost	FLC	99.30	Low	Fast	High efficiency when used with boost converter
[9]	Buck-Boost	FLC	96.10	Low	Medium	Function effectively. However, prematurely converge cause low tracking efficiency.
[20]	Boost	PSO	98.50	Medium	Medium	Unstable steady-state oscillation
[19]	Boost	ABC	99.79	Low	Fast	High efficiency, easy implementation, and highly flexible.

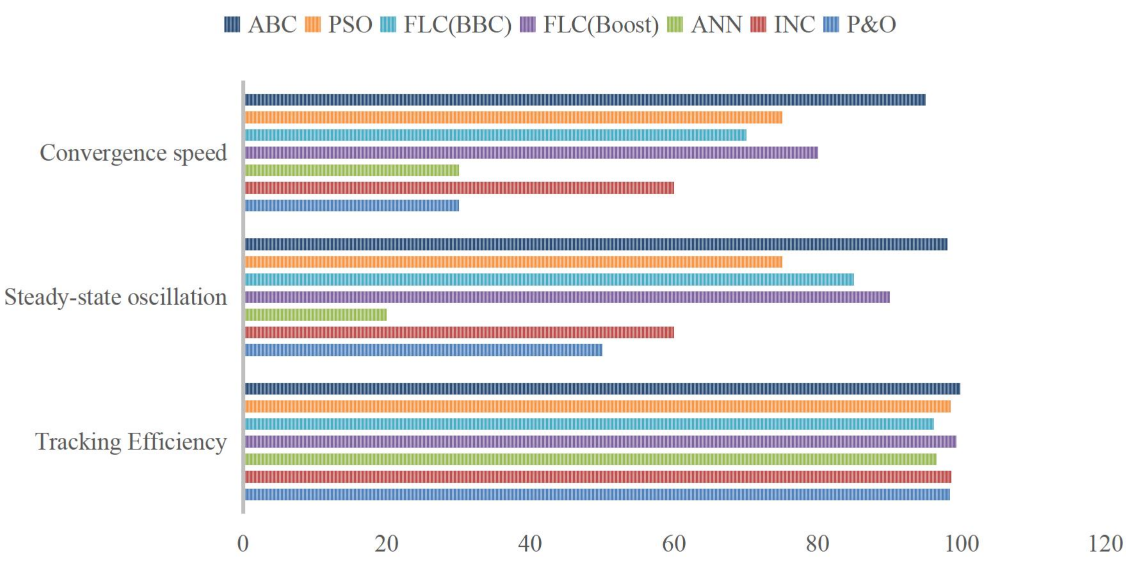

Fig. 9. Graph for Convergence speed, steady state oscillation, and tracking efficiency in previous research

5. Conclusion

The recent research papers on MPPT were reviewed in this literature mainly focus on conventional MPPT converters and the controllers used. The perks and flaws of each type of converters were briefly discussed and formulated. A concise comparative study has been done and presented as an analysis of findings with the help of appropriate research reviews. The analysis summary compares the MPPT controllers based on its tracking efficiency, convergence speeds and steady-state oscillation. All MPPT controllers shown good tracking efficiency as all the algorithm were able to achieve efficiency more than 90% with the ABC leads at 99.79%. This result shows that bio-inspired algorithms have good results in term of tracking efficiency followed by soft computing algorithm and conventional algorithms respectively. However, in terms of convergence speed and steady-state oscillation, only ABC proves superior compared to others. This problem may be caused by the algorithms were unable to accurately track GMPP, trap in local optima, and the algorithm's characteristic itself slowly tracking the GMPP. The suitability between the converter and controller also may affect the performance itself as shown in FLC's results. FLC can perform better with MPPT boost converter compared to MPPT buck-boost converter. At the end, a categorize comparison is provided which can be helpful in deciding ideal MPPT for the user's need. This review can be regards as useful resource for new researchers working on MPPT systems.

Acknowledgements
This research was funded by a grant from Ministry of Higher Education of Malaysia FRGS/1/2022/TK08/UNIMAP/02/47.

References
[1] Mollik, Md Sazib, SM Sajjad Hossain Rafin, Abdullah Al Mamun, Abdul Munaf Mohamed Irfeey, Ahmed S. Soliman, and Osama A. Mohammed. "Improved Performance of a Two-Stage Converter Topology Using Incremental Conductance-Based MPPT Design for Grid-Tied PV Systems." In *SoutheastCon 2023*, pp. 490-497. IEEE, 2023. https://doi.org/10.1109/SoutheastCon51012.2023.10115210

[2] Ayop, Razman, and Chee Wei Tan. "Design of boost converter based on maximum power point resistance for photovoltaic applications." *Solar energy* 160 (2018): 322-335. https://doi.org/10.1016/j.solener.2017.12.016
[3] Tan, Weng-Hooi, and Junita Mohamad-Saleh. "Critical review on interrelationship of electro-devices in PV solar systems with their evolution and future prospects for MPPT applications." *Energies* 16, no. 2 (2023): 850. https://doi.org/10.3390/en16020850
[4] Kanagaraj, N., and Mohammed Al-Ansi. "Maximum Power Extraction Control Algorithm for Hybrid Renewable Energy System." *Computer Systems Science & Engineering* 45, no. 1 (2023). https://doi.org/10.32604/csse.2023.029457
[5] Bahadur, Shamrat, Kalyan Mondol, Ashif Mohammad, Farhana Mahjabeen, Tamzeed Al-Alam, and Md Bulbul Ahammed. "Design and Implementation of Low Cost MPPT Solar Charge Controller." (2022).
[6] Yi, Feilong, and Faqiang Wang. "Review of voltage-bucking/boosting techniques, topologies, and applications." *Energies* 16, no. 2 (2023): 842. https://doi.org/10.3390/en16020842
[7] Sutikno, Tole, Ahmad Saudi Samosir, Rizky Ajie Aprilianto, Hendril Satrian Purnama, Watra Arsadiando, and Sanjeevikumar Padmanaban. "Advanced DC–DC converter topologies for solar energy harvesting applications: a review." *Clean Energy* 7, no. 3 (2023): 555-570. https://doi.org/10.1093/ce/zkad003
[8] Akhtar, Mohammad Faisal, Siti Rohani S. Raihan, Nasrudin Abd Rahim, Mohammad Nishat Akhtar, and Elmi Abu Bakar. "Recent developments in DC-DC converter topologies for light electric vehicle charging: a critical review." *Applied Sciences* 13, no. 3 (2023): 1676. https://doi.org/10.3390/app13031676
[9] Khan, Farha, and Abu Tariq. "Comparative Analysis of Solar Fed DC-DC Converter Controlled with Different Types of MPPT Algorithm." In *2023 International Conference on Power, Instrumentation, Energy and Control (PIECON)*, pp. 1-6. IEEE, 2023. https://doi.org/10.1109/PIECON56912.2023.10085886
[10] Naidu, I. E. S., S. Srikanth, A. Rao, and Adabala Venkatanarayana. "A novel mine blast optimization algorithm (MBOA) based MPPT controlling for grid-PV systems." *AIMS Electronics & Electrical Engineering* 7, no. 2 (2023). https://doi.org/10.3934/electreng.2023008
[11] Chellakhi, Abdelkhalek, Said El Beid, and Younes Abouelmahjoub. "An improved adaptable step-size P&O MPPT approach for standalone photovoltaic systems with battery station." *Simulation Modelling Practice and Theory* 121 (2022): 102655. https://doi.org/10.1016/j.simpat.2022.102655
[12] Taghvaee, Mohammad Hossein, Mohd Amran Mohd Radzi, S. M. Moosavain, Hashim Hizam, and M. Hamiruce Marhaban. "A current and future study on non-isolated DC–DC converters for photovoltaic applications." *Renewable and sustainable energy reviews* 17 (2013): 216-227. https://doi.org/10.1016/j.rser.2012.09.023
[13] Ayop, Razman, Muhammad Fariz Izzwan Zaki, Chee Wei Tan, Shahrin Md Ayob, and Mohd Junaidi Abdul Aziz. "Optimum sizing of components for photovoltaic maximum power point tracking buck converter." *Solar Energy* 243 (2022): 236-246. https://doi.org/10.1016/j.solener.2022.07.032
[14] Khan, Rashid Ahmed, Hwa-Dong Liu, Chang-Hua Lin, Shiue-Der Lu, Shih-Jen Yang, and Adil Sarwar. "A novel high-voltage gain step-up DC–DC converter with maximum power point tracker for solar photovoltaic systems." *Processes* 11, no. 4 (2023): 1087. https://doi.org/10.3390/pr11041087
[15] Zaid, Mohammad, Javed Ahmad, Adil Sarwar, Zeeshan Sarwer, Mohd Tariq, and Afroz Alam. "A transformerless quadratic boost high gain DC-DC converter." In *2020 IEEE international conference on power electronics, drives and energy systems (PEDES)*, pp. 1-6. IEEE, 2020. https://doi.org/10.1109/PEDES49360.2020.9379778
[16] Mishra, Anjanee Kumar, and Bhim Singh. "Design of cost effective solar PV powered SRM driven agriculture pump using modified buck-boost converter." *International Journal of Emerging Electric Power Systems* 19, no. 5 (2018): 20180028. https://doi.org/10.1515/ijeeps-2018-0028
[17] Mohamed Hariri, Muhammad Hafeez, Mohd Khairunaz Mat Desa, Syafrudin Masri, and Muhammad Ammirrul Atiqi Mohd Zainuri. "grid-connected PV generation system—Components and challenges: A review." *Energies* 13, no. 17 (2020): 4279. https://doi.org/10.3390/en13174279
[18] Gu, Bo, Hao Hu, Jian Zhao, Hongtao Zhang, and Xinyu Liu. "Short-term wind power forecasting and uncertainty analysis based on FCM–WOA–ELM–GMM." *Energy Reports* 9 (2023): 807-819. https://doi.org/10.1016/j.egyr.2022.11.202
[19] González-Castaño, Catalina, Carlos Restrepo, Samir Kouro, and Jose Rodriguez. "MPPT algorithm based on artificial bee colony for PV system." *Ieee Access* 9 (2021): 43121-43133. https://doi.org/10.1109/ACCESS.2021.3066281
[20] Charin, Chanuri, Dahaman Ishak, Muhammad Ammirrul Atiqi Mohd Zainuri, Baharuddin Ismail, and Mohamad Kamarol Mohd Jamil. "A hybrid of bio-inspired algorithm based on Levy flight and particle swarm optimizations for photovoltaic system under partial shading conditions." *Solar Energy* 217 (2021): 1-14. https://doi.org/10.1016/j.solener.2021.01.049

[21] Harrison, Ambe, Njimboh Henry Alombah, and Jean de Dieu Nguimfack Ndongmo. "A New Hybrid MPPT Based on Incremental Conductance-Integral Backstepping Controller Applied to a PV System under Fast-Changing Operating Conditions." *International Journal of Photoenergy* 2023, no. 1 (2023): 9931481. https://doi.org/10.1155/2023/9931481
[22] Hichem, Louki, Omeiri Amar, and Merabet Leila. "Optimized ANN-fuzzy MPPT controller for a stand-alone PV system under fast-changing atmospheric conditions." *Bulletin of Electrical Engineering and Informatics* 12, no. 4 (2023): 1960-1981. https://doi.org/10.11591/beei.v12i4.5099

Author	E-Mail
Muhammad Aniq Shahmi Bimazlim	aniq12@gmail.com
Chanuri Charin	chanuri@unimap.edu.my
Baharuddin Ismail	
Yessi Jusman	