Quasi Z-Source Inverter as MPPT on Renewable Energy using Grey Wolf Technique

Quota Alief Sias
Department of Electrical Engineering
Universitas Negeri Malang
Malang, Indonesia
quota.alief.ft@um.ac.id

Irham Fadlika
Department of Electrical Engineering
Universitas Negeri Malang
Malang, Indonesia
irham.fadlike.ft@um.ac.id

Irawan Dwi Wahyono
Department of Electrical Engineering
Universitas Negeri Malang
Malang, Indonesia
irawan.dwi.ft@um.ac.id

Arif Nur Afandi
Department of Electrical Engineering
Universitas Negeri Malang
Malang, Indonesia
an.afandi@ieee.org

***Abstract* — Z-Source Inverter (ZSI) is famous power converter who has capability to deal with voltage sags, improved power factor and wide voltage range of output. Quasi Z Source Inverter (QZSI) is the modern ZSI who has continuous current of input and can reduce stress of the passive component. This paper proposes simple boost QZSI circuit as Maximum Power Point Tracking (MPPT) using Grey Wolf Optimization (GWO) algorithm in photovoltaic system. Grey Wolf algorithm has been compared with the Perturb and Observed (P&O) technique for gaining the maximum power from the sun. Both techniques can get the optimum power of solar panel not only at constant sun light condition but also under varying irradiance levels. The value of average power obtained from GWO technique is greater than P&O. Although the value of solar radiation changes, the output voltage remains stable and both algorithms carry on obtaining optimal power of the sun.**

Keywords — GWO, MPPT, QZSI

I. INTRODUCTION

One of the cleanest renewable energy sources and now being widely applied is solar panel technology [1]. This technology can be applied almost all over the world as long as there is sunlight. Photovoltaic (PV) technology is widely used by people all over the world in the last decade because of its simplicity as renewable energy. This is also to be the most popular topic research because of its unique characteristics. Using simple resistive loads, photovoltaic operates at different voltage levels depended on load values under constant sunlight and constant temperature conditions. There is only one point of voltage and current in operating area that produces the most optimal power and it is called the Maximum Power Point (MPP). So this technology generally requires a power conditioner that holds the voltage remain to the optimal point for the purpose of gaining the optimal power. The DC-AC converter or inverter is required as a power conditioner because the solar cells produce DC voltage while almost all existing loads require AC voltage.

Electrical system using solar panel has a lot of configurations such as using battery or not, using MPPT or not, using DC or AC loads and so on. This paper just explain simple solar panel system without battery and using three phase AC load because almost electrical grid presently use alternating current system. Because using AC loads, Inverters or the DC-AC converter is used in this research. This paper explain QZSI for implementing MPPT and apply GWO as the recent intelligent algorithm to gain the optimum power of the sun.

II. PHOTOVOLTAIC SYSTEM AND QUASI Z SOURCE INVERTER

A. *Varying Irradiance Levels and MPPT on PV System*

The power of solar panels is depended on the sun irradiance levels [1]-[5]. Fig.1 shows that the higher the irradiance of sunlight, the greater the power will be gained. From the P-V graph of Fig. 1, there is one point represent the highest power of the sun. This MPP is obtained from one specific value of voltage and one specific value of current stated at I-V graph. The PV System generally used MPPT as power conditioner to force the operating value of current and voltage to the MPP.

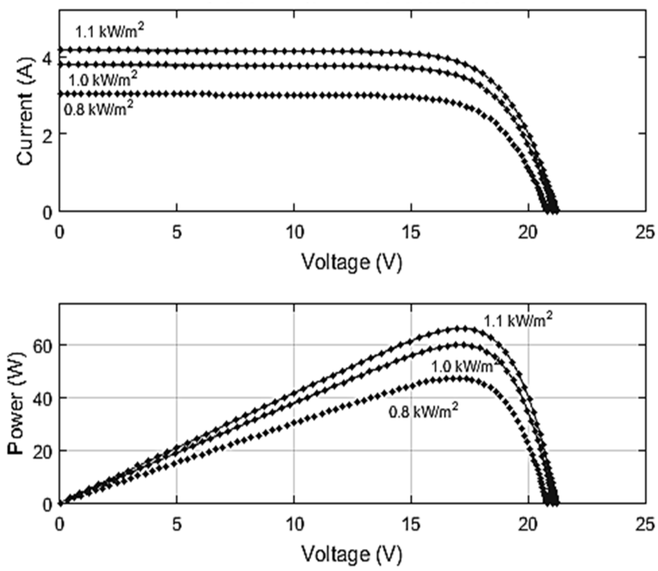


Fig. 1. I-V and P-V characteristic curves of solar panel at varying irradiance

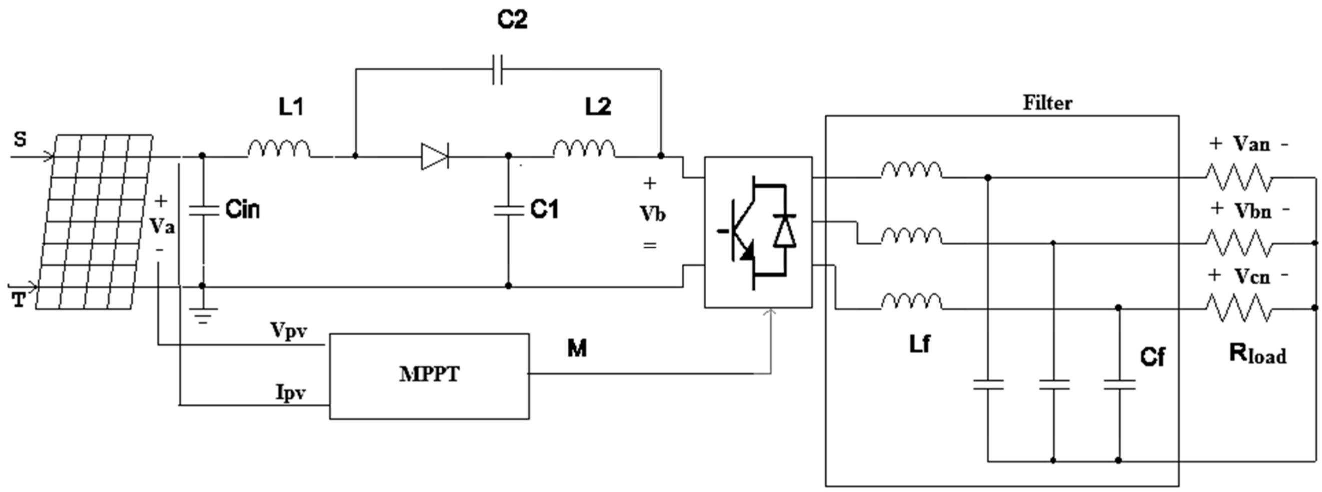


Fig. 2. Simple Boost QZSI circuit as MPPT of Photovoltaic Technology

The results of research show that MPPT implementation is able to absorb sun energy by 99% [2]. The common MPPT technique and the simple one is Perturb and Observe (P&O) technique. It has high efficiency and does not require tunning parameters periodicly [3]. P&O is a very simple technique because it does not require knowledge of the curves of solar panel characteristics [4]. P&O can also be implemented at affordable price using arduino microcontrollers [5]. The simple explanation of the P&O technique is shown in Fig.3. The basic principle of this technique is measure the gradient m = ΔP/ΔV from the power and voltage characteristic curve. The gradient will be zero at MPP (ΔP/ΔV=0). Operating voltage value of P&O should be increased to get the maximum power when having positive gradient (ΔP/ΔV>0) and vice versa.

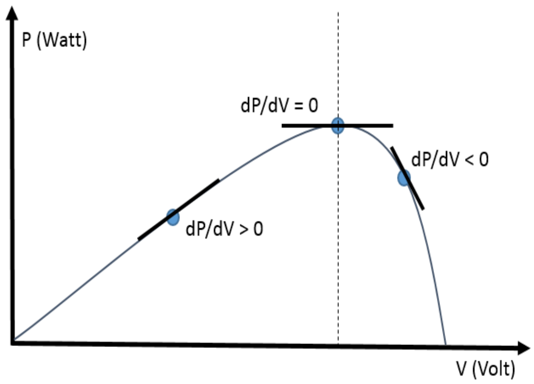


Fig. 3. Basic principle of P&O technique

Fig.4 shows the flow diagram of the P & O technique. Adjusting the operating voltage value on the converter is done by increasing or decreasing the duty cycle. The P & O process is very simple because it only requires voltage and current sensors so that the value of the power generated will also be known. Voltage and power are measured and compared to the results of previous measurements so that the gradient dP/dV of the curve is obtained. This gradient of the curve will generate a new duty cycle value and the process will be repeated.

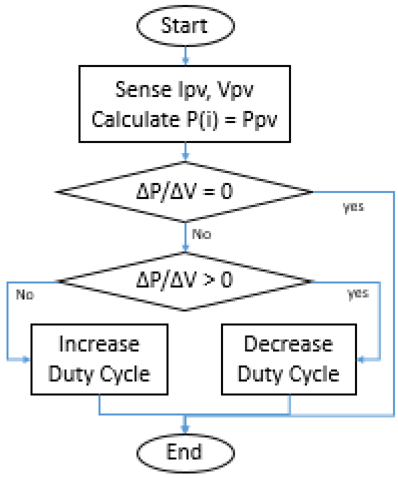


Fig. 4. Flow diagram of P&O technique

B. Simple Boost Quasi Z Source Inverter

QZSI is the development of ZSI topology which can reduce passive component stress and has continuous input current features [6]-[8]. This paper use the simple boost control to get the higher output voltage. QZSI is an inverter that has two operating conditions, shoot-through and non-shoot-through conditions [8]-[11]. In shoot-through state, condition of the diode is off (open circuit) while in non-shoot-through state, the diode is on (close circuit). QZSI has two important parameters: shoot-through duty cycle and modulation index and has relationships as in (1), (2) and (3) [9].

$$\frac{Vpn}{Vb} = \frac{M}{2} \tag{1}$$

$$\frac{Vb}{Va} = \frac{1}{1-2D} \tag{2}$$

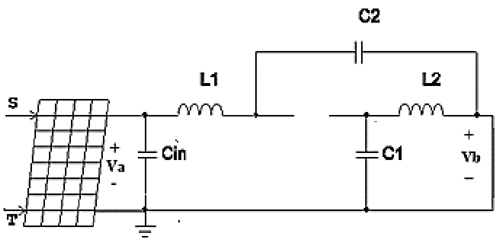
$$M \leq 1 - D \tag{3}$$

The modulation index M is used to control output AC phase neutral voltage Vpn as in (1) and transfer function of Vb/Va in DC port is controlled by shoot-through duty cycle D as in (2). The relationship between parameters M and D for simple boost control is given by (3). Form (2), the value of 1-2D can not be empty so that the operating value D is from 0 to 0.5. Thus from (3), the value of M is limited only in the range 0.5 to 1.

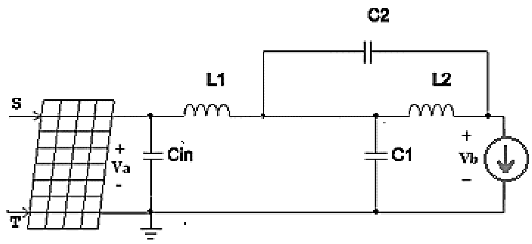
TABLE I. COMPONENTS OF CIRCUIT

Parameter	Value
C1, C2	1 mF
L1, L2	1 mH
Rload	25 Ω
Cin	5uF

The value of modulation index M generally has a constant value to maintain the constant output AC voltage. Because the sunlight is not constant in nature, this paper propose to change the value of M to get the better output voltage. This paper implements the P&O and Grey Wolf methods to adjust the value of M. QZSI can also be used as MPPT on PV System to ensure maximal conversion efficiency [10][11]. The circuit used in this paper is shown in Fig.2 and all the component values are stated in the Table 1.



(a) shoot-through state



(b) not-shoot-through state

Fig. 5. Operation conditions of the QZSI

In shoot-through state shown in Fig 5a, diode is off and the output voltage Vb is zero (short circuit). In this condition, Vcarrier > Vp and Vcarrier > Vref (Va,Vb,Vc) shown in Fig.6 so that the diode is reversed biased. The period in this state is defined as Tst and for non-shoot-through state defined as Tnst. Total period in one cycle is T = Tst+Tnst. Shoot-Through duty cycle D is defined as shoot-through periode devided by total periode (D=Tst/T).

In non-shoot-through state shown in Fig 5b, the inverter is operated normally since the diode is on (forward biased). Considering the average voltage accross the inductor in one cycle of switching periode is zero, so the relationship of output voltage Vb to input voltage Va is obtained as (2). It can be noticed from (2) that the voltage boosting is obtained by using shoot-through state between upper and lower switches of an inverter leg.

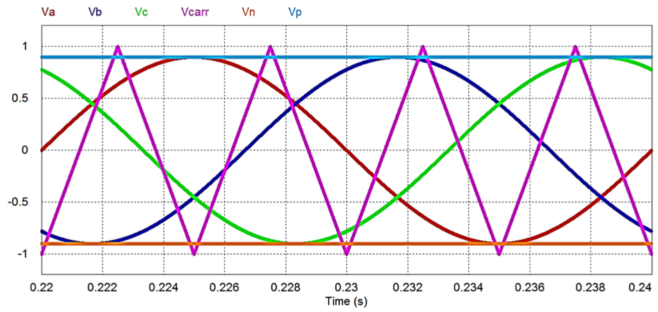


Fig. 6. Illustration of switching pattern of QZSI using Simple Boost Control

III. MPPT DESIGN USING GREY WOLF TECHNIQUE

The evolutionary methods as meta-heuristic algorithm are usually used to solve optimization problems. They continue to be developed in order to improve the performance of the previous techniques for example the Harvest Season Artificial Bee Colony (HSABC) algorithm proposed on 2013 which can be faster than Genetic Algorithms (GA) on the emission and economic dispatch problem [12]. P&O as the most simple MPPT technique is also developed for time to time to get the better results without the evolutionary method for the first generation [13] and the popular one is MPPT using the evolutionary technique in the recent studies [14].

Grey Wolf algorithm, optimizer published on 2014, has good competitive results compared to the other algorithms for solving 29 benchmarked test functions [15]. It can also be used to solve the real problem such as in PV modeling because of the limited information from the manufacturer datasheet [16]. GWO can also be used as MPPT compared to Improved-PSO (IPSO) method in DC system [14]. This paper explain MPPT using GWO and QZSI for the AC loads. The GWO technique inspired by hunting mechanism of grey wolves and their leadership hierarchy in nature [14]-[16]. GWO algorithm has three main steps of hunting process: tracking, pursuing and attacking. On pursuing process, the encircle behavior can be modeled in (4) and (5).

$$\boldsymbol{D} = |\boldsymbol{C}\,.\boldsymbol{Xp}(t) - \boldsymbol{X}(t)| \qquad (4)$$

$$\boldsymbol{X}(t+1) = \boldsymbol{Xp}(t) - \boldsymbol{A}\,.\boldsymbol{D} \qquad (5)$$

where A, C and D represent GWO coefficient vectors as in [14], Xp is the position vector of the prey, X indicates the position vector of grey wolf. And t is the current iteration. The vectors A and C are calculated in (6) and (7). During iterations, the value of a *is* linearly decreases from 2 to 0 and the components r_1, r_2 are random vectors in [0, 1].

$$\boldsymbol{A} = 2.\boldsymbol{a}\,.r_1 - \boldsymbol{a} \qquad (6)$$

$$\boldsymbol{C} = 2\,.r_2 \qquad (7)$$

The first step for implementing GWO for MPPT is defining the duty cycle d as a grey wolf and modify (5) to become (8). The value A and D is calculated by the previous equations. The optimal power can be obtained by iteration process of calculating d. The fitness function of calculating power is defined by (9) and the number of iteration is represented by k and the current number of grey wolves is indicated by i. Flow diagram of Grey Wolf Technique and the iteration process are shown in Fig.7.

$$d_i^{k+1} = d_i^k - \boldsymbol{A}\,.\,\boldsymbol{D} \quad (8)$$

$$P(d_i^{k+1}) > P(d_i^k) \quad (9)$$

This paper use the P&O and GWO techniques as MPPT by controlling and iterating the modulation index M of the QZSI. The initial value of M in P&O is 0.75 because the operating value is limited from 0.5 to 1. GWO Technique use three grey wolves, and the initial value is 0.6, 0.75, and 0.9. P&O use the gradient concept and the GWO use (4)-(9) for each iteration to adjusting modulation index M until converge state.

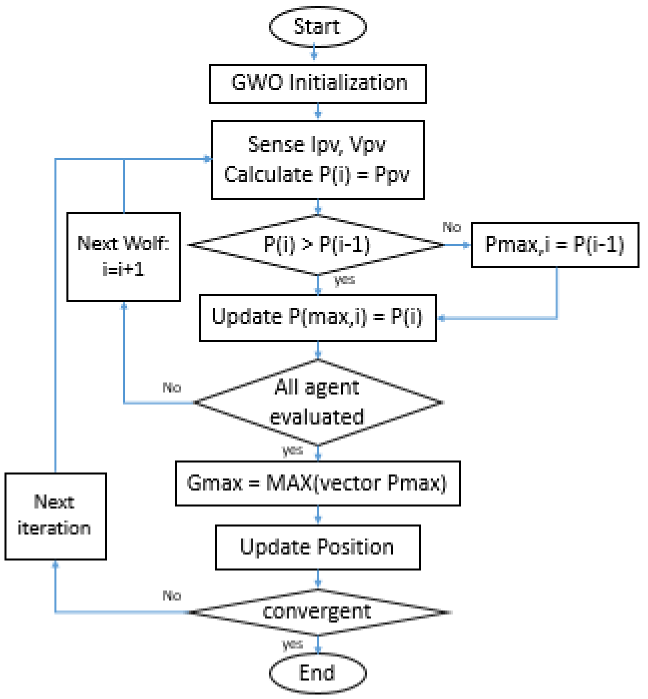


Fig. 7. Flow diagram of Grey Wolf technique

IV. Simulation Results and Analysis

The performances of both MPPT methods (P&O and GWO) are pointed in Standart Test Condition (STC) at the first analysis. And the final, both MPPT methods are also be compared under varying condition of sunligh levels. The iteration process of adjusting modulation index M of QZSI by P&O is stated by the red line in Fig.8. The initial value of M is 0.75 as stated before and the iteration process has brought it to the steady value of M at 0.6. GWO method, using three grey wolves in different initial values of M (0.6, 0.75 and 0.9), stated by the blue line shows the fast iteration process and converge and steady before 0.5 s.

A. Output Power Performance under Constant Irradiance

In STC (25^{o}C and 1kW/m^2), The PV model used in this paper has the 60 Watt peak for optimal power same as in [13]. The performance results of both MPPT are shown in Fig.9. P&O obtain 51,41 W (85.4%) and GWO has higher result at 53.65 W (89.1%) of the optimal power 60,21 Watt. Much power gained has been lost when the process of iteration before the steady state. After converged, both techniques give the same power gained result up to 99% after 0.2 s. From average power obtained, it can be conclude that the GWO method has the higher efficiency than the P&O technique.

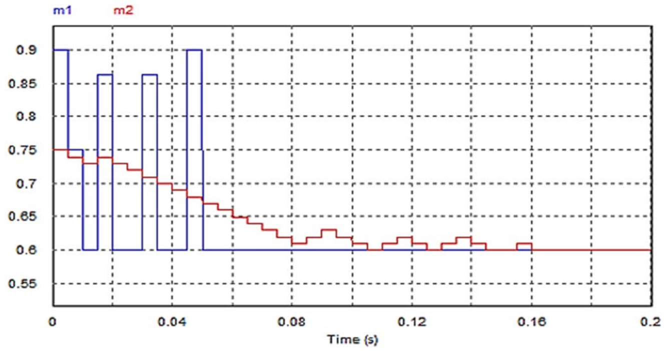


Fig. 8. The index modulation performances of QZSI by P&O (red line) and GWO (blue line) under STC.

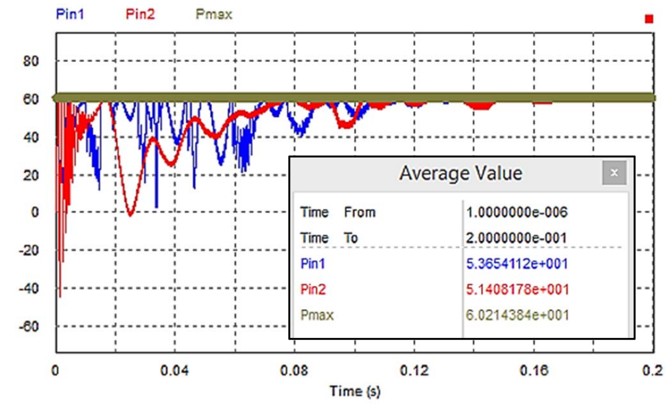


Fig. 9. The performances of QZSI by P&O (red line) and GWO (blue line) under STC.

B. Output Power Performance under Varying Irradiance

Both methods P&O and GWO are tested under varying sunlight levels by the suddenly changing the irradiance upper and lower the STC. First, the initial of optimal power from the highest irradiance is setted in 65 Watt and 47 Watt for the lowest irradiance. The conditions is setted by changing the irradiance from the highest power to the lowest, going to the STC and finally from the lowest to the highest one.

Fig.10 and Fig.11 explain the output voltage of three phase system performance using LC filter or only the capacitive filter. Using the balance three phase load 25 Ω, both MPPT methods generate the balance voltage output. Although the power and irradiance conditions are changed rapidly, voltage output performances from both MPPT methods are excellent because they still constant or remain stable. Fig.12 make the clear point that both MPPT methods can be used to obtained the optimal power. P&O obtain 54.31 W (97.61%) and GWO still has higher result at 54.34 W (97.66%) of the optimal power 55.64 Watt.

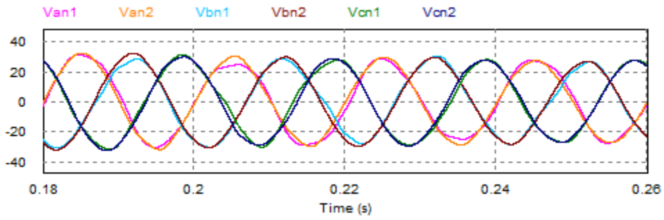


Fig. 10. Voltage performances of QZSI using LC filter

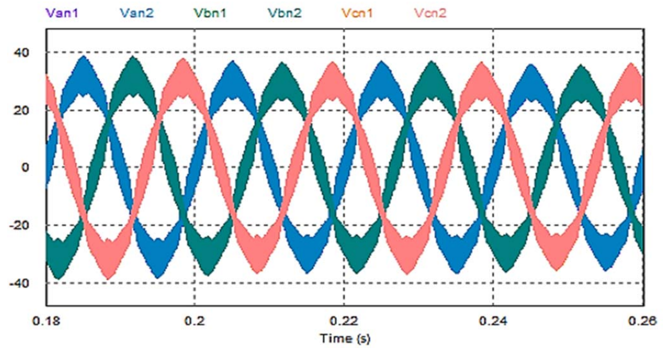


Fig. 11. Voltage performances of QZSI using only capacitive filter

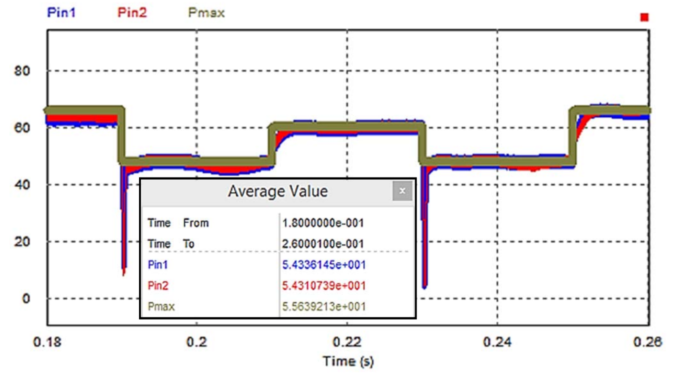


Fig. 12. Output power performance of QZSI by P&O (red line) and GWO (blue line) under varying irradiance.

V. Conclusion

Both techniques P&O and GWO can be used as MPPT in QZSI implementation and have good performance for gaining the optimal power under constant and varying irradiance levels. GWO are faster to converge so that the performance of average power output value is also more higher than P&O. Under constant irradiance level, GWO have obtain 3.7 % more power than P&O. Under varrying irradiance level, GWO have obtain 0.05 % more power than P&O. Although the value of solar radiation changes, the output voltage of QZSI remains stable and both algorithms carry on obtaining optimal power of the sun.

Acknowledgment

This paper is part of the research supported by Universitas Negeri Malang, Malang, Indonesia, for the PNBP Research Program issued on the letter number 21.2.6/UN32.14/LT/2018. The authors would also like to express the sincere gratitude to all contribution of the Electrical Engineering Department and the Electric Energy Conversion laboratory, Universitas Negeri Malang, Malang, Indonesia.

References

[1] E. I. Batzelis, G. E. Kampitsis, S. A. Papathanassiou, and S. N. Manias, "Direct MPP calculation in terms of the single-diode pv model parameters," IEEE Transactions on Energy Conversion, vol. 30, no. 1, pp.226-236, August 2014.

[2] V. C. Sontake, and V. R. Kalamkar, “Solar photovoltaic water pumping system-A comprehensive review”, Renewable and Sustainable Energy Reviews, 59, pp.1038-1067. January 2016.

[3] E. Dallago, A. Liberale, D. Miotti and G. Venchi, "Direct MPPT algorithm for PV sources with only voltage measurements," IEEE Transactions on Power Electronics, vol. 30, no. 12, pp 6742-6750, December 2015.

[4] M. A. Elgendy, B. Zahawi, and D. J. Atkinson,"Assessment of Perturb and Observe MPPT algorithm implementation techniquesfor PV pumping applications," IEEE Transactions on Sustainable Energy, vol. 3, no. 1, pp 21-33, January 2012.

[5] M.K.D. Ulaganathan, C. Saravanan, and O. R. Chitranjan, "Cost-effective Perturb and Observe MPPT method using arduino microcontroller for a standalone photo voltaic system," International Journal of Engineering Trends and Technology (IJETT), vol. 8,no. 1,pp 24-28, February 2014.

[6] J. Liu, J. Hu, and L. Xu, "Dynamic Modeling and Analysis of Z Source Converter—Derivation of AC Small Signal Model and Design-Oriented Analysis," IEEE Transactions on Power Electronics, vol. 22, no. 5, pp 1786-1796, September 2007.

[7] J. Anderson and F. Z. Peng, "Four quasi-Z-source inverters." In Power Electronics Specialists Conference, 2008. PESC 2008. IEEE, pp. 2743-2749. IEEE, 2008.

[8] J. Liu, S. Jiang, D. Cao, and F. Z. Peng, "A digital current control of quasi-Z-source inverter with battery," IEEE Transactions on Industrial Informatics, vol. 9, no. 2, pp. 928-937, May 2013

[9] D. Sun, B. Ge, D. Bi and F. Z. Peng, "Analysis and control of quasi-Z source inverter with battery for grid-connected PV system," International Journal of Electrical Power & Energy Systems, vol 46, pp. 234-240, March 2013.

[10] J. Khajesalehi, M. Hamzeh, K. Sheshyekani and E. Afjei, "Modeling and control of quasi Z-source inverters for parallel operation of battery energy storage systems: Application to microgrids," Electric Power Systems Research, vol. 125, pp. 164-173, August 2015.

[11] R.Sathishkumar, V.Malathi and E. Sakthivel, "Real Time Implementation of Quazi Z-Source Inverter Incorporated with Renewable Energy Source," Energy Procedia, vol. 117, pp. 927-934. Juny 2017

[12] A. N. Afandi, I. Fadlika and A. Andoko, "Comparing Performances of Evolutionary Algorithms on the Emission Dispatch and Economic Dispatch Problem," TELKOMNIKA (Telecommunication Computing Electronics and Control), vol. 13, no. 4, pp. 1187-1193, December 2015.

[13] Q. A. Sias and I. Robandi, "Recurrence Perturb and Observe algorithm for MPPT optimization under shaded condition," 2nd International Seminar on Intelligent Technology and Its Applications (ISITIA), pp. 533-538, July 2016.

[14] S. Mohanty, B. Subudhi and P.K. Ray, "A new MPPT design using grey wolf optimization technique for photovoltaic system under partial shading conditions," IEEE Transactions on Sustainable Energy, vol. 7, no. 1, pp. 181-188, January 2016.

[15] S. Mirjalili, S. M. Mirjalili and A. Lewis, "Grey wolf optimizer," Advances in engineering software, vol. 69, pp.. 46-61, March 2014.

[16] Darmansyah and I. Robandi. "Photovoltaic parameter estimation using Grey Wolf Optimization," 3rd International Conference on Control, Automation and Robotics (ICCAR), pp. 593-597, April 2017.