ISSN 2614-4859

Optimizing the Use of MPPT in PLTS for Hybrid Systems by Using STS as a Transfer Switch

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ABSTRACT

Keywords
PLTS
MPPT
Static Transfer Switch
Power Quality

To save energy nowadays is recommended to switch to renewable energy sources. In Indonesia, solar energy is abundant, so PLTS is made. The supply of PLTS is expected to reach maximum use. However, solar panels have many obstacles such as variations in temperature and sunlight intensity, MPPT systems are needed to find the maximum power point of the solar panels. Unfortunately, in Indonesia, the sunlight of short duration with the ideal irradiation time that can produce electricity from solar panels is 4 to 5 hours per day, so a PLN supply is still needed to support the continuity of the power supply. Because two sources are used, there is a problem where the load needs high continuity during power switching, so STS (Static Transfer Switch) is used for very fast power switching. Simulation results, when using EMR (Electromechanical Relay) the power transfer process takes 50ms or 5 cycles while STS takes 2ms or ¼ cycles. With very fast response to STS, sensitive equipment is kept safe from power quality disturbances such as voltage sag and voltage swell.

1. Introduction

To reduce the use of fossil energy, it is recommended to switch to renewable energy. There are several sources of renewable energy like Solar, Wind, Ocean Energy, etc. Solar energy is a widely used source because it is most reliable, secure, environment friendly, less maintenance, and noiseless generation [1]. The amount of available light energy and the efficiency of the solar panels used to store energy [2]. The power generated from solar PV is highly dependent on weather conditions (irradiation and temperature). This change may result in changes to the P-V and I-V curves of the solar PV. Since the I-V characteristics curve of PV cells varies nonlinearly with the irradiation and temperature, it is essential to operate the PV system to a specific point to extract maximum solar energy. This technology is usually named MPPT [3][4]. Evaluation of maximum power point (MPP) is an important research topic in PV systems and their applications [5], [6].

In this study, MPPT was used using the Fuzzy method. FLC is designed with five membership functions which are expected to reach maximum power with changes in irradiation and temperature. MPPT system with a buck converter. The output from the solar panel and converter is in the form of DC voltage which is stored in the battery, which is then converted into AC voltage through an inverter before supplying household loads [7][17].

Duration of sunlight in Indonesia is ideally 4 to 5 hours, the use of supply from PLTS still requires backup supply from PLN to support the continuity of power supply. Because it uses two sources, there is a problem, namely, the load requires high continuity when a power switch occurs. Sensitive equipment such as relay, inverter, and PLC are not resistant to power quality disturbances, to protect sensitive equipment, the use of STS (Static Transfer Switch) is used to keep it safe from power quality disturbances such as voltage sag and voltage swell. Thus, the source of electrical energy is created continuously and minimizes the crisis of the shortage of electrical energy in the field of renewable energy [15][16].

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2. The Proposed Method/Algorithm

2.1. Photovoltaic

PV is the technology that generates direct current (DC) electrical power measured in watts (W) or kilowatts (kW) from semiconductors when they are illuminated by photons. As long as the light is shining on the solar cell (the name for the individual PV element), it generates electrical power [8]. Equivalent circuit of a PV cell is shown in Fig.1.

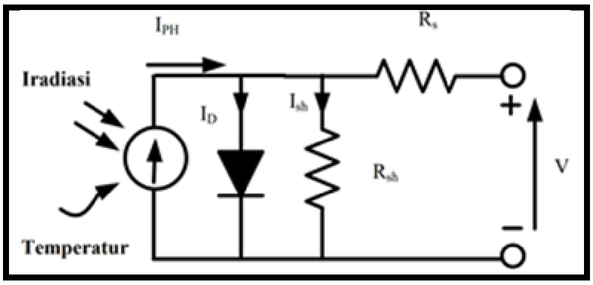

Fig. 1. Photovoltaic Cell Equivalent Circuit

The current produced by photovoltaic is the source of current minus the current flowing through the diode and the shunt resistor (Rsh). As in Fig.2 in this study, the photovoltaic module output power can be calculated by:

$$I_{pv} = N_p I_{pv} - N_s I_o \left[e^{\left(\frac{Q(V_{pv}+I_{pv}R_S)}{N_S AKT}\right)} - 1 \right] \quad (1)$$

$$P = V_{pv} I_{pv} = (N_s V_{cell})\,(N_p I_{cell}) \quad (2)$$

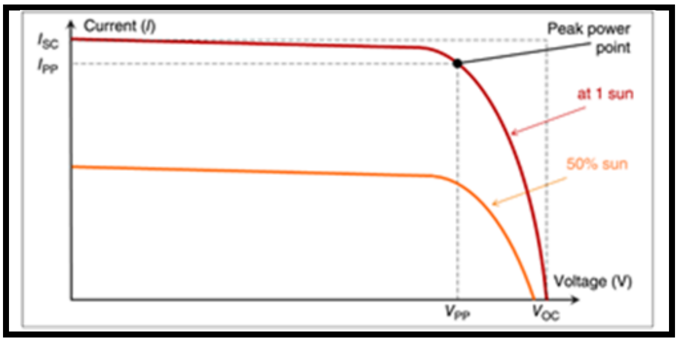

Fig. 2. Typical I–V characteristics of PV cell at different light levels

The so-called current-voltage (or I-V) characteristic, illustrated in Fig. 2 shows how much current and voltage can be delivered by a solar cell at different levels of light intensity. For example, the extreme right-hand end of the line shows the so-called open-circuit voltage (VOC) and the left-hand end of the line shows the short-circuit current (ISC) [9].

2.2. Buck Converter

Buck Converter is a DC-DC converter that produces an output voltage that is smaller than the input voltage. The resulting output voltage has the same polarity as the input voltage. Buck converter is also known as step down converter. The circuit is shown in Fig.3 [10][17][18][20].

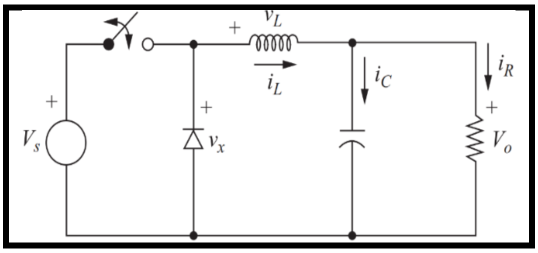

Fig. 3. Buck Converter

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$$D = \frac{Vout}{Vin} \tag{3}$$

$$L = \frac{Vout \times (1-D)}{\Delta IL \times fsw} \tag{4}$$

$$C = \frac{Vout\ (1-D)}{8\ x\ L\ x\ \Delta Vo\ x\ fsw} \tag{5}$$

Equations (3) to (5) are used to find the component value of the buck converter in the CCM.

2.3. Static Transfer Switch

Static Transfer Switch (STS) is an important component that works to protect electrical devices from various electrical problems. Static Transfer Switch can provide fast transfer of power switching on sensitive loads to an alternative ac power source when the main source is faulty. Application of Static Transfer Switch as protection against power quality disturbance [12][13].

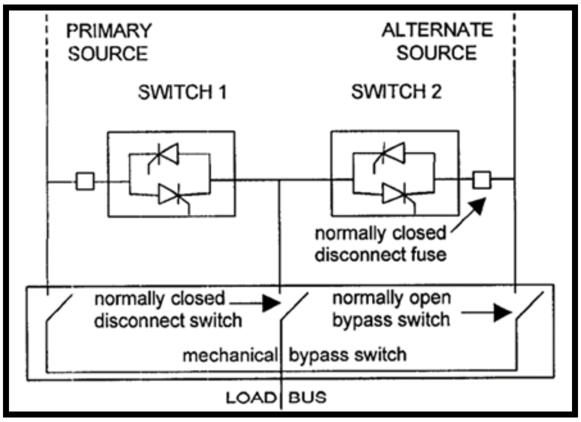

Fig. 4. A Figure Caption

Electrical power system disturbances consist of transients, variations in a short time, instantaneous variations, temporary variations, variations in a long time, voltage imbalances, wave distortions, voltage fluctuations and power frequency variations. The following is the classification of power quality disturbances according to their characteristics [14]:

a. Sag: A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min;
b. Swell: An increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. Typical values are 1.1–1.8 pu;
c. Transient: Voltage disturbance in the form of high amplitude and occurs in a short time (<0.5 cycles);
d. Voltage unbalance: large variation and/or phase angle at different phases;
e. Harmonics: deviation of the voltage and/or current waveform from a pure sinusoidal waveform due to unwanted frequencies affecting the fundamental waveform;
f. Frequency deviation: frequency variation from the value of 50/60 Hz;
g. Flicker: sag or swell that occurs repeatedly;
h. Voltage deviation: the presence of over-voltage or under-voltage for a long time;
i. Blackout: the total loss of input voltage for several cycles or more.

Static Transfer Switch circuit consists of two pairs of thyristors per phase connected as shown in Fig.4 When a source is selected to supply the load, the control logic turns on the thyristor. Power then flows from the selected source to the load [22].

3. Method

The main purpose of this paper is to optimize the power released by solar panels with the MPPT system. Solar panels and PLN are connected to STS as a power transfer at one source to increase the continuity of high electrical energy sources.

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3.1. Photovoltaic

Table 1. Parameter of Photovoltaic Module

Parameter	Value
Maximum Power (Pmax)	100 W
Tolerance	± 3 %
Voltage at Maximum Power (Vmp)	17.8 V
Current at Maximum Power (Imp)	5.62 A
Voltage Open Circuit (Voc)	21.8 V
Current Open Circuit (Isc)	6.05 A
Standard Test Condition (STC)	1000/25 W/m2/°C
Max system V	540 V
Dimension	1196 × 541 × 30 mm
Test Condition	1000 W/m2, 25°C

In this paper, 2 photovoltaics from Polycrystalline are used with 100-Watt power shown in Table 1. Photovoltaic is connected in parallel so that the power obtained is 200 Watt. In this parallel, the photovoltaic current will be two times greater.

3.2. Buck Converter

Table 2. Parameter of Buck Converter

Parameter	Symbol	Value	Unit
Rated Output Power	Pout	200	Watt
Input Voltage	Vin	21.8	Volt
Output Voltage	Vout	14.4	Volt
Frequency Switching	Fs	40	kHz
Current Ripple	rIo	10	%
Voltage Ripple	rVo	0.5	%
Inductor	L	68	μH
Capacitor	C	78.125	μF

In addition, this paper requires a parameter to determine the component value that can be calculated with the converter buck topology. By using a 40 kHz switching frequency it is expected that the waves generated by this buck converter will be smoother and so that the inductance values of L can be smaller. This buck converter has parameters as shown in Table 2.

3.3. MPPT Controller

MPPT is an algorithm to find the maximum point of the output voltage and current on the solar panel. The way MPPT work is by changing the operating or working point on the P-V characteristic curve of the solar panel so that the DC-DC converter can generate maximum power from the solar cell at every change in irradiation and temperature. In Fig.5 it is explained that different levels of solar irradiation can affect the P-V characteristic curve.

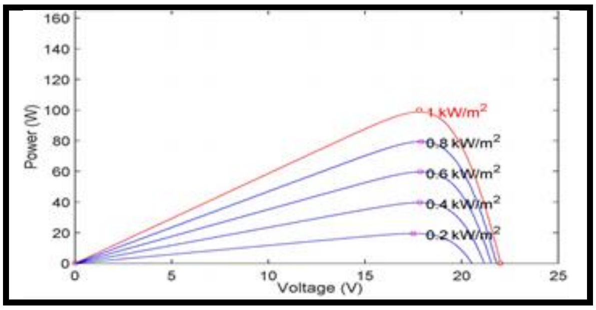

Fig. 5. P-V Characteristics at Irradiance Variation

The fuzzy logic control has increased its interest in MPP tracking applications [21]. In MPPT system, FLC is used to find the maximum power value from the solar panel by adjusting the duty cycle of the buck converter. In general, the main parts of FLC are shown in Fig.6 [11].

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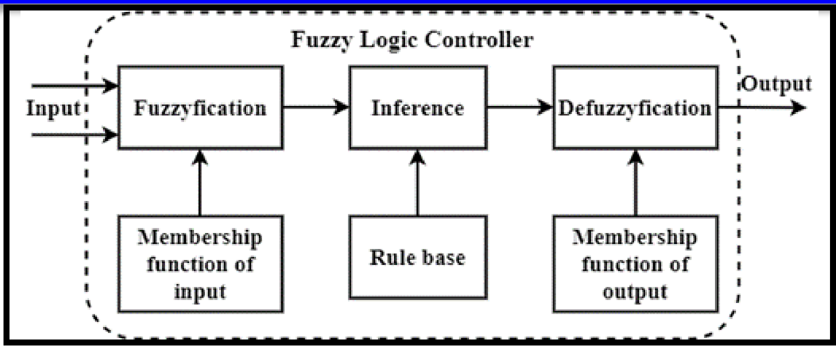

Fig. 6. Block Diagram of Fuzzy Logic Controller

$$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \quad (6)$$

$$dE(k) = E(k) - E(k-1) \quad (7)$$

Fuzzy control contains three parameters that are fuzzification, fuzzy inference system, and defuzzification. Overall, the system fuzzy-sets distributed to the represents fuzzy variables called membership function. The value changes of membership function between 0 and 1. The input of the FLC used in this paper is an error (E), a change in error (dE), and a duty cycle (D) as the output. The FLC input is defined in equation (6) and equation (7) [11][19].

4. Results and Discussion

MPPT testing was carried out with variations in irradiation and temperature variations. Furthermore, PLTS and PLN are connected to STS, testing the impact of using STS on power quality compared to using EMR.

4.1. Power Output with MPPT in Various Irradiance

The MPPT response test was carried out on changes in irradiation. The test was carried out with a constant temperature of 25ºC and various irradiance from 550 W/m² to 1000 W/m² with a step of 50 W/m². The comparison of the power generated by the system without MPPT and with MPPT can be seen in Table 3 and Fig.7.

Table 3. Power Comparison With and Without MPPT in Various Irradiance

Irradiance (W/m2)	Pmax (W)	MPPT			Without MPPT		
		Pin (W)	Pout (W)	η (%)	Pin (W)	Pout (W)	η (%)
550	108,43	108,43	107,76	99,460	96,77	96,99	89,243
600	118,54	118,54	118,13	99,654	99,70	100,34	84,115
650	128,62	128,62	127,83	99,386	102,00	103,03	79,310
700	138,68	138,68	137,90	99,434	103,89	105,27	74,913
750	148,72	148,72	148,00	99,515	105,48	107,19	70,925
800	158,73	158,73	157,93	99,604	106,85	108,87	67,318
850	168,71	168,70	166,06	99,666	108,07	110,36	64,055
900	178,66	178,66	172,53	99,727	109,16	111,70	61,097
950	188,57	188,57	177,81	99,785	110,14	112,91	58,409
1000	198,45	198,45	182,24	99,838	111,05	114,03	55,958

From the simulation result, based on Table 3, it is known that the highest power value that can be generated by solar panels is 198.45 watt when irradiance of 1000W/m². The maximum power produced by solar panels in various irradiance with MPPT has an average efficiency of 99.60% and without MPPT has an average efficiency of 70.53%.

4.2. Power Output with MPPT in Various Temperature

The MPPT response test was carried out on temperature changes. The test was carried out with a constant irradiance of 800 W/m² and various temperatures from 17ºC to 35ºC with a step of 2ºC. The comparison of the power generated by the system without MPPT and with MPPT can be seen in Table 4 and Fig.7.

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Table 4. Power Comparison With and Without MPPT in Various Temperature

Temperature (°C)	Pmax (W)	MPPT			Without MPPT		
		Pin (W)	Pout (W)	η (%)	Pin (W)	Pout (W)	η (%)
17	163,78	163,79	163,06	99,556	112,80	114,87	68,871
19	162,52	162,53	161,83	99,572	111,29	113,35	68,481
21	161,26	161,26	160,59	99,586	109,80	111,85	68,093
23	159,99	159,94	159,29	99,595	108,32	110,36	67,705
25	158,73	158,56	157,93	99,604	106,85	108,87	67,318
27	157,45	157,13	156,53	99,613	105,39	107,39	66,932
29	156,17	155,67	155,08	99,622	103,93	105,92	66,548
31	154,89	154,16	153,59	99,631	102,49	104,46	66,165
33	153,61	152,61	152,06	99,640	101,05	103,01	65,783
35	152,33	151,03	150,50	99,649	99,62	101,57	65,401

From the simulation result, based on Table 4 it is known that the highest power value that can be generated by solar panels is 163.78 watt when the temperature of 17°C. The maximum power produced by solar panels in various temperatures with MPPT has an average efficiency of 99.6% and without MPPT has an average efficiency of 67,13%.

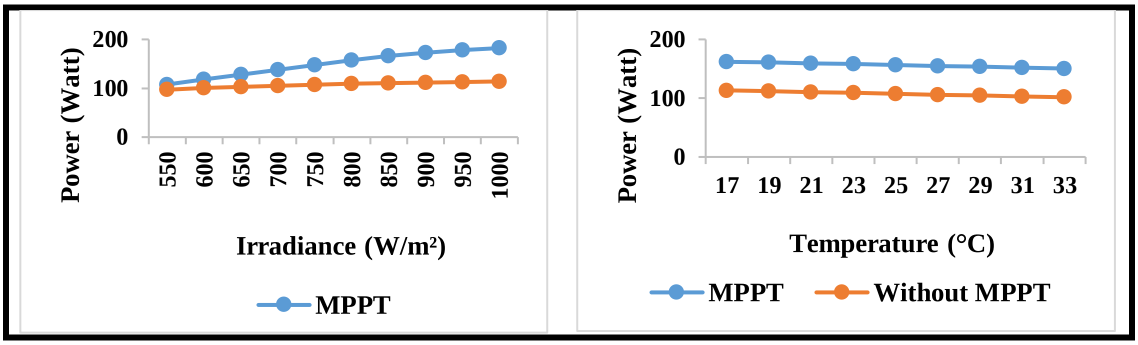

Fig. 7. Power Comparison in Various Irradiance and Various Temperature

4.3. Transfer Switch

The process of switching power from one source is carried out in the event of a disturbance. The main source (PLN) and the backup source (PLTS) are connected by a static transfer switch (STS). The inverter output voltage is sensed continuously to find out whether the backup source, namely PLTS, is ready to supply the load to reduce the use of the main source, namely PLN.

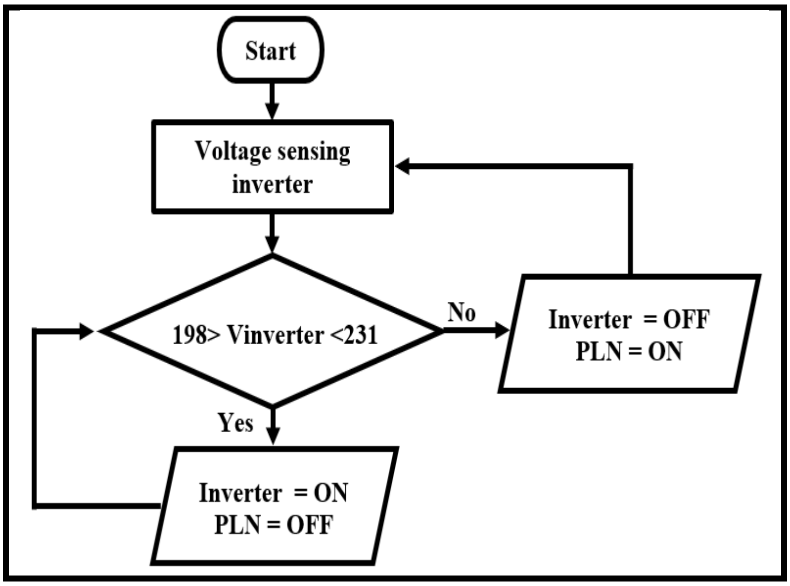

Fig. 8. Block Diagram Process Transfer Switch

According to the IEEE 1159-1995 standard, the allowable voltage is -10% to +5% of the nominal voltage. The nominal voltage is 220 Volt, the allowable voltage limit is 198 Volt to 231 Volt.

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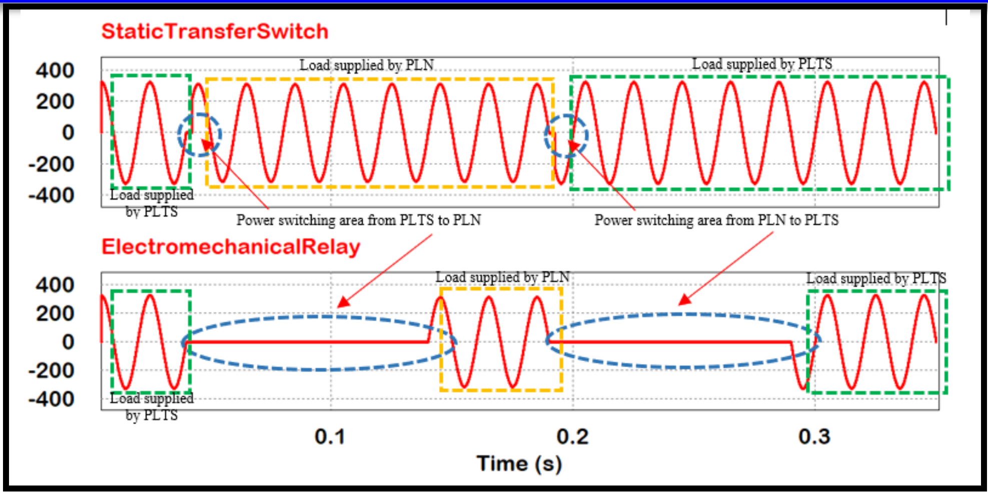

Fig. 9. Comparison of Response with STS and EMR when Switching Power

Table 5. Power Transfer Process

V Inverter (Volt)	V PLN (Volt)	PLTS	PLN	V load (Volt)	Speed Transfer Switch (Millisecond)	
					With STS	With EMR
< 198	220	OFF	ON	220	2	50
> 231	220	OFF	ON	220	2	50
198 - 231	220	ON	OFF	198- 231	2	50

Fig.9 describes a comparison of the speed of power transfer from one source using STS and EMR. Where the STS responds when the transfer switch is 2ms while for the EMR it is 50ms.

5. Conclusion

In this paper, the FLC as an MPPT system has been presented. The system simulation results ran well. It can be concluded that the used MPPT method is stable and has high efficiency with the conditions of irradiation and temperature changes. The average efficiency of this MPPT system when the condition of irradiation and temperature change is 99.60%.

Very fast response when switching power on STS, which is ¼ cycle or 2ms, while power quality disturbances such as voltage sag and voltage swell occur between 0.5 cycles to 1-minute duration so that sensitive equipment such as computer, relay, inverter, and PLC will be protected from power quality problems. It's different when using EMR, because the response is quite long, which is 50ms, sensitive equipment will feel the impact of interference.

References

[1] S. K. Saha and Jaipal, "Optimization Technique Based Fuzzy Logic Controller for MPPT of Solar PV System," *2018 International Conference on Emerging Trends and Innovations In Engineering And Technological Research (ICETIETR)*, Ernakulam, India, 2018, pp. 1-5.

[2] B. H. Hamadani and M. B. Campanelli, "Photovoltaic Characterization Under Artificial Low Irradiance Conditions Using Reference Solar Cells," in *IEEE Journal of Photovoltaics*, vol. 10, no. 4, pp. 1119-1125, July 2020.

[3] A. R. Nansur, A. Syah Laili Hermawan and F. D. Murdianto, "Constant Voltage Control Using Fuzzy Logic Controller (FLC) to Overcome The Unstable Output Voltage of MPPT in DC Microgrid System," *2018 International Electronics Symposium on Engineering Technology and Applications (IES-ETA)*, Bali, Indonesia, 2018, pp. 19-24.

[4] S. Narendiran, S. K. Sahoo, R. Das and A. K. Sahoo, "*Fuzzy logic controller based maximum power point tracking for PV system,*" *2016 3rd International Conference on Electrical Energy Systems (ICEES)*, Chennai, India, 2016, pp. 29-34.

[5] E. M. Vicente, P. D. Santos Vicente, R. L. Moreno, and E. R. Ribeiro, "High-efficiency MPPT method based on irradiance and temperature measurements," IET Renewable Power Gener., vol. 14, pp. 986–995, 2020.

[6] J.-S. Ko, J.-H. Huh, and J.-C. Kim, "*Overview of maximum power point tracking methods for PV system in micro grid*," Electron., vol. 9, 2020, Art. no. 816.

[7] Muhammad H. Rashid, Power Electronics Devices, Circuits, and Applications, Florida: Pearson Education Limited, 2014.

[8] Antonio Luque, Steven Hegedus, Handbook of Photovoltaic Science and Engineering, Wiley, John Wiley & Sons, 2003.

[9] Philip R. Wolfe, The Solar Generation Childhood and Adolescence of Terrestrial Photovoltaics First Edition, John Wiley & Sons, 2018.

[10] Daniel W. Hart, Power Electronics, New York: The McGraw-Hill Companies, 2011.

[11] M. Z. Abdullah, I. Sudiharto and R. P. Eviningsih, "Photovoltaic System MPPT using Fuzzy Logic Controller," *2020 International Seminar on Application for Technology of Information and Communication (iSemantic)*, Semarang, Indonesia, 2020, pp. 378-383.

[12] A. Sannino, "*Static transfer switch: analysis of switching conditions and actual transfer time*," *2001 IEEE Power Engineering Society Winter Meeting. Conference Proceedings*, Columbus, OH, USA, 2001, pp. 120-125 vol.1.

[13] T. Mahmood and M. A. Choudhry, "*Application of Static Transfer Switch for Feeder Reconfiguration to Improve Voltage at Critical Locations*," *2006 IEEE/PES Transmission & Distribution Conference and Exposition: Latin America*, Caracas, Venezuela, 2006, pp. 1-6.

[14] "IEEE Recommended Practice for Monitoring Electric Power Quality," in *IEEE Std 1159-1995*, vol., no., pp.1-80, 30 Nov. 1995.

[15] R. Rakhmawati, Irianto and B. W. Dionova, "Design and implementation of hybrid energy system for DC load applications," *2017 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 2017, pp. 109-114.

[16] C. A. Iskak, N. A. Windarko and R. Rakhmawati, "Design and Implementation Bidirectional DC-DC Converter for Load Sharing and Charging Battery," *2019 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 2019, pp. 455-459.

[17] R. Rakhmawati, Irianto, F. Dwi Murdianto and G. T. Ilman Syah, "Performance Evaluation of Speed Controller Permanent DC Motor in Electric Bike Using Fuzzy Logic Control System," *2018 International Seminar on Application for Technology of Information and Communication*, 2018, pp. 110-115.

[18] M. Q. Duong, H. Tran and C. A. Hossain, "Influence of elemental parameter in the boost and the buck converter," *2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC)*, 2017, pp. 528-531.

[19] N. D. Bhat, D. B. Kanse, S. D. Patil and S. D. Pawar, "DC/DC Buck Converter Using Fuzzy Logic Controller," *2020 5th International Conference on Communication and Electronics Systems (ICCES)*, 2020, pp. 182-187.

[20] K. Bendaoud *et al*., "Fuzzy logic controller (FLC): Application to control DC-DC buck converter," *2017 International Conference on Engineering & MIS (ICEMIS)*, 2017, pp. 1-5.

[21] P. Ray and A. K. Sinha, "Modelling and simulation of grid power management with modified fuzzy logic based MPPT tracking with hybrid power energy system," *2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE)*, 2015, pp. 1-6.

[22] "IEEE Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances," in *IEEE Std 1250-1995*, vol., no., pp.0_1-, 1995.