Implementation of Parallel Boost For Hybrid Battery Charging with Load Sharing Algorithm Based on P&O MPPT and Fuzzy Logic Controller

Eka Prasetyono, Putra S Permana, Novie A Windarko
Department of Electrical Engineering
Politeknik Elektronika Negeri Surabaya
Surabaya, Indonesia
eka@pens.ac.id, putraseptianpermana@gmail.com, ayub@pens.ac.id

***Abstract*—Photovoltaic (PV) energy is greatly influenced by environmental factors such as solar irradiation, wind speed and ambient temperature. *According to local time of installed PV, The intensity of solar* irradiation *on the earth's surface* during daylight *is determined by the position of the sun in the sky.* In the case of PV with MPPT algorithm for battery charging, the charging current is linear to *intensity of solar* irradiation, so that it is not suitable for constant current battery charging application. For the reason, this paper proposes hybrid charging with parallel boost converter for constant current battery charging system. The discussion highlighted on controller ability for sharing energy between PV and existing grid electricity. The load sharing algorithm described in this paper is PV as main energy source and existing grid electricity as secondary energy source. The charging current is emphasized on PV energy. Meanwhile, lack current from the demand charging current is taken from existing grid electricity. To implement load sharing algorithm, the first boost converter is controlled by P&O MPPT algorithm and the second boost converter will be controlled with fuzzy logic to manage energy sharing. Both, control method in this paper is implemented on STM32F407 a 32 bit microcontroller as standalone digital controller. As the result, hybrid charging with load sharing algorithm for constant current battery charging has an ability to share energy each other with an error ±3.4% from 2 ampere charging current.**

Keywords—component; photovoltaic; parallel boost converter; load sharing; fuzzy logic;

I. INTRODUCTION

Sunshine as energy source can be used to an electricity generation through solar PV module. However, PV module have very low efficiency in generating electricity from solar energy. The PV energy is greatly influenced by environmental factors such as solar irradiation, wind speed and ambient temperature [1,2]. According to local time of installed PV, the intensity of solar irradiation on the earth's surface during daylight is determined by the position of the sun in the sky [3,4]. When the sun's position is perpendicular to the PV surface, the solar irradiation is maximum. This position make the PV power output is also in the maximum condition. While, The angle between the sun and the PV surface changed, the solar irradiation and PV power output is reduced.

One of the techniques to absorb PV energy in maximum stage is used DC-DC power converter and controlled by maximum power point tracking algorithm (MPPT). The P&O method is often used to control the MPPT and this method is very simple to be implemented to control duty cycle of DC–DC boost converter in order to obtain the MPPT [5]. In the case of PV with MPPT algorithm for battery charging, the charging current is linear to intensity of solar irradiation [6]. The charging will be maximum at noon and morning. In the evening the charging is not maximal.

The charging method of battery depends on battery applications. The applications are roughly classified into main power (cycle use) application and standby/backup power application [7]. In the main power battery application commonly used constant-current, constant-voltage, modified constant-voltage charging method [7-9]. For the reason, this paper proposes hybrid charging with parallel boost converter for constant current battery charging system. The discussion of this paper is highlighted on controller ability for sharing energy between PV and existing grid electricity. The load sharing algorithm described in this paper is PV as main energy source and existing grid electricity as secondary energy source. The charging current emphasized on PV energy. Meanwhile, lack current from the demand charging current is taken from existing grid electricity. The rechargable betteries discussed in this paper discussion is seale lead-acid battery type.

To implement load sharing algorithm, the first boost converter is controlled by P&O MPPT algorithm and the second boost converter will be controlled with fuzzy logic to manage energy sharing. The MPPT must be used to collect maximum PV energy for battery charging [6,10]. Then, loading sharing algorithm used fuzzy logic controller because it has good performance and widely used on renewable energy load sharing [11-13]. Both, control method in this paper is implemented on STM32F407 a 32 bit microcontroller as standalone digital controller.

II. PV MODULE, BATTERY CHARGING AND FUZZY LOGIC

A. Characteristic of PV Module.

The PV module energy is highly influenced by solar irradiation and temperature. Fig. 1 and 2 show characteristic of the PV module which represents curve of power and voltage (P-V) and also show characteristics of the PV module with different irradiance and temperature [1,2].

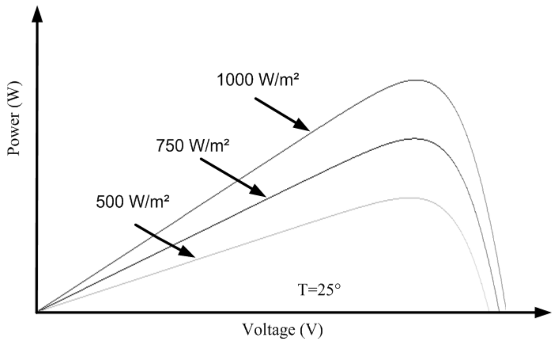

Fig. 1. Influence of the solar irradiance for constant temperature

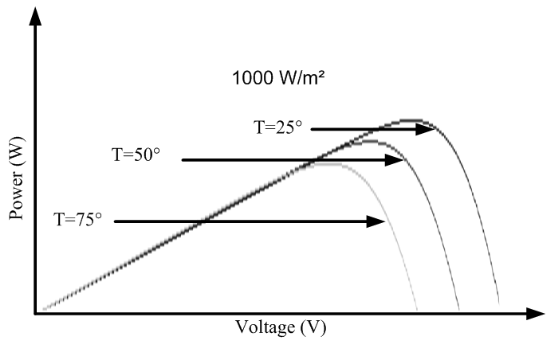

Fig. 2. Influence of the solar temperature for constant irradiance

The solar irradiance highly depend on the position of the sun in the sky to the PV installed on the Earth's surface [1,3]. When the sun's position are perpendicular to the PV surface on noon time, the solar irradiance is in the maximum condition. However, as the angle between the sun and the PV surface changes, the solar irradiance is reduced [2]. For this reason can be concluded that solar irradiance always changes every time. It made PV power out always changing also [3,6]. The daily characteristic of solar irradiance in the function of time can be seen on Fig. 3 below.

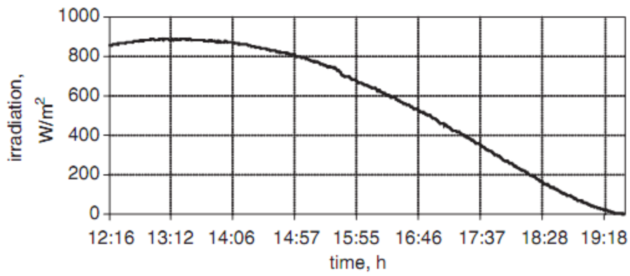

Fig.3 – Daily characteristic of solar irradiance [6].

For standalone PV battery charging with MPPT is also influenced by solar irradiance every time [6]. It can be seen on Fig 4. The charging current is maximum at noon and goes smaller in the evening.

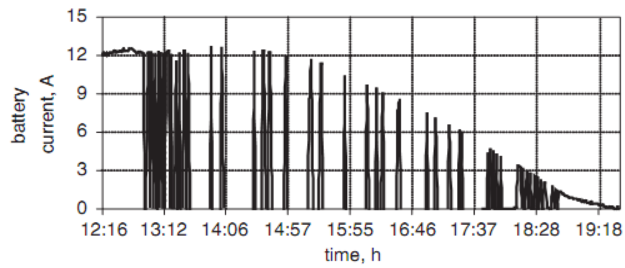

Fig.4 – Characteristic of Standalone PV for battery charging [6].

B. Methods of Charging the Sealed Lead-Acid (SLA) Battery.

The rechargeable batteries are widely used in renewable energy systems to store electricity energy [6]. There are many type of rechargeable batteries in the world, but in this paper discussion of rechargeable batteries focused only on sealed lead-acid (SLA) battery type. The charging of SLA batteries is not difficult process, a number of methods for charging lead-acid batteries have been developed to meet the rules for proper charging [7,8]. Common charging of SLA methods are known as the constant-current, constant-voltage, modified constant-voltage, float charging, and trickle charging method [7-9]. The characteristic of charging method of SLA battery can be seen on Fig. 5 below.

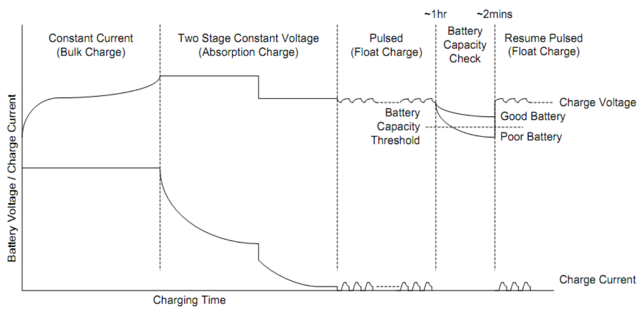

Fig.5 – The characteristic of charging method of SLA battery [9].

The constant-current charging method is a fixed current applied for a certain time to the battery to recharge it. The charging current value is set to a low value, usually less than 10% from capacity or 0.1C for slow charging and 30% from capacity or 0.3C for fast charging. The constant-current charging method is not used for lead-acid batteries on long time charging, because of the gassing which is likely to occur when charging a battery too long [8].

The constant-voltage charging method is a fixed voltage applied to the battery to recharge it. The value of initial charging current (current value at the beginning of the battery charge) is in the maximum value according to the battery capacity and its level of charge. The initial charging current can reach higher values. It sometimes even exceed the maximum charge current prescribed by the battery manufacturer when the battery depth of discharge is high. For this reason, purely constant-voltage charging is infrequently used to charge lead-acid batteries that are used in cyclic charge-discharge applications.

In this paper, for hybrid battery charging with load sharing algorithm and the battery charging current is emphasized on PV energy, the constant-current charging method is selected as method of charging.

C. Fuzzy Logic Controller.

Fuzzy set theory was first introduced by Lotfi A. Zadeh in 1965. Since then the fuzzy set theory is widely used to solve problems that cannot be solved in the conventional method [14]. The fuzzy set theory on control system is call fuzzy logic controller. The fuzzy logic controller relates its output to input using a list of IF-THEN rules. The IF is part of a rule that describes regions of input variables specifies the condition for a rule holds. A particular input value belongs to these regions to a certain degree represented by a degree of membership which is assigned to the variables according to the membership functions definition. The THEN is part of a rule refers to values of the output variable to obtain the output of the controller. The degree of membership of the IF part of all rules are evaluated with rule based inference system and all rules of the THEN part are averaged and weighted by these membership degrees.

According to development of technology, currently fuzzy set theory has been widely used for the application of the power converter control. The fuzzy logic controller for DC-DC converter applications can be implemented in computer simulations and also on microcontroller [5,12-14], because fuzzy logic controller for DC-DC converter applications didn't require heavy computing process. In this paper fuzzy logic controller was implemented on a 32bit microcontroller family STM32F407 ARM Cortex M4F to automatically control the second boost of parallel boost converter. The second boost converter is controlled for the process of charging the battery according to the load sharing algorithm on hybrid system.

III. Methods and Design

The general block diagram of proposed hybrid battery charging system is shown in Fig. 6. The charging current is emphasized on PV energy. Meanwhile, lack current from the demand charging current is taken from existing grid electricity. To implement load sharing algorithm, the first boost converter is controlled by P&O MPPT algorithm and the second boost converter will be controlled with fuzzy logic to manage energy sharing. Both, control method in this paper is implemented on STM32F407 a 32 bit microcontroller as standalone digital controller.

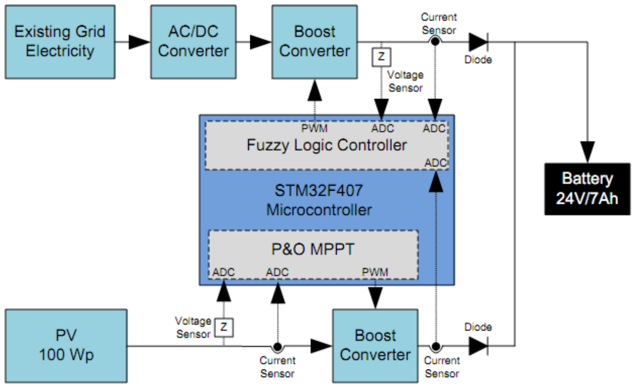

Fig.6 – General block diagram for proposing hybrid battery charging system.

According to the general block diagram on Fig. 6, the proposed system of hybrid charging can be described as follows:

A. Boost Converter

A boost converter (step-up converter) is a DC-to-DC power converter to produce a higher output average voltage than the input voltage [15]. The basic schematic with the switching waveform of a boost converter is shown in Fig 7.

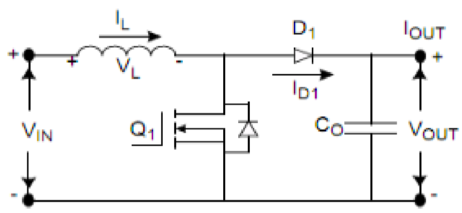

Fig. 7 – Boost converter and its signal of operation

In a boost converter, an inductor (L) is placed in series with the input voltage source VIN. The input source feeds the output through the inductor and the diode D1. The output capacitor value should be large enough to supply the load with the minimum ripple in the output voltage. The relation between output and input voltage, as shown in Equation 1 below.

$$Vout = \frac{Vin}{(1-D)} \quad \text{................(1)}$$

B. P&O MPPT

The P&O is one of the most discussed and used algorithms for MPPT. The algorithm worked on the PV panel by modifying the converter duty cycle [16]. To be able to implement P&O MPPT, the application needs to measure the panel voltage and current. To simplify the understanding on how P&O work look at Fig. 8. The decreasing voltage on the right side of the MPP will increase power. Furthemore, increasing voltage on the left side of the MPP will raise the power. This is the main idea behind P&O. After performing an increase in the panel operating voltage, the algorithm compares the current power reading with the previous one. If the power has increased, it keeps the same direction (increase voltage), otherwise it changes direction (decrease voltage). This process is repeated at each MPP tracking step until the MPP is reached. After reaching the MPP, the algorithm naturally oscillates around the correct value.

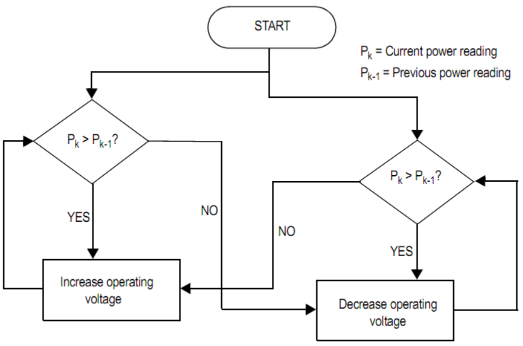

Fig. 8 – Flowchart of P&O MPPT

C. Design of Fuzzy Logic Control

The function of fuzzy logic controller is to control second boost converter with load sharing algorithm. The fuzzy logic controller will manage energy sharing between PV and existing grid electricity. The input of fuzzy logic controller is taken from current sensor, then current value processed as error and delta error. The design of membership function of error and delta error can be seen on Fig. 9 and 10.

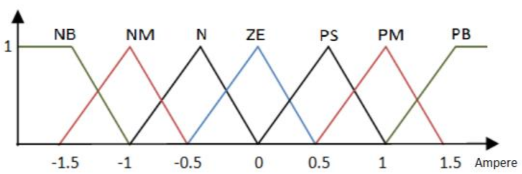

Fig. 9 – Membership function of input error

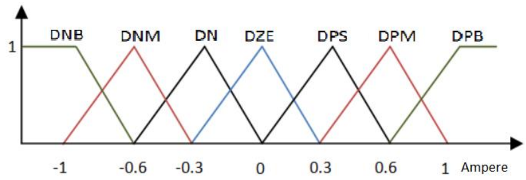

Fig. 10 – Membership function of input delta error

The inference system of fuzzy logic controller in this paper used 7x7 combination rule based on input error and input delta error. Detail of inference rule based can be seen on Table 1 below.

Table 1. Rule Base of Fuzzy Logic Control (7 x7)

		Error						
		NB	NM	NS	ZE	PS	PM	PB
ΔError	DNB	KBS	KBS	KBS	KBS	KB	K	BS
	DNM	KBS	KBS	KBS	KB	K	BS	T
	DNS	KBS	KBS	KB	K	BS	T	TB
	DZE	KBS	KB	K	BS	T	TB	TBS
	DPS	KB	K	BS	T	TB	TBS	TBS
	DPM	K	BS	T	TB	TBS	TBS	TBS
	DPB	BS	T	TB	TBS	TBS	TBS	TBS

The membership function of defuzzification in this paper use singleton type as shown on Fig. 11.

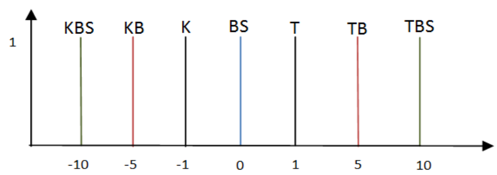

Fig. 11. Membership function of output

The output value of defuzzification process can be calculated with weighted average formula as below.

$$\text{Defuzzification Output} = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=1}^{n} W_i} \quad \text{..............(2)}$$

IV. Result and Discussion

The result of field measurement test with PV 100WP on April 2015 shown that solar irradiance always changes every time and also it made PV power out always change. The hourly characteristic of PV power output in the function of time with maximum load on the test date can be seen on Fig. 12 below.

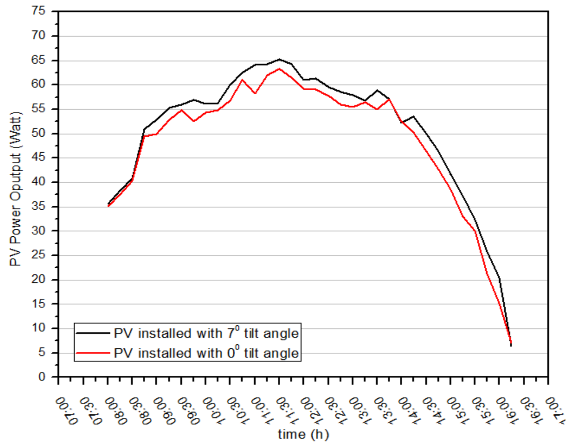

Fig. 12. Hourly characteristic of PV power output.

Refers to the Fig 12. When the sun's position is perpendicular to the PV surface, the PV power output is in the maximum condition. However, as the angle between the sun and the PV surface changes, the PV power output is also reduced. The next field test is the hourly characteristic of PV power output without MPPT in the function of time with different load on the test date can be seen on Fig. 13. The PV delivers maximum energy only on correct load. If load is not correct, PV only delivers energy according to the load demand, so that MPPT must be used to make PV always in maximum load.

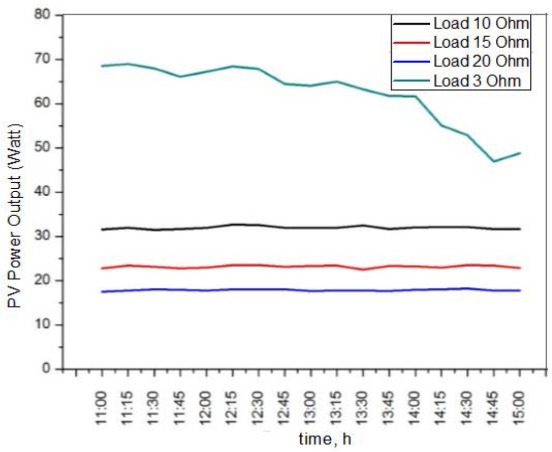

Fig. 13. Hourly characteristic of PV power output without MPPT.

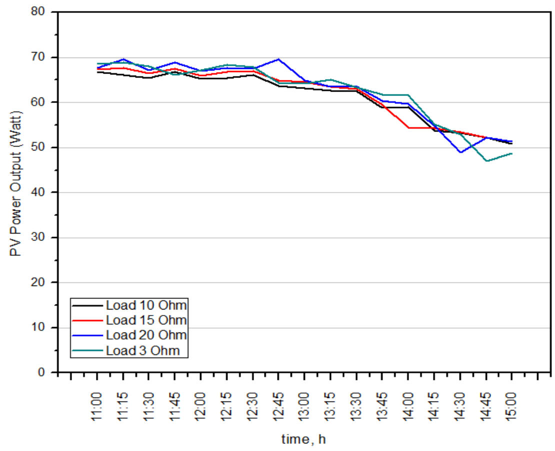

Fig. 14. Hourly characteristic of PV power output with MPPT.

In the morning and evening the PV output power is in the low power. The proposed hybrid battery charging will work on this condition to full fill demand of charging current. In this paper on the field test used SLA battery 24V/7Ah (series connection of two batteries 12V/7Ah). The set point of charging taken from 30% of battery capacity (fast charging) that is 2Ampere. The result of hybrid charging with load sharing algorithm can be seen on Fig. 15. The controller show its ability to share energy each other with an error ±3,4% from 2 ampere charging current.

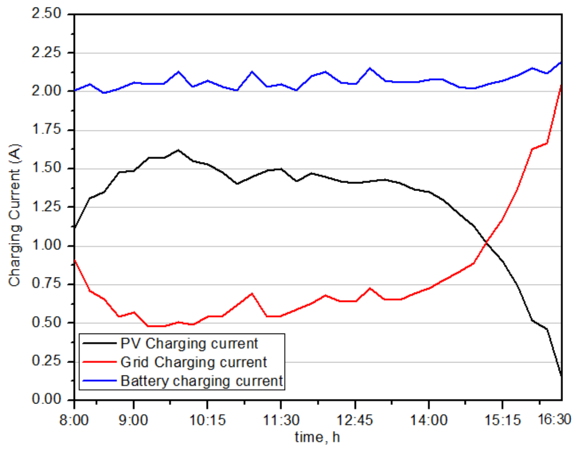

Fig.15 – Result of hybrid battery charging with load sharing algorithm.

Refers to Fig. 15, when charging current from PV goes low, the lack current of charging to full fill set point 2A is taken from existing grid electricity. Furthermore, when PV charging current is high the lack current of charging taken from grid will be smaller. This process is repeated at each controllers until the charging current set point 2A is reached. After reaching the charging current set point the algorithm naturally oscillates around the correct value.

V. CONCLUSION

The result of implementation of parallel boost converter for hybrid battery charging with load sharing algorithm based on P&O MPPT and fuzzy logic controller show that the charging current was emphasized on PV energy and lack current of the demand charging current was taken from existing grid electricity. By this reason, it can be concluded both control method worked well. At last, Hybrid charging with load sharing algorithm for constant current battery charging has an ability to share energy each other with an error ±3,4% from 2 ampere charging current.

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