Arduino Based Maximum Power Point Tracking Battery Charge Controller using Fuzzy Logic Algorithm for a Hybrid AC/DC Source

Kristin Gail C. Cuevas[1],Vivien E. Hora[2],Kristine Mae R. Jimenez[3], Johnn Niño D. Manato[4],Mary Joy I. Porlaje[5]

ElectronicsEngineeringDepartment
TechnologicalUniversityofthePhilippines-Manila
San Marcelino St. cor. Ayala Blvd., Ermita, Manila
[1]`kristingail.cuevas @tup.edu.ph`
[2]`vivien.hora@tup.edu.ph`

Abstract— **This paper presents a Fuzzy-based Maximum Power Point Tracking Battery Charge Controller for a Hybrid AC/DC Source. This study is developed to provide a maximum power point tracking battery charge controller using fuzzy logic algorithm for rural areas that uses solar panels and AC generators. The software implements fuzzy logic algorithm using the Fuzzy Logic Toolbox in MATLAB and Arduino IDE. Fuzzy logic is a mathematical system where something can be represented in continuous values between 0 and 1. It basically represents systems based on human reasoning. The hardware comprises of four components – the switched mode power supply, the source switching circuit, buck-boost converter and the diversion load controller. The pre-testing conducted based on the methodology indicates that the proposed charge controller is efficient in maximizing the input power that enters the charge controller under different conditions. The current efficiency rate of the charge controller is 96.02%. The average battery charging time for a fully-discharged 12V Lead-Acid Battery using AC source, DC source and both AC and DC sources are 2 hours and 30 minutes, 8 hours and 15 minutes and 5 hours and 30 minutes, respectively, while discharging it took 3 hours and 40 minutes.**

Keywords— Maximum Power Point Tracking (MPPT), Fuzzy Logic, Buck-Boost Converter, Charge Controller

I. INTRODUCTION

Electricity is a basic need to every human. However, in some areas in the Philippines weren't provided with electricity due to its distance from the main city. People from these isolated communities tend to use renewable energy power plants and store the created electricity in batteries. The most common renewable energy that produce electricity is the solar energy. As presented in the study of Hiwale, et al. [1], one of the most vital and easily harvested renewable energy source is the solar energy.

Charging batteries using available renewable energy will solve the problem of inconveniences caused by not being connected to the power grid. Many people do not have access to electricity. According to the Shouman [2], most of these people lives in rural areas and others in a remote site to be able to reached by the main grid. However, if overcharging of the batteries occurs, battery performance or even its lifespan can be reduced. To prevent this, a charge controller is used. Greeshma, et al. [3], proposed that to attain the most effective charging and discharging status of the battery, a fuzzy control strategy is developed.

A study by Hamid, et al. [4] stated that charging without an MPPT controller will result to wasted power. Also, according to Brand [5] charge control must supply the battery with a higher voltage than the battery's rated voltage to overcome the battery's internal resistance.

This research study is for the design of a charge controller for battery charging. It controls the electric current that flows to the battery from a hybrid AC and DC source where AC is supplied by a generator while DC comes from the photovoltaic system. In the paper of Enchckal, et al. [6], its hybrid battery charge controller was not considered with only one source. A standby power source from the main grid is also associated in case of power interruption. In a hybrid system, a solar panel is often included to make up for the erratic factors that affect the harvesting of electricity as stated by Durgam, et al. [7]

Giddaiah, et al. [8] presented a study about control of PV charger system using SEPIC converter that in order to locate the maximum power of the PV module, a battery charger is required. This charger needs to regulate the charging of the battery for better state-of-charge and for the battery to last.

The researchers used MPPT for buck-boost converter based on fuzzy logic. Fuzzy logic controller is used to manage the output voltage of the buck-boost converter to obtain a desired output as indicated in a similar study by Jaber [9]. Also, stepping up the input voltage can be done using Fuzzy algorithm according to Won [10]. Using fuzzy control, the proposed system in a paper by Patil [11], the dependability of the converter and the power acquired can be enhanced, and its output can result to less overshoots.

Most studies about battery charge controller are implemented with MPPT system. Some of these are the study of Selvan [12] that focused on extracting maximum output power deserting the changes in solar irradiation and atmospheric temperature using MPPT in PV system. Incremental Conductance and Perturb and Observe method are the most common algorithms implementing MPPT but then the Fuzzy Logic Algorithm is one of the best method known for its good stability and high response rate. Also, MPPT can be integrated in buck-boost converter. In the study of Mudki, et al. [13], he presented a MPPT-based buck boost converter that converts a DC voltage into a higher or lower voltage level than the input voltage efficiently. A hybrid PV

system and wind power system with Fuzzy controller was studied and proposed by Saranya et al. [14] to obtain the required SOC value designed for the charging and discharging state of the battery.

II. THEORETICAL BACKGROUND

This section details the theoretical knowledge used by the researchers in achieving maximum power.

A. Buck-Boost Converter

Numerous studies, journals and published papers are studied and consulted for the design of the circuit. In the study of Sahin, et al. [15], a DC-DC Buck Boost Converter was designed and implemented using Fuzzy Logic Controller, PI controller and combined algorithm. Figure 1 shows the schematic diagram of a buck boost converter. When the switch is on, the current will pass through the MOSFET, but it will be blocked by the diode. This will result for the current to flow through the inductor, resistor and out of the capacitor. When the switch is off, the current will flow from the inductor through the resistor, capacitor and diode. This will discharge the inductor and to be charged again in the next cycle.
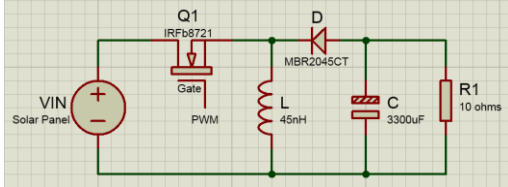

Fig. 1 Buck Boost Converter Inverting Topology **[15]**

Figure 2 illustrates the operation of the buck boost converter with its input coming from a 150W monocrystalline solar panel. The voltage produced by the solar panel depends on the intensity of the sunlight ranging from 0V – 22V. This voltage must be bucked or boosted to meet the charging voltage of the battery which is 13.8V. Also, controlling the input voltage of the battery can increase its lifespan for long term use to attain high SOC and prevent battery life from deteriorating, a proper charge/discharge control approach must be considered [16]
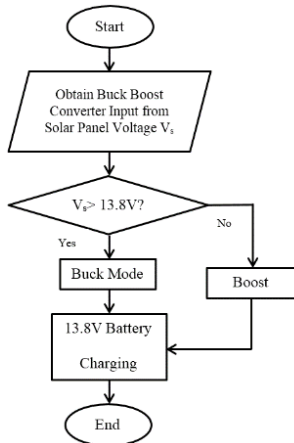

Figure 2 Buck-Boost Converter Input Flowchart

B. Fuzzy Logic

The Fuzzy logic controller (FLC) is a mathematical system that converts a language control strategy [17]and can be acquired using the values between 0 and 1.It can be very suitable for obtaining the linearity and time invariance of a system or when the human understanding is different from its model [18].The fuzzy logic system has four main parts, namely: fuzzification, rule base, inference engine, and defuzzification.

Fuzzification involves converting the input values to linguistic labels. To relate the input values to the output model properties, if-then rules are formed in the rule base.

The rules are combined to form output control actions which are applied to the inference engine.

The inference engine which is carried out by using Mamdani's method determines the degree of the fuzzy input with respect to each rule and decides which rules are to be used according to the input field.

Defuzzification is performed according to the membership function of the output variable. It uses the center of gravity to compute the output of this fuzzy logic system. This is the most popular defuzzification method and is commonly used in actual applications.

III. METHODOLOGY

The block diagram of the charge controller is shown in figure 3. It has two sources, the AC source or the generator and the DC source or the solar panel. The output of the generator is converted into DC from single-phase AC while the output of the solar panel is fed to the buck boost converter. The output voltage of the buck boost converter is being monitored by the voltage sensor to become the input of the Arduino which implements the Maximum Power Point Tracking system using the fuzzy logic algorithm that determines the duty cycle that is needed for the switching of the MOSFETs in the buck boost converter. The outputs of the AC/DC converter and the buck boost converter are fed to the Source Switching Circuit which controls whichever output is fed to the load. This circuit is used to switch among the sources based on its availability. This controller circuit can switch between the DC and AC source. Once the battery is fully charged, the output of the switching circuit is diverted to a dummy load that prevents damage to the system and the battery.
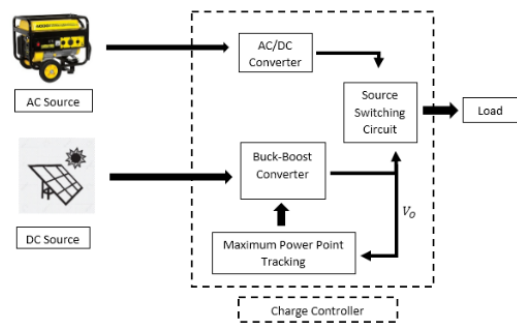

Figure 3 Block diagram of the system

A. Hardware Development

The hardware of the system is composed of a Switched Mode Power Supply, regulator, Arduino Mega 2560, Buck Boost Converter, source switching circuit, and diversion load controller. It also includes fan and LCD. These parts of the system are discussed in this section.

Figure 4 shows the circuits used in the project. (a) Switched Mode Power Supply converts AC voltage of the generator used into 13.8V DC that is needed to charge the battery, (b) Regulator Circuit steps down the produced voltage of the SMPS needed by Arduino Mega 2560, (c) Arduino Mega and Uno uploads the code into the hardware for fuzzy logic and diversion load controller respectively, (d) Buck Boost Converter Circuit steps down or steps up the input DC voltage into 13.8V, (e) Source Switching Circuit switches the default DC Source into AC Source whenever the power produced by the Solar Panel is insufficient for charging and (f) Diversion Load Controller Circuit prevents overcharging and damaging of the battery.
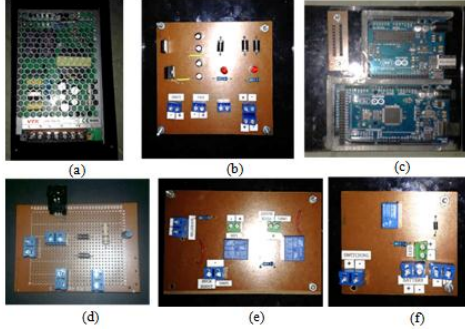

Figure 4 Devices of the Project: (a) Switched Mode Power Supply, (b) Regulator Circuit, (c) Arduino, (d) Buck Boost Converter Circuit, (e) Source Switching Circuit and (f) Diversion Load Controller Circuit

B. Fuzzy Inference Model for MPPT

The system flowchart of the software is shown in Figure 5. It shows the process of obtaining the inputs for the fuzzy logic controller. It starts from assigning the value of the reference voltage into that of the desired voltage output. The output voltage of the buck boost converter is compared to the reference voltage and if they are equal, it means that the output of the dc-dc converter is already the desired 13.8 volts to supply to the battery. If the output voltage is lesser or greater than the reference voltage, the error and change of error is determined and will be the inputs of the fuzzy logic controller, thus producing the duty cycle to determine the switching pulses to be delivered to the gate of the MOSFET of the buck converter until the desired output voltage is achieved.

- *Inputs*

Two inputs will undergo fuzzification which are the Error and Change of Error. The Error is defined as the difference between the reference voltage and the measured output voltage of the buck boost converter; it is designed ranging from -13.8 to 13.8. The Change of Error is calculated from the difference of the error and the previous value of error; the change of error does not produce very large values because the error values are almost the same from its previous values so it was limited in the range -5 to 5.

- *Output*

The output is the duty cycle and is ranged from 0 to 1 representing the 0 to 100 percent duty cycle of the system.

- *FIS Type*

There are several types of membership functions but due to their simple formulas and computational efficiency, both triangular MFs and trapezoidal MFs have been used extensively, especially in real-time implementations [19]. Triangular membership function was used in the fuzzy logic toolbox for the inputs and output and each is assigned to five linguistic variables, namely NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big). The triangular membership function is usually used in fuzzy logic applications because of its simplicity compared to the other types of membership functions.

- Defuzzification

The Center of Gravity (CoG) is used in defuzzification. It is also called Center of Area (CoA) because it is similar in determining the center of gravity in physics and it is the method used to obtain the duty cycle of the system.
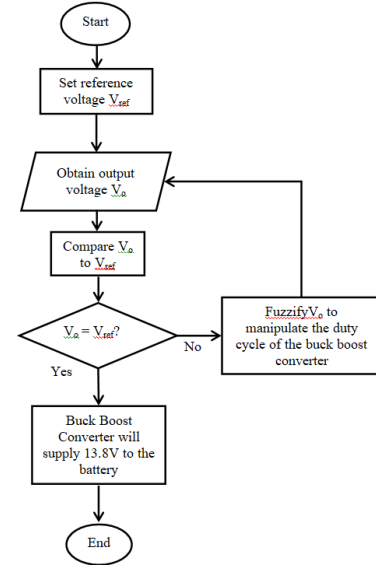

Figure 5 Fuzzy Control input flowchart

The Fuzzy Logic Toolbox in Figure 6 provides functions to model, analyze and simulate systems based on fuzzy logic. The toolbox lets users design the system using different functions and rules depending on the needs of the system.

Triangular membership function was used in the fuzzy logic toolbox for the inputs and output and each is assigned to five linguistic variables, namely NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big).
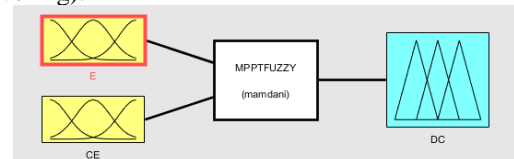

Figure 6 Fuzzy Logic Toolbox interface

Table 1 consists of the ranges of the five membership functions of Error, Change of Error and Duty Cycle.

Fuzzy rules and membership functions can be established when the weather changes to solve the MPPT problem [20]. From the five membership functions for each of the inputs, it produces twenty-five rules to determine the fuzzy outputs as seen on Table 2. These rules are presented in the MATLAB Fuzzy Logic Designer as if-then statements.

TABLE I. MEMBERSHIP FUNCTION RANGE

	NB	NS	ZE	PS	PB
Error (V)	-13.8 to -6.9	-13.8 to 0	-6.9 to 6.9	0 13.8	6.9 to 13.8
Change of Error (V)	-5 to -2.5	-5 to 0	-2.5 to 2.5	0 to 5	2.5 to 5
Duty Cycle (%)	0 to 0.25	0 to 0.5	0.25 to 0.75	0.5 to 1	0.75 to 1

TABLE II. FUZZY RULE TABLE

CE / E	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

C. Testing Procedure

1) Efficiency of the Fuzzy Logic Controller

The Fuzzy Logic Controller is tested by measuring the output of the buck boost converter to check if the MOSFET will switch on or off using an LED when the Arduino sends a HIGH or LOW to the gate of the MOSFET.

2) Battery Charge Controller Efficiency

The efficiency of the battery charge controller is measured by the following:

1. Record the values of Irradiance, V_{MPP}, I_{MPP}, V_{OUT} and I_{OUT} of the system.
2. The V_{OUT} column is averaged and then divided by the desired output voltage 13.8 to get the efficiency of the system.

3) Maximum Power Point Tracking Efficiency

The Maximum Power Point Tracking efficiency is measured by the following:

1. Compute the power in and power out by multiplying the voltages and current obtained.
2. Compare the power in and power out and measure how big the power loss to acquire the efficiency.

4) Charging and Discharging Time of the Battery

Measure the time it takes to charge the battery when the AC and DC source are used. The discharge time is also recorded when the battery is used to power up the flood lights used as load.

D. Formulas

The following formulas are used in the project:

1) For Buck-Boost Converter

The most important equation for designing the Buck-Boost converter are total power loss (1), and its efficiency (2).

$$P_{LS} = P_{rDS} + P_{SW} + P_D + P_{rL} + P_{rC} \quad (1)$$

$$n = \frac{P_O}{P_O + P_{LS}} \quad (2)$$

where P_{LS} is the total power loss, P_{rDS} is the MOSFET conduction loss, P_{SW} is the switching loss, P_D is the diode conduction loss, P_{rL} is the loss in the ESR of the inductor, P_{rC}

is the loss in the ESR of the filter capacitor, n is the efficiency of the Buck-Boost converter, and P_O is the output power.

2) For Fuzzy Logic Algorithm System

For testing the efficiency of the system, the following formula is used:

$$Error_{1(AVE)} = \frac{Error_{T1} + Error_{T2} + Error_{T3} + \cdots + Error_{T10}}{number\ of\ trials}$$
$$(3)$$

$$Error_{2(AVE)} = \frac{Error_{T1} + Error_{T2} + Error_{T3} + \cdots + Error_{T10}}{number\ of\ trials}$$
$$(4)$$

3) For battery efficiency

The efficiency of the battery charge controller is computed using (5):

$$Efficiency = \frac{V_{OUT}}{V_{REF}} \times 100 \quad (5)$$

where V_{OUT} is the output voltages and V_{REF} is the reference voltage, which is 13.8 V.

4) For Maximum Power Point Tracking Efficiency

The efficiency of the Maximum Power Point Tracking capability of the system is obtained using (6):

$$Efficiency = \frac{P_{OUT}}{P_{IN}} \times 100 \quad (6)$$

IV. RESULTS AND DISCUSSION

This section presents the results of the methodologies done in section IV of this paper. This includes presentation of the results of the data gathered.

A. Overview of the Data

1) Efficiency of the Fuzzy Logic Controller

TABLE III. VOLTAGES AT BUCK AND BOOST MODE

Trial	Voltage at which Buck Mode Starts	Error₁ ($|V_{ref} - V_{buck}|$)	Voltage at which Boost Mode starts	Error₂ ($|V_{ref} - V_{boost}|$)
1	13.94V	0.14	13.45V	0.35
2	13.81V	0.01	13.71V	0.09
3	13.91V	0.11	13.67V	0.13
4	13.89V	0.09	13.76V	0.04
5	13.96V	0.16	13.52V	0.23
6	13.89V	0.09	13.62V	0.18
7	13.84V	0.04	13.64V	0.16
8	13.96V	0.16	13.52V	0.28
9	13.99V	0.19	13.32V	0.48
10	13.86V	0.06	13.59V	0.21
Average	**0.105**		Average	**0.215**

Table 3 specifies at which voltage does the Fuzzy Logic Algorithm starts the buck or boost mode. The fuzzy logic controller has a high accuracy in giving switching pulses to the MOSFET of the buck boost converter. Applying (3) and (4), where $Error_{1(AVE)}$ is the average error of the controller

for buck, $Error_{2(AVE)}$ is the average error for boost, and $Error_{T1}$ to $Error_{T10}$ is the error on the first trial up to the tenth trial, the computed average error of the controller is 0.105 for the Buck Mode and 0.215 for the Boost Mode. Having this small error, means that the Fuzzy Logic Controller can give switching pulses to the buck boost converter that can make it produce an output voltage close to the reference voltage which is needed by the battery.

2) Battery Charge Controller Efficiency

Table 4 has six columns, the trial number, the Irradiance which is the amount of sunlight that strikes the solar panel, the I_{MPP} and V_{MPP} are the current and voltage from the solar panel that enters the system, the I_{OUT} and V_{OUT} are the current and voltage that the system produces.

In getting the efficiency of the battery charge controller, 28 trials were made. However only 10 trials were shown in table 4. In computing for the efficiency, 28 trials were used and by using (5), an efficiency of 96.02% was acquired.

TABLE IV. EFFICIENCY OF BATTERY CHARGE CONTROLLER

Trial	Irradiance	I_{mpp} (A)	V_{mpp} (V)	I_{out} (A)	V_{out} (V)
1	1900	1.06A	18V	1.22A	13.8V
2	2000	0.98A	18.47V	1.14A	13.99V
3	2000	0.9A	18.52V	1.08A	14V
4	2000	0.9A	18.34V	1.1A	14.01V
5	2000	0.91A	18.48V	1.04A	14.01V
6	2000	0.78A	18.51V	0.97A	14.01V
7	2000	0.83A	18.32V	0.92A	14V
8	550	2.05A	14.3V	1.84A	13V
9	400	1.62A	14.57V	1.52A	12.9V
10	1200	1.74A	15.02V	1.69A	13V

3) Maximum Power Point Tracking Efficiency

TABLE V. MAXIMUM POWER POINT TRACKING EFFICIENCY

Trial	P_{in} (W)	P_{out} (W)	Efficiency
1	19.08W	16.836W	88.24%
2	18.1006W	15.9486W	88.11%
3	16.668W	15.12W	90.71%
4	16.506W	15.411W	93.37%
5	16.8168W	14.5704W	86.64%
6	14.4378W	13.5897W	94.13%
7	15.2056W	12.88W	84.71%
8	29.315W	23.92W	81.60%
9	23.6034W	19.608W	83.07%
10	26.1348W	21.97W	84.06%

The Maximum Power Point Tracking efficiency is computed by comparing the power in and power out of the system to determine how big or how small the power loss is. Each efficiency is obtained by dividing the P_{OUT} by P_{IN}.

In table 5, 10 trials were only shown but 28 trials were used in computing the efficiency of the Maximum Power Point capability of the system. Using (6), efficiency of each trial was computed. After getting the efficiency for each trial, it is averaged to acquire the total efficiency of the maximum power point tracking capability of the system. 88.235% is the calculated efficiency of tracking the maximum power.
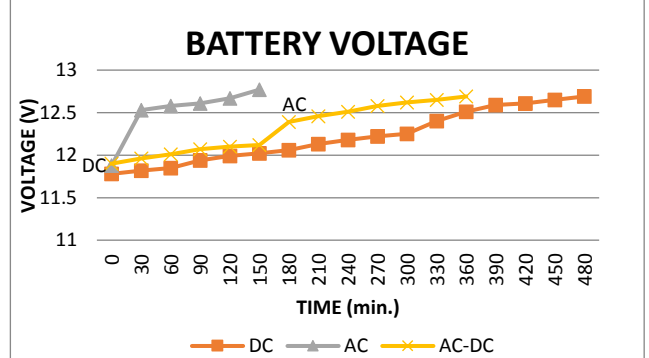
4) Charging and Discharging Time of the Battery

Figure 7 Battery voltage while charging using the different sources
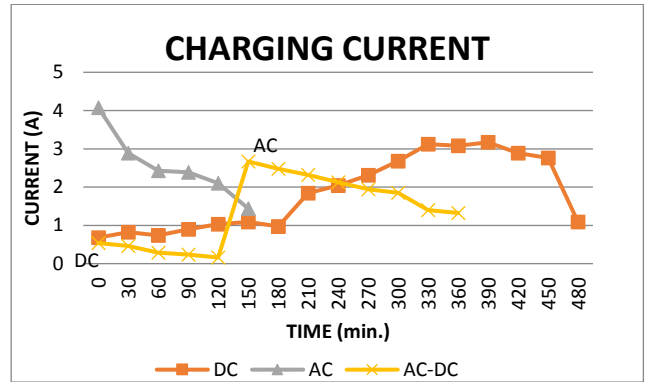

Figure 8 Charging current of different sources

Figure 7 illustrates the battery voltage and charging time using different sources with a 30 minutes interval per sample. In this, the charging duration per source varies greatly with AC source as the shortest, then AC-DC source, and lastly the DC source. The battery voltage of the AC source rises abruptly while with the DC source, it rises gradually. Using AC-DC source, there's a sudden increase of the battery voltage of when the source switched from DC to AC.

The charging current and duration of the different sources is shown in figure 8 with samples taken every 30 minutes. Having the shortest time of charging, AC source is observed that the charging current abruptly decreases at first then gradually decreases. Charging using DC source took more time due to varying charging current which depends on the time of the day. Furthermore, on AC-DC source, the charging current on the DC part is decreasing and abruptly increases when switched to AC.
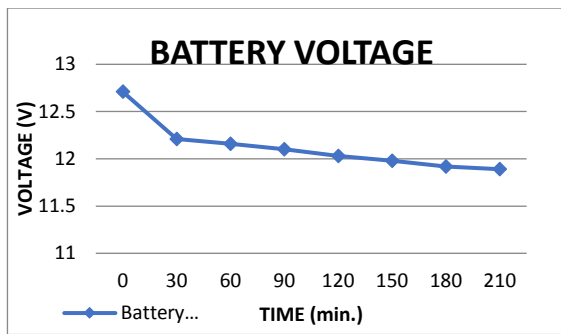
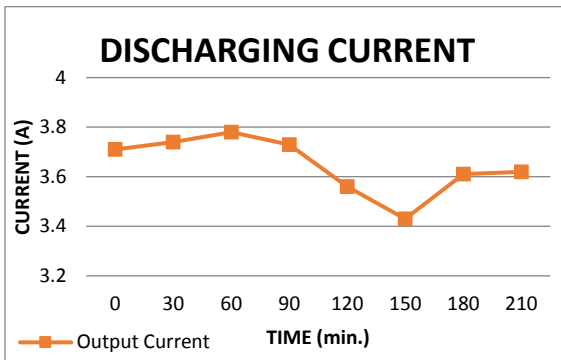Figure 9 Battery voltage while discharging

Figure 10 Current delivered to the two 30-watt load

Figure 9 displays the battery voltage while discharging with the two 30-watt floodlight. It shows that on the first 30 minutes, the battery voltage drastically decreases then gradually decreases over time. The discharging of the battery took 3 hours and 30 minutes.

Figure 10 shows the delivered current to the two 30-watt load. It illustrates that the battery supplies an average current of 3.6475A. The battery took 3 hours and 30 minutes to fully discharge the battery.

V. CONCLUSIONS

The effectiveness of the Fuzzy Logic Algorithm was observed and found out that it has a high efficiency rate because it produces an output voltage close to the reference voltage by having a small amount of error. In charging a 12V Lead-Acid battery, it was discovered that the average battery charging time using AC source, DC source and both AC and DC sources are 2 hours and 30 minutes, 8 hours and 15 minutes and 5 hours and 30 minutes, respectively, however, discharging it took 3 hours and 40 minutes.

ACKNOWLEDGMENT

REFERENCES

[1] A. S. Hiwale, M. V. Patil and H. Vinchurkar, "An Efficient MPPT Solar Charge Controller," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* vol. III, no. 7, pp. 10505-10511, 2014.

[2] E. R. Shouman, "Forecast Renewable Energy for Electricity to Assist Decision Makers with Case study-Economics Solar Energy for Electricity Supply in Rural Areas in Egypt," *International Journal of Applied Engineering Research,* vol. XI, no. 5, pp. 3596-3604, 2016.

[3] V. J. Greshma and R. Sasidharan, "Battery Charging Control using Fuzzy Logic based Controller in a Photovoltaic System," *International Advanced Research Journal in Science, Engineering and Technology,* vol. III, no. 3, pp. 114-117, 2016.

[4] M. R. Hamid, J. Rahimi and S. Chowdhury, "Design and Development of a Maximum Power Point Tracking(MPPT) charge controller for Photo-Voltaic(PV) power generation system," *American Journal of Engineering Research (AJER),* vol. V, no. 5, pp. 15-22, 2016.

[5] P. Brand, "Chapter 4 Alternator Charging System," in *How To Repair Your Car, Motorbook International*, 2006, p. 61.

[6] A. G. Enchckal, A. C. Abraham, M. K. Shareena and K. Shijina, "A Relay Based Controller Designing of Hybrid Power Systems," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* pp. 2505-2511, 2015.

[7] S. S. Durgam, A. B. Musale, B. S. A., P. S. Gahane and L. B. Awale, "Ac Hybrid Charge Controller," *Int. Journal of Engineering Research and Applications,* pp. 5-10, 2015.

[8] A. Giddaiah, K. K. and R. Nandyal, "Control of PV Charger System with SEPIC Converter," *International Journal of Engineering Research and Application (IJERA),* vol. III, no. 4, pp. 1111-1120, 2003.

[9] F. S. Jaber, "Universiti Tun Hahussein Onn Malaysia Institutional Repository," May 2011. [Online]. Available: eprints.uthm.edu.my/1730/1/FATHI_SHABAN_JABER.pdf. [Accessed March 2018].

[10] C.-Y. Won, D.-H. Kim and S.-C. Kim, "A New Maximum Power Point Tracker of Photovoltaic Array Using Fuzzy Controller," *IEEE Xplore,* pp. 396-403, 2008.

[11] B. U. Patil and S. R. Jagtap, "Design of Fuzzy Based Controlling System for Buck Converter," *International Journal of Advanced Research in Computer Engineering and Technology(IJARCET),* vol. VII, no. 6, pp. 1649-1656, 2015.

[12] S. Selvan, K. Girish and Umayal, "Comparative Study of Perturb and Observe and Fuzzy Logic Control Based MPPT Algorithms," *International Journal of Advances in Engineering & Technology,* vol. VII, no. 6, pp. 1649-1656, 2015.

[13] A. Mudkhi and S. Deshmukh, "Microcontroller Based MPPT Buck-Boost Converter Using 555 Timer," *International Journal of Engineering Research & Technology,* vol. II, no. 7, pp. 1080-1084, 2013.

[14] S. D. Saranya, S. S. and G. R., "Fuzzy Logic Based Energy Management System for a Microgrid," *ARPN Journal of Engineering and Applied Sciences,* vol. X, no. 6, pp. 2663-2669, 2015.

[15] M. Sahin and H. Okumus, "Fuzzy Logic Controlled Buck-Boost DC-DC Converter for Solar Energy-Battery System," *IEEE Xplore,* pp. 349-397, 2011.

[16] K. Pawar, P. Sahu, B. Narayan and S. Sharma, "Design of Charging and Discharging of Battery in a Renewable Energy based DC Micro-grid," *International Journal for Innovative Research in Multidisciplinary Field,* vol. II, no. 10, pp. 245-249, 2016.

[17] C. Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller," *IEEE Transactions on Systems, Man, and Cybernets,* vol. XX, no. 2, pp. 404-418, 1990.

[18] S. Kaur and G. Bharti, "Two Inputs Two Outputs Fuzzy Controller System Design Using MATLAB," *International Journal of Advances in Engineering, Sciences and Technology,* vol. II, no. 3, pp. 209-218, 2012.

[19] O. A. M. Ali, A. Y. Ali and B. S. Sumait, "Comparison between the Effects of Different Types of Membership Functions on Fuzzy Logic Controller Performance," *International Journal of Emerging Engineering Research and Technology,* vol. III, no. 3, pp. 76-83, 2015.

[20] J. Ji, "Research on MPPT Methods for Photovoltaic System Based on Microgrid," in *New Jersey Institute of Technology*, New Jersey, 2013.