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Battery Charging Performance Using 12 Volts Solar Power Line Source

Raymundo V. Romero
Professor VI, College of Engineering and Technology, Partido State University, Goa, Camarines Sur

ABSTRACT: This study analysed battery charging performance using 12 volts PV cells and a designed system. Specifically, this: 1) analysed battery charging performance: a) at varying amount of cloud cover in the atmosphere; b) with different capacity of solar battery, and 2) This analysed voltage behaviour during battery relaxation. It designed a system with four 12V, 100W and three 12V, 50W solar panels in parallel to produce 12V, 550W power output. The system was used to analyse voltage behaviour in charging two 12V, 100AH batteries, one is a dead while other is functional. Voltage reading was done using the open circuit voltage (OCV). The behaviour of voltage in charging of two batteries were interpreted through the derived mathematical model and by differentiation. It was found that the designed system of collecting energy is capable of charging 12V, 100AH battery within four hours when the atmosphere is cloudy and is shorten to two hours in clear atmosphere even if the charging time is started at early 6:00AM. However, the event is not applicable for the dead battery. During battery relaxation the battery is in equilibrium situation within four hours noting that the voltage reading does not change while it is decreasing in dead battery.

KEYWORDS: Battery, charging performance, PV cells, power output, voltage

I. INTRODUCTION

Today's mass consumers heavily rely on energy technologies and their ongoing development as continuing advancement in consumer electronics demands additional battery power [1]. However, photovoltaic (PV) generators suffer from fluctuating output power due to the highly fluctuating primary energy source that significantly can lead to power system instability and power quality problems [2]. The speed and magnitude of these fluctuations are well-known and have been quantified not only with irradiance data [3] but also with power output measurements [4] while it was demonstrated that the larger the PV system is, the lower the PV fluctuations [5].

Energy storage used for electricity grid services are broadly grouped into three categories such as: short which lasts up to one minute and is concerned primarily with power quality; medium which spans minutes to hours to compensate for the temporal mismatch between generation and demand; and long which provides energy wheeling services over periods of hours and days [6]. Battery life time is reduced if there is low PV energy availability for longer period or improper charging and discharging so that the battery charging needs control for achieving high state of charge and longer battery life [7] so that necessarily proper controller for battery charging is an inevitable need. The main function of the battery charging controller in standalone PV system is to fully charge the battery without permitting overcharging while preventing reverse current flow at night and deep discharge under load conditions [8]. However, due to unstable weather conditions as well as the frequent variations in load demand, the PV power flow delivered to the load could be fluctuated while the battery charging efficiency will be reduced [9]. To overcome these issues and also increase the overall efficiency of solar PV systems, the PV array must operate at its maximum power point [10]. Among the best practical methods available for accurate state of charge indication is the direct measurement which is based on the measurement of battery variables such as the battery voltage, the battery impedance, and the voltage relaxation time after application of a current step [11].

After the end of a charging or discharging sequence, the battery voltage keeps evolving towards a finite value, during hours or even days, although no current is exchanged with the battery that corresponds to the battery relaxation [12]. Battery cycle life deteriorates over time as it is impacted by multiple factors and interconnected degradation mechanisms [13]. The application-specific usage dominates the degradation path, and an accurate aging prediction is still a challenge [14] that more battery lifetime tests need to be carried out to improve the understanding of the damage mechanisms and to further validate the models. Some of these tests should isolate specific damage mechanisms or the impact of different operating conditions, such as the variable impact of cyclic use at different depths of discharge [15]. The need for increased energy and power density and longer cycle life has spurred much research and development towards more efficient batteries and has also called for more effective battery management systems that monitor and control cell voltages and temperatures [16]. This study analysed battery charging performance using 12 volts PV cells with a designed system

specifically at different set ups such as: a) at different amount of cloud cover in the atmosphere; b) with different capacity of solar battery, and it
analysed voltage behaviour during battery relaxation

II. METHODOLOGY

The materials used, data gathering procedure and the designed system are the important factors considered to conduct this study.

A. Materials used

The materials used are the following: solar panels with 3-50 watts and 4-100 hundred watts capacity, electrical wire, electrical tape, 30 amperes charge controller, two 12 volts, 100 AH deep cycle lead acid batteries with one of condition and the other is a dead battery. Dead battery occurs when the plates of the battery eventually become coated with non-reactive material making them difficult or impossible to recharge [17] while in practice once the plates of a battery were dead, the battery is discarded and a new one is installed since dead cells cannot be fixed [18]. Digital multimeter was used to measure the voltage.

B. Data gathering procedure

The data were gathered by taking the voltage reading from two set ups: a) when the dead battery was connected in the system and b) the functional battery was connected. The time interval in reading the voltage reading was for every 30 minutes. In measuring the voltage, the open circuit voltage (OCV) was applied which is generally defined as the voltage between the terminals of an electrochemical cell when no current flows through the cell [19]. As it can be measured directly, it is used as a control tool in electrochemical energy storage devices [20].

C. The designed system

The solar panels are connected in parallel shown in the diagram below (See Figure 1). With the designed system, the total voltage of the connected panel is equal to the voltage of the individual panel while the total power is the sum of the power of the individual panel and the total current is the sum of the individual current produced by the panel [21] so that the equations are written as:

total current (I_T)
total voltage
and total power

$$I_T = I_{M_1} + I_{M_2} + I_{M_3} \dots$$

$$V_T = V_{M_1} = V_{M_2} = V_{M_3} \dots$$

$$P_T = P_{M_1} + P_{M_2} + P_{M_3} \dots$$

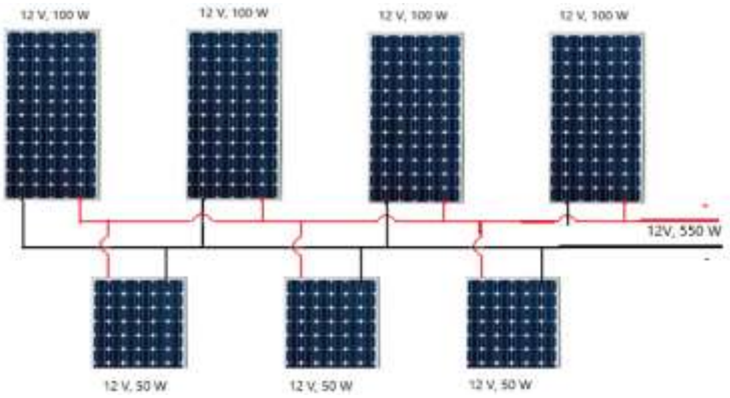

Figure 1. The designed system diagram for solar panel in parallel connection

Theoretically, the designed system based from the equation produced a total voltage of 12 volts (V) and a total power of 550 watts (W). Among the parameters that were considered are the charging performance and the Voltage reading during battery relaxation. The result was interpreted by mathematical modelling and differentiation

III. RESULT AND DISCUSSION

A. Charging performance of the batteries

The dead battery charge positively during first one hour of charging however the charging direction fluctuates in the preceding time demonstrating that to attain the targeted maximum voltage is difficult. The functional battery charge positively except on an isolated case that the temperature decreases, however the decrease was very minimal (See Table 1). Worth highlighting of the event is when firstly, although the charging levels nominally correspond to 10% increments in initial state of charge, defining 'full depletion' as the point at which the manufacturer-specified cut-off voltage is reached has limitations [22]. The condition may be affected that during a charge at a constant voltage, the charge acceptance of the battery decreases following asymptotic profile that can be related to the decrease of the reaction interface area and the increase of the acid sulfuric concentration in the pores of the active material demonstrating that the discharge is stopped when the cell voltage reaches a voltage limit which is called the end-of-discharge voltage, however, for the negative electrode, deep discharges are critical because of the danger of reversal [23]. End-of-discharge for new battery is fixed by the battery manufacturer in order to avoid deep discharges and the risk of battery polarity inversion, which are critical for both electrodes [24]. The end of life (EOL) is related to the concept of failure in global terms, which can be defined as the fact of something not working or no longer working as well as it should while it was clarified that the end of life is dependent on the

Table 1. Charging Performance of the Batteries

Time AM	Dead battery at clear atmosphere			Functional battery at cloudy atmosphere			Functional battery in clear atmosphere	
	V	ΔV	T (°C)	V	ΔV	T (°C)	V	T (°C)
6:00	6.98	0	28	9.67	0	22	10.48	28
6:30	7.59	+0.61	30	11.10	+1.43	24	11.58	30
7:00	7.60	+0.01	34	11.80	+0.70	25	11.58	31
7:30	6.82	-0.78	32	11.93	+0.13	26	11.59	33
8:00	6.82	0	32	11.94	+0.01	26	12.17	34
8:30	6.81	-0.01	35	11.99	+0.05	27		
9:00	6.81	0	35	11.92	-0.07	24		
9:30	6.83	+0.02	37.50	11.95	+0.03	24		
10:0	6.82	-0.01	37.50	12.02	+0.07	24		

battery characteristics as well as on the application specifications [25]. From low voltage (V) reading the functional battery when charge during cloudy and non-cloudy atmosphere was able to attain the targeted maximum voltage. However, it takes four hours to attain the targeted voltage during cloudy atmosphere compared to only two hours when the atmosphere is clear. Although the effect is immediate, heavy cloud blocks the direct component of the solar irradiance resulting to minimum value of daily energy [26].
By taking the voltage (V) reading in the table as the y axis and the time of charging as the x axis, the derived mathematical model for the dead battery is a straight-line formula which is expressed by the straight-line equation (See figure 2):

$$y = -0.418x + 7.1069$$

The negative sign demonstrates that the voltage decreases as the battery was being charged. By finding the derivative of the equation, it appeared to become:

$$\frac{dy}{dx} = -0.418$$

The change in voltage reading (ΔV) in the dead battery is decreasing of 0.418 V/Hr while being charged. Batteries can be quickly discharged when the renewable energy source is no longer present for a while. Overloading or subjecting to high temperatures affects its longevity, thus improvement for small autonomous energy system reliability was suggested that include reduction of heat and excess charges [27]. But in the case of the dead battery, self-discharging is more dominant than collecting the energy. Although, it is widely known that battery operation at elevated temperature (T) generally induces faster degradation of capacity over cycles, but the thermal history of the battery should be carefully considered because it remains and continues to affect the self-discharge rate afterwards [28].

B. Charging performance

The functional battery was able to attain the targeted voltage within four hours in cloudy atmosphere. Starting from 10.48 V reading at 6:00 AM that eventually was upgraded to 11.58 at 6:30 AM and was able to gain up to 12.17 V at 10:00 AM. This shows that even at early morning with cloudy atmospheric condition, the battery has the capacity to collect energy. The mathematical model for functional battery when charged at cloudy atmosphere is expressed by the equation:

$$y = 0.2042x + 10.57$$

while when it was charge in clear atmosphere, the equation is:

$$y = 0.4537x + 10.195$$

The derivatives of the battery being charged with cloudy atmosphere is:

$$\frac{dy}{dx} = 0.204$$

while in clear atmosphere is:

$$\frac{dy}{dx} = 0.4537$$

The equation demonstrates that the battery was able to charge in cloudy atmosphere at 0.204 V/Hr and with clear atmosphere at 0.4537 V/Hr. Even if the charging activity was started at early 6:00 AM, the battery with cloudy atmosphere was able to charged fully with four hours while in clear atmosphere was within two hours. The charging time is better if compared using an electronic device charging station which were able to reduce the total charging time of the battery by half from 6.67 hours to 3.33 hours [29] or when using a single solar cell that could fully charge in 3 hours of solar irradiation [30].

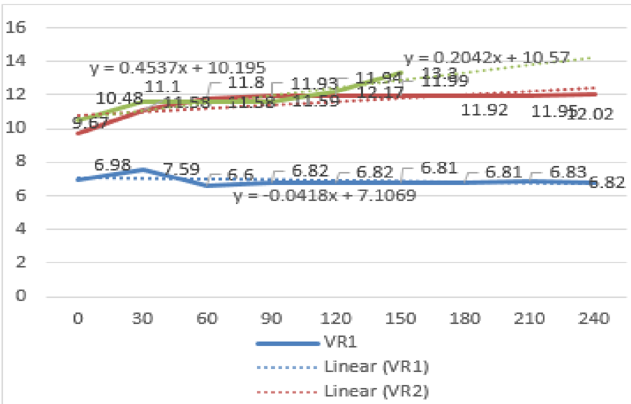

Figure 2. Voltage reading against time for dead and functional battery

C. Voltage behavior during battery relaxation

After the end of a charging or discharging sequence, the battery voltage keeps evolving towards a finite value, during hours or even days, although no current is exchanged with the battery and this corresponds to the battery relaxation [31]. Battery relaxation is completely different for dead and functional battery. It was found that in four hours of observation, the change in voltage reading (ΔV) in the dead battery is decreasing that may be a result due to self-discharging but it was stated that it may take over 24 hours before the battery voltage stabilizes [32]. The functional battery is at stable condition.

Table 2. Voltage reading during Battery relaxation at 30 minutes interval

Time (Hrs.)	Dead Battery		Functional Battery	
	V	ΔV	V	ΔV
0	10.99	0	12.02	0
0.50	9.35	1.64	12.02	0
1.00	9.05	0.30	12.02	0
1.59	8.98	0.07	12.02	0
2.00	8.92	0.06	12.02	0
2.50	8.85	0.07	12.02	0
3.00	8.83	0.02	12.02	0
3.50	8.74	0.09	12.02	0
4.00	8.49	0.25	12.02	0

Self-discharge leads to a capacity loss with time [33] while the phenomena are caused by the electrochemical reactions between the active materials in the plates, the electrolyte, the current collector, the separator, and other components in the cell or by the ohmic leakage currents [34].

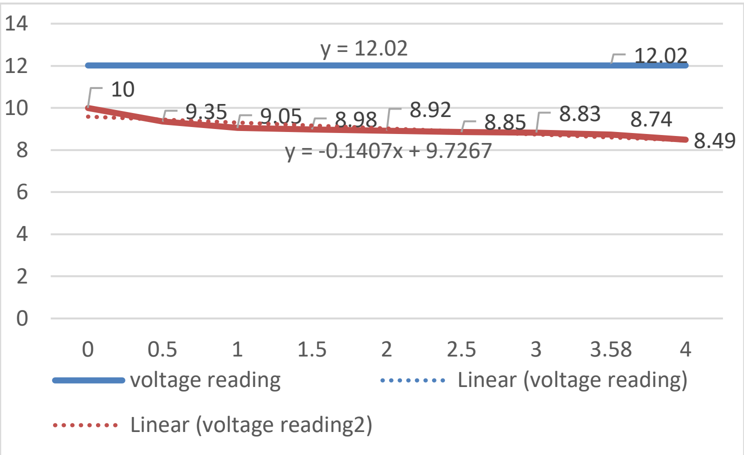

Figure 3. Voltage reading during battery relaxation at 30 minutes interval

Figure 3 demonstrated that the voltage reading during battery relaxation of the dead battery is decreasing within four hours of observation. The straight-line equation is:

The negative sign indicates that the voltage is decreasing. However, when the derivative is applied, the equation becomes:

$$\frac{dy}{dx} = -0.1407$$

which means that the rate of self-discharge in four hours of battery relaxation is 0.1407 volts per hour. Self-discharge is usually quantified in terms of capacity loss, although other performance values are sometimes used in which the phenomena may cause reversible or irreversible changes inside the battery system that during battery relaxation may be caused by the reaction of charged active material with the solution, the grid, or other components in the cell [35]. The voltage reading during battery relaxation of the functional battery is horizontally straight within four hours of observation. The straight-line equation is:

$$x = 12.02$$

The derivative of equation for battery relaxation of the functional battery is:

$$\frac{dy}{dx} = 0$$

Which means that within four hours of observation, no changes occur in the voltage reading of the battery. It does not increase nor decrease. The self-discharge of lead acid batteries was shown to be affected by battery voltage, temperature, antimony alloy concentration and the prevailing mass transfer mode while another factor is battery aging [36]. Being new could be the reason for the voltage of the battery at equilibrium state during battery relaxation. Since self-discharge is a naturally occurring phenomena in lead-acid batteries, there exists a need for developing a better understanding of this effect and for generating some quantitative methods for predicting its consequences [37].

CONCLUSIONS

The designed system which is composed of four 12V, 100W and three 12V, 50W was connected in parallel to produce a total of 12V, 550W energy is capable of charging 12V, 100AH battery within four hours when the atmosphere is cloudy and is shorten to two hours in clear atmosphere even if the charging time is started at early 6:00AM. However, the event is not applicable for the dead battery. During battery relaxation the battery is in equilibrium situation within four hours of observation that the voltage reading does not change while in dead battery the voltage reading is decreasing. It was recommended to conduct more study particularly on the lifespan of the battery using the designed system of charging.

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