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An Experimental Study on Deep-Cycle Battery Charging Methods

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Abstract:* Deep cycle batteries can be recharged in a variety of different ways. The most common methods are the use of solar panels via a solar charge controller and the use of an external charging unit connected to a source of electrical power. This paper experimentally studied the characteristics of solar system and the utility power supply methods of charging deep-cycle battery. Investigative study were carried out to experimentally explore the strength and weaknesses of the two charging methods with a view to identify their impact on the performance of deep-cycle battery. The methodology employed for the study is measurement and instrumentation method. Handheld digital clamp meter were used for direct measurement of the charging parameters. MATLAB software were used to analyzed the data and results were presented in tabular and graphical forms. Experimental result shows that charging deep-cycle battery using solar panels takes longer time than the utility power supply, while battery that were fully charged using the utility power supply discharges faster. The study explored that charging deep-cycle battery using solar panels prolong the useful life time of the battery, thereby considered economical. The presented results help engineers to better choose a more suitable charging method based on the design requirements and the system constraints that they are facing.

***Keywords:* Photovoltaic cell, Utility Power Supply, Deep-cycle Battery, Measurement and Instrumentation.**

I. INTRODUCTION

Solar batteries are really deep-cycle batteries that provide energy storage for solar, wind, grid-backups and other renewable energy systems. They are ideally suited for these applications because of their long and reliable life [1] [2] [14]. Essentially there are two things that quickly and easily destroy battery: either undercharging or overcharging [3]. Deep cycle batteries are simply containers for a number of lead-plates, filled with sulfuric acid. Undercharging them ultimately causes lead sulfate to accumulate on the plates and eventually destroy the battery because the normal chemical reaction will be unable to continue [4] [15]. On the other hand, overcharging the battery accelerate the natural corrosion of the plates due to excess electrons being literally boiled out of the electrolyte [4] [5]. It is far easier to discharge battery than to recharge. Both the charge and discharge of batteries involve significant inefficiencies. As a rule of thumb for each ampere hour of power taken out of a battery 1.5 amp hours must be replaced [6]. In order to complete the chemical process, which recharges a battery the electrolyte, must reach 104°F [6] [7].

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The method used to 'heat up' the electrolyte is the application of charging current (amps) to a discharged battery. If insufficient charge is applied to bring the electrolyte to this temperature the batteries will never fully recharge, and over time, their capacity will be reduced [8] [9]. Once a battery is fully charged, the charging current has to be dissipated somehow. The result is the generation of heat and gasses both of which are bad for batteries. The essence of good charging is to be able to detect when the reconstitution of the active chemicals is complete and to stop the charging process before any damage is done while at all times maintaining the cell temperature within its safe limits [10] [11] [12]. Detecting this cut off point and terminating the charge is critical in preserving battery life. In the simplest of chargers this is when a predetermined upper voltage limit, often called the termination voltage has been reached. This is particularly important with fast chargers where the danger of overcharging is greater. However, the lifespan of a deep cycle battery will vary considerably with how it is used, how it is maintained and charged, temperature, and other factors [13] [16]. On this note, this paper consider charging and temperature as major factors which are affecting the use life period of deep-cycle battery. The paper is determined to experimentally investigate the effect of solar panels and utility power supply charging methods on the performance of deep-cycle battery.

II. MATERIALS AND METHOD

The materials used in this study are 1KVA PV array, 20 Amps charge controller, 1KVA inverter, 2 number deep-cycle batteries, constant utility power supply and installation accessories. The methodology employed is measurement and instrumentation method described below.

- Provision of 1KVA inverter with inbuilt charging facility were made.
- A 1KVA solar array were assembled and installed.
- Provision of 2 number, same product, 12V deep-cycle batteries were made.
- The two batteries were discharged to almost 0%.
- One battery was connected to the solar array via charge controller and the other battery was connected to the utility power supply via the inverter concurrently.
- After 30 minutes, the two batteries were disconnected and allow to settled for 5 minutes.

- The battery voltage, charging voltage, charging current, ambient temperature for the two exercises were measured and recorded.
- The two batteries were reconnected back to their respective source of charging for another 30 minutes.
- Then, activity No. 6, 7 and 8 were repeated six times daily for 4 days consecutively.
- Before the next day, the two batteries were discharge to 0% with equal loads connected to each battery.
- During the discharge, their discharging time and levels of discharge were measured and recorded.
- The average of the 4 days data were analyzed using MATLAB software. Result was presented in tabular and graphical forms.

III. DATA COLLECTION

Tables 1(a&b) to 4(a&b) below presents the data collected from solar panels and the utility power supply methods of charging deep-cycle battery for 4 days consecutively.

Day One:

Table 1 a: Charging Parameters Using Solar Panels

Time	Ambient Temp. (^{0}C)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00 AM	25	11.15	6.75	10.92	0
11:40 AM	26	11.43	5.5	11.32	0
12:20 PM	27	11.66	4.7	11.54	0
1:00 PM	28	11.82	3.3	11.78	0
1:40 PM	28	11.89	2.5	11.85	10
2:20 PM	29	12.03	2.1	11.93	20
3:00 PM	30	12.34	1.56	12.18	30

Table 1b: Charging Parameters Using Utility Supply

Time	Voltage Supply (AC)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00 AM	217	11.23	12.1	10.71	0
11:40 AM	198	11.5	12.3	11.37	10
12:20pm	207	12.05	12.5	11.78	20
1:00 PM	210	12.59	12.6	12.32	60
1:40 PM	216	12.64	12.7	12.62	70
2:20 PM	223	12.69	12.8	12.67	90
3:00pm	203	12.87	12.6	12.71	100

Day Two:

Table 2a: Charging Parameters Using Solar Panels

Time	Ambient Temp. (^{0}C)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00am	24	11.49	7.7	11.34	0
11:40am	25	11.71	6.6	11.63	0
12:20pm	26	11.82	6	11.78	0
1:00pm	27	11.94	5.8	11.86	10
1:40pm	28	12.06	5.4	12.01	20
2:20pm	29	12.17	4.7	12.1	30
3:00pm	30	12.34	2.4	12.23	40

Table 2b: Charging Parameters Using Utility Supply

Time	Voltage Supply (AC)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00am	200	11.2	11.9	10.57	0
11:40am	219	11.45	12.1	11.33	0
12:20pm	222	12.3	12.2	11.88	10
1:00pm	212	12.56	12.3	12.43	60
1:40pm	215	12.78	12.4	12.67	90
2:20pm	199	12.89	12.5	12.84	100
3:00pm	208	13	12.4	12.95	100

Day Three:

Table 3a: Charging Parameters Using Solar Panels

Time	Ambient Temp. (^{0}C)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00am	27	11.11	6.5	10.89	0
11:40am	28	11.43	6.3	11.32	0
12:20pm	28	11.67	6.1	11.54	0
1:00pm	29	11.82	5.7	11.79	0
1:40pm	30	11.96	5.4	11.85	10
2:20pm	31	12.11	4	12.06	20
3:00pm	31	12.24	1.8	12.16	30

Table 3b: Charging Parameters Using Utility Supply

Time	Voltage Supply (AC)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)

11:00am	189	11.47	11.8	10.67	0
11:40am	200	11.98	11.9	11.73	0
12:20pm	223	12.06	12	12.02	20
1:00pm	215	12.32	12.1	12.19	30
1:40pm	204	12.48	12.3	12.37	60
2:20pm	210	12.67	12.4	12.58	80
3:00pm	207	12.84	12.4	12.76	100

Day Four:

Table 4a: Charging Parameters Using Solar Panels

Time	Ambient Temp. (^{0}C)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00am	26	11.17	6.9	10.89	0
11:40am	27	11.47	6.6	11.35	0
12:20pm	28	11.71	5.7	11.59	0
1:00pm	29	11.85	4.8	11.83	0
1:40pm	30	11.98	3.2	11.87	10
2:20pm	31	12.14	2.8	12.09	20
3:00pm	32	12.26	2.2	12.18	30

Table 4b: Charging Parameters Using Utility Supply

Time	Voltage Supply (AC)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00am	218	11.15	12.1	11	0
11:40am	209	11.4	12.3	11.28	0
12:20pm	198	12.05	12.4	11.73	0
1:00pm	201	12.2	12.5	12.13	30
1:40pm	217	12.36	12.5	12.28	50
2:20pm	220	12.49	12.6	12.43	60
3:00pm	215	12.67	12.5	12.58	80

IV. RESULT OBTAINED FROM SOLAR PANELS

Table 5 below presents the average values of charging current and voltage from solar panels, ambient temperature in ^{0}C, battery voltage level as well as the state of charge.

Table 5: Average DC Charging Current and Voltage from Solar Panels

Time	Ambient Temp. (^{0}C)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)

11:00am	25	11.23	6.96	11.01	0
11:40am	26	11.51	6.25	11.41	0
12:20pm	27	11.72	5.63	11.61	0
1:00pm	28	11.86	4.9	11.82	10
1:40pm	28	11.97	4.13	11.9	20
2:20pm	29	12.11	3.4	12.05	30
3:00pm	30	12.3	1.99	12.2	40

Result presents that at 11:00hrs to 12:20hrs (i.e 1 hour, 20 minutes interval) the state of the charge is at 0%. However, at 13:00hrs the state of the charge increase to 10% and continue to increase by 10% at an intervals of 40 minutes. Similarly, figure 1 and 2 below shows the behaviors of the charging current and voltage. It also present the state of the battery charge in which the charging current decreased with increase in the charging voltage.

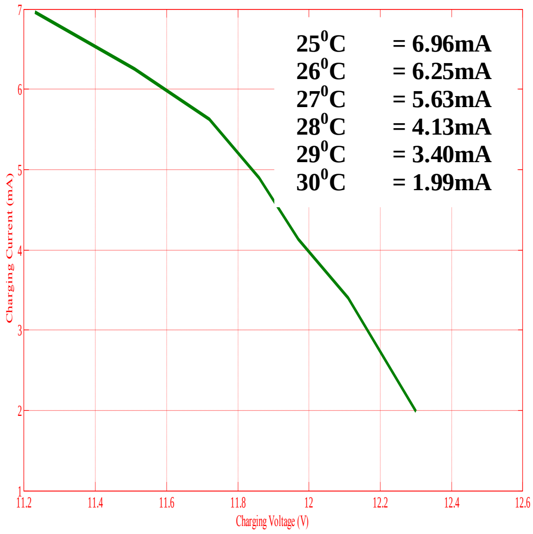

Fig 1. I - V Characteristics Curve of PV Module

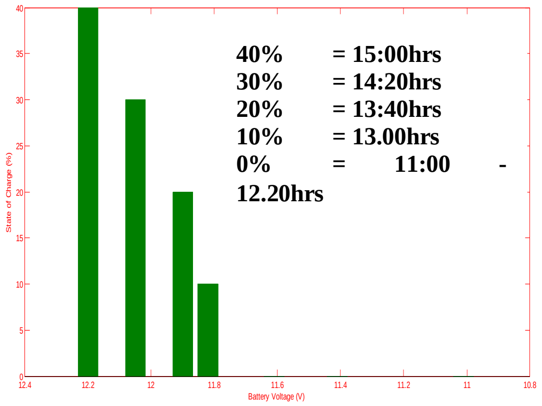

Fig 2: PV Module Battery Charge levels with Time

Conclusively, after 4 hours of the whole experiment from 11:00am to 3:00pm, the maximum charge level obtained is 40%. This indicate that at average of 28^0C of ambient temperature the battery is expected to charge for 10 hours before it will reach 100% charge level.

V. RESULT OBTAINED FROM UTILITY SUPPLY

Table 6 below presents the average values of charging current and voltage from the utility power supply, ambient temperature in ^{0}C, battery voltage level as well as the state of charge.

Table 6: Average DC Charging Current and Voltage from Utility Power Supply

Time	Voltage Supply (AC)	Charging Voltage (V)	Charging Current (mA)	Battery Voltage (V)	State of Charge (%)
11:00am	218	11.26	11.98	10.71	0
11:40am	209	11.58	12.15	11.43	0
12:20pm	198	12.12	12.28	11.85	10
1:00pm	201	12.42	12.38	12.27	40
1:40pm	217	12.57	12.45	12.49	70
2:20pm	220	12.69	12.6	12.63	90
3:00pm	215	12.85	12.64	12.75	100

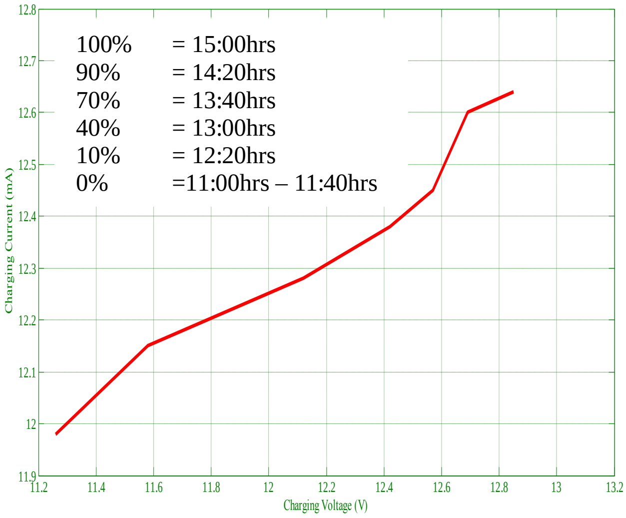

Fig 3: I – V Characteristics Curve for the Utility Supply

Figure 3 and 4 above presents the graph of charging current and voltage, state of the battery charge against time. Result presents that increase with time, while the charging voltage increase or decrease is directly proportional to the AC voltage supply. However, result presented that from 11:30hrs to 11:40hrs the battery charge level moved from 0% to 10%. However, the subsequent 40 minutes the charge level shoot to 40%, 70%, 90% and 100% at 15:00hrs respectively.

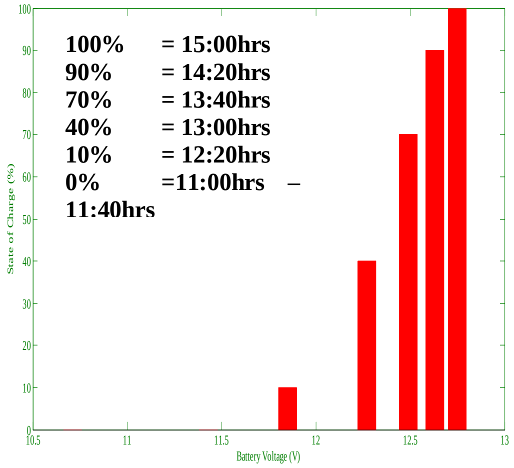

Fig 4: Battery Charge and Voltage levels with Time using Utility Supply

VI. DISCUSSION

Findings confirmed that the state of battery charge using both the solar modules and the utility power supply is directly proportional to the amount of charging current. Charging current from solar panels decrease with increase in ambient temperature and the charging voltage. Similarly, increase or decrease in the charging current from the inverter connected to the mains is directly proportional to AC power supply. The study confirmed that using solar modules at average ambient temperature of 28^0C, the battery is expected to be 100% charged in 10 hours while using the utility supply it will be at 100% charge in 3 hours. Meaning that charging battery using solar modules takes longer time to recharge a battery than using utility power supply. On the other hand, battery that were recharged with the utility power supply discharges faster.

VII. CONCLUSION AND RECOMMENDATION

This paper has successfully analyzed the solar system and the utility power supply methods of charging deep-cycle battery experimentally. The study confirmed that charging solar deep-cycle battery with solar modules is safer and economical, but slower. It prolong the useful life time of a battery because of its slower rate of charging and discharging. However, charging using the utility power supply is faster, discharged faster and increases the failure rates of battery. The study concluded that charging deep-cycle battery with solar panels is the best, safe, and economical method of charging than using inverter via AC supply. The study recommends that future studies should carry out a comparative study between solar system and solar-hybrid methods of charging deep-cycle battery.

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