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Charging of Batteries and Checking their Autonomy with Variable Stand-Alone Photovoltaic Systems in Field Conditions

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Abstract* — *Solar energy is a vital that can make environment friendly energy more flexible and commercially widespread. As Sun is not available the whole day and during cloudy days, storage of electricity is required. Storage batteries are expensive and so are the solar photovoltaic (PV) panels. Hence, it is imperative that each stand-alone PV system is suitably designed depending on load (resistive) and autonomy requirements. In this work, 2 KW to 5 KW stand-alone photovoltaic systems for variable load requirements for charging of batteries is studied. Experiments are done to change the PV string size and number of strings to see its effect on actual charge delivery. The experimental setup has been made in which panel string size, batteries capacity and load may be varied.

Index Terms* — *Batteries, Photovoltaic (PV) Panels.

I. INTRODUCTION

Fossil fuels like gas and oil are not renewable source of energy as they cannot be used again they are gone. There are many Eco-friendly energy sources like wind and solar. One of the important applications of renewable energy technology is the installation of photovoltaic (PV) systems using sunlight to generate electricity without releasing any additional pollutants. As Sun is not available throughout the year, batteries are required for energy storage. The use of batteries is necessary to reduce the influence of the fluctuation of solar power [1]. To do charging and seeing the autonomy provided by the batteries, 20 modules of 250 Wp standard rating each are used. Battery bank of 96V, 600AH capacity is used with 5KW system. Battery capacity is varied 96V, 400AH and 96V, 200AH as per load requirements. Experiments are done to change the PV string size and number of strings to see its effect on actual charge delivery. The experimental setup has been made in which panel string size, batteries capacity and load may be varied.

II. EXPERIMENTAL SETUP

Stand-alone PV systems can be used to power homes in remote areas, where majority of population does not have access to electricity. To perform the experiment 20 modules of 250 Wp rated power, 35.7V maximum power voltage (V_{MP}), 7.65A maximum power current (I_{MP}), 8.07A short circuit current (I_{SC}), 45.1V open circuit voltage (V_{OC}) and 1000V maximum system voltage, measured at standard test condition (STC) are used. Initially, 5KW PV system was installed with battery bank of 96V, 600A-H capacity. Battery capacity is varied 96V, 400A-H and 96V, 200A-H as per load requirements. The experimental setup has been made in which batteries capacity and load may be varied. Stand-alone PV system is shown in Fig.1.

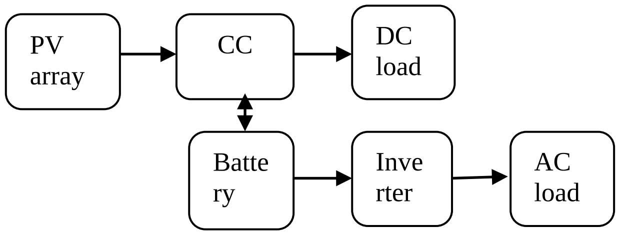
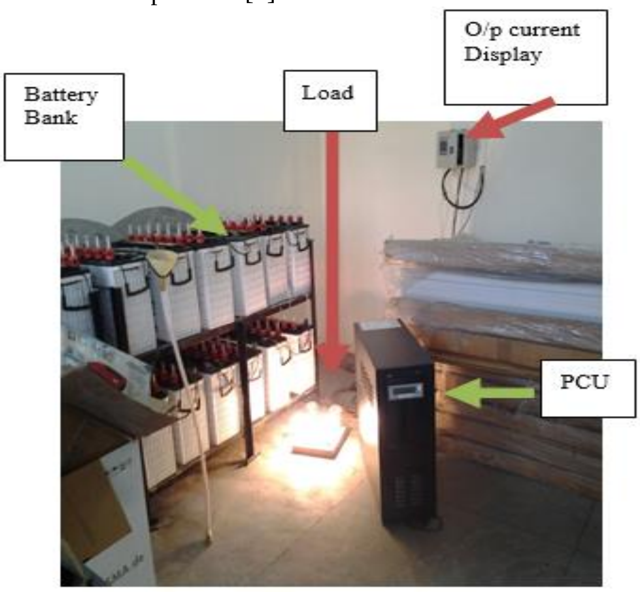


Fig. 1. Block diagram of stand-alone PV system

The Stand-alone PV system is composed of PV modules, battery bank, power conditioning unit (inverter, charge controller (CC) etc.) and load. The solar array sizing and battery capacity needed will depend upon the load demand and environmental conditions at the site. The size of this storage capacity is described as the ampere-hour (A-H) rating of a battery. The PV generation depends upon the shading condition. PV operation is most efficient at high irradiation and at low temperature [2].



(a)

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(b)

Fig. 2 Captured photo of Experimental setup (a) indoor system components, (b) Outdoor stand-alone PV panels

In the experiment, load is varied by 200W, 400W, 800W and 1KW, battery bank is varied by 200AH and 400AH, PV array is also varied by 2KW, 3KW, 4KW and 5KW.

III. WORKING

Initially, the batteries are charged without load means in this case, the charging time of the battery remains same for a particular capacity battery as load is not running along with charging process. Discharging time of batteries totally depends upon the load. Lead acid batteries are used in the experiment. The size of the battery plates and amount of electrolyte determines the amount of charge lead acid batteries can store [3]. The size of this storage capacity is described as the ampere-hour (A-H) rating of a battery.

A 96-volt battery having 200 A-H rating means that it can supply 10 amps of current for 20 hours or 20-amps of current for 10 hours. Lead acid batteries can be connected in parallel to increase the total A-H capacity and connected in series to increase the total voltage. A 96V, 600A-H lead-acid battery is used which is used as two parts each of 96V but with different capacity such as 200A-H and 400A-H.

The charging of battery depends on its capacity as well as on load i.e. 400A-H battery bank, batteries will take little more time to be charged as compared to 200A-H battery. The battery autonomy will also be more in case of 400A-H as compared to 200A-H but this will result in additional battery cost. In lead-acid cells, the electrolyte (sulphuric acid) participates in the cell's normal charge/discharge reactions. As the cells are discharged, the sulphate ions are bonded to the plates — sulphuric acid leaves the electrolyte. The process is reversed when the cell is recharged [4].

Theoretically batteries should be charged according to current between C/20 and C/10 rate which means that 200A-H and 400A-H batteries should not be charged by more than 20A and 40A current respectively. If the array current is not limited according to the C/20 or maximum C/10 rate than the batteries will get overcharged and this will create problem in charging as well as in discharging. The upper cut-off voltage i.e. 117V and lower cut-off voltage i.e. 86V is set in the charge controller to prevent the batteries from over charging and deep discharging. Theoretically, the autonomy or the discharge time of the battery can be calculated by formula (1), (2) & (3).

Total DC energy = (upper cut-off voltage of battery) * (Battery Capacity used) (1)

Battery can be discharged only 20% and about 80% of battery remains charged always to avoid battery from deep discharge.

Watt-Hour available = Total DC energy * 0.2 (2)

Discharge time = (Watt-Hour available) / (Total Load running from the battery) (3)

IV. RESULTS AND DISCUSSION

In the experiments, nominal battery arrays voltage is 96V. During charging, battery voltage can go to maximum of 117V at full charge and decreases to 86V at cut off. Battery capacity could be varied from 200AH or 400AH. The battery voltage was fixed at 96V keeping in view the 5KW inverter setting. The experimental results which are presented here are: Charging of battery without load, discharging of the battery at different capacity with varying load and PV array size.

A. Charging of Battery

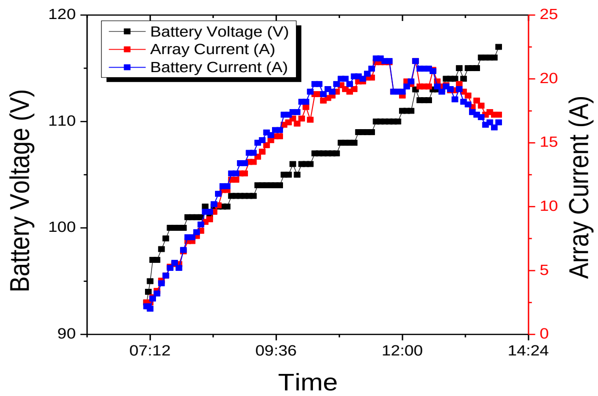

Fig. 3 Charging curve of 400AH battery with 3KW system

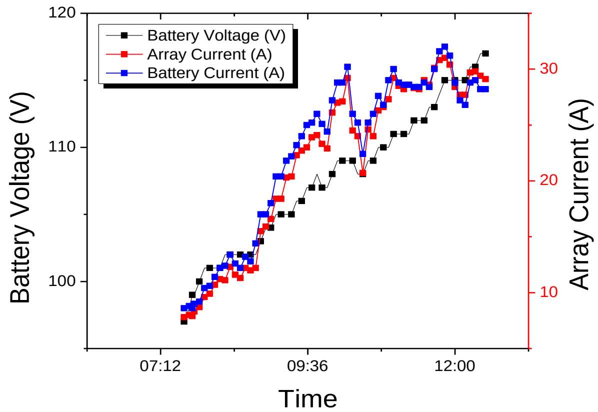

Fig. 4 Charging curve of 400AH battery with 4KW system

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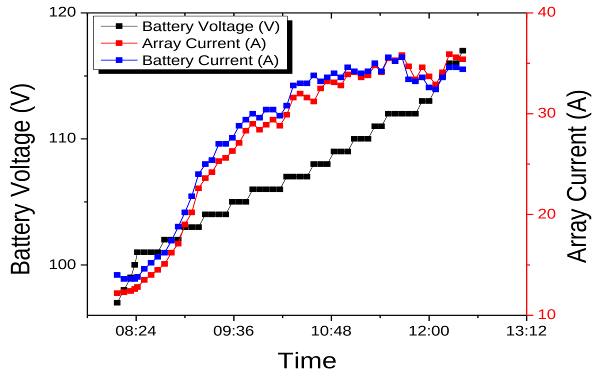

Fig. 5 Charging Curve of 400AH battery with 5 KW systems

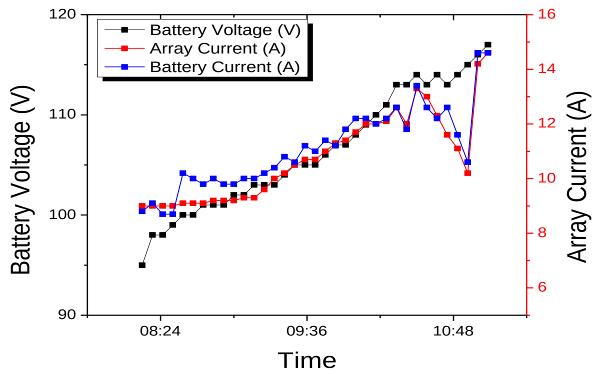

Fig. 6 Charging Curve of 200AH battery with 2 KW system

From the above charging curves, it is clear that while charging batteries without load array current is almost equal to the battery current as entire array current is used to charge the battery only. Charging time completely depends upon the solar irradiation. If battery is charged with load then it will take more time as compared to charged without load, as some of the array current is used to run the load along with charging the battery. Charging data of battery with solar irradiation (W/m^2) is summarized in Table I.

Table I Charging data of battery without load

Battery Capacity (A-h)	PV array size(KW)	Charging Time (hrs)	Charging Voltage V(from-to)	Radiation
200	2	2 hrs 50 mins	93V-117V	315.20-967.32
400	3	6 hrs 45 mins	93V-117V	201.54-840.02
	4	4 hrs 55 mins	93V-117V	421.45-1068.7
	5	4 hrs 20 mins	93V-117V	320.32-957.28

B. Discharging of Battery

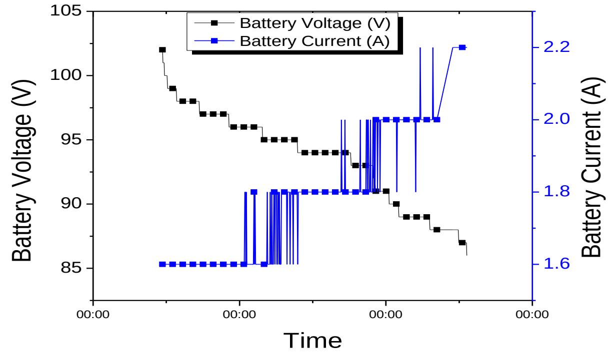

Fig.7 Discharging curve of 400AH battery using 200W load

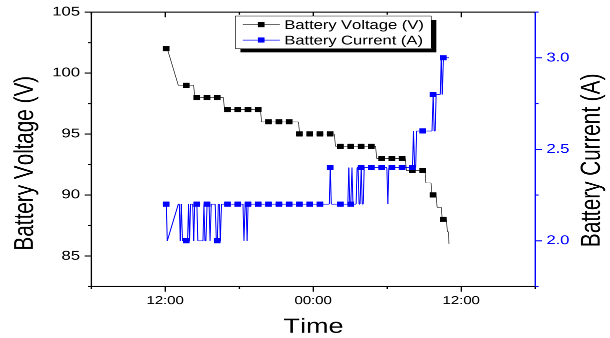

Fig. 8 Discharging curve of 200AH battery using 200W load

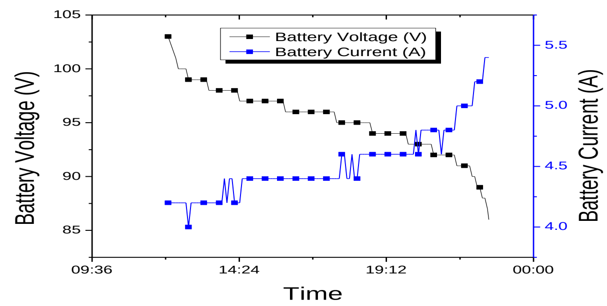

Fig. 9 Discharging curve of 200AH battery using 400W load

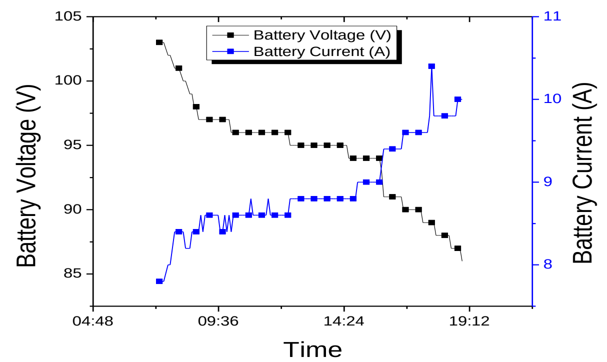

Fig. 10 Discharging curve of 400AH battery using 800W load

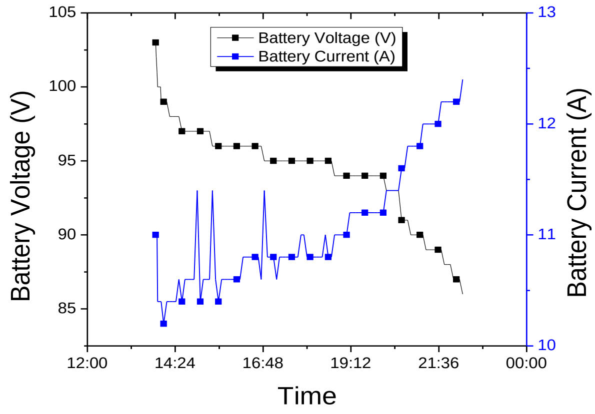

Fig. 11 Discharging curve of 400AH battery using 1KW load

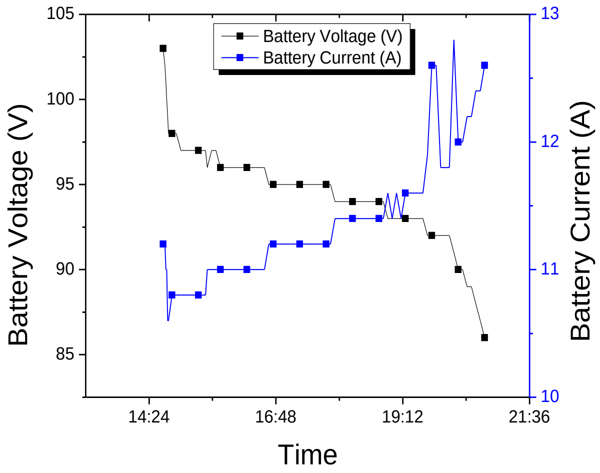

Fig. 12 Discharging curve of 200AH battery using 1KW load

It is clear from the above discharging curve that when battery voltage decreases, battery current increases. Battery gets discharged upto 86V, which is the minimum voltage at which inverter turns off automatically. Experimental and theoretical discharging data of battery is summarized in Table II.

Table II Discharging data of battery

Battery Capacity (A-h)	Load (W)	Load current	Discharging Voltage V(from-to)	Experimental Discharging Time (hrs)	Theoretical Discharging Time (hrs)
200	200	0.651 or 3%	102V-86V	23 hrs 03 mins	23.4 hrs
	400	1.41 or 6%	102V-86V	10 hrs 28 mins	11.7 hrs
	1000	3.572 or 16%	103V-86V	5 hrs 55 mins	4.68 hrs
400	200	0.628 Or 3%	102V-86V	49 hrs 58 mins	46.8 hrs
	800	2.795 or 12%	103V-86V	11 hrs 35 mins	11.7 hrs
	1000 (1KW)	3.572 or 16%	103V-86V	9 hrs 20 mins	9.36 hrs

400AH battery while running 200W load is capable of providing 2 days autonomy. Whereas, 400AH and 200AH battery while running 400W and 200W load respectively, provide 1 day autonomy. Rest of the cases provides less than day autonomy. From all above discharging results it is clear that experimental values for battery discharging time are different from theoretical values. Discharging time depends upon the load. Charging time depends upon solar irradiation, when solar irradiation is more than battery is charged at faster rate and vice-versa when solar irradiation is low.

V. CONCLUSION

The charging time and discharging runtime for different battery capacities and under different load conditions have been studied. As per the stipulated charging current limits of batteries between C/20 and C/10, 200A-H battery have to be used with 2KW PV system and 400A-H battery can be used with 3KW, 4KW and 5KW PV systems. The resistive load is varied to 200W, 400W, 800W and 1000W to find out the run time of the fully charged batteries. Theoretical and experimental values are analysed for all the above cases. The experimental values closely match with that of theoretical values. Further it is observed that the battery charging time depends upon the solar irradiation available on the day and battery discharging depends upon load.

VI. ACKNOWLEDGMENT

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Sumedha Sengar, M.Tech from Banasthali Vidyapith, B.Tech from UPTU in 2012, Published two papers in International Conferences i.e. one held in JNU, New Delhi and another in IIT, Kanpur in 2014, done one year research (dissertation) work in IIT, Kanpur on stand-alone Photovoltaic systems.

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