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NEW TECHNIQUE FOR DETERMINING BATTERIES SERIES RESISTANCE

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ABSTRACT

In this paper the electrical behavior of lead acid battery (LAB) energized by solar cells array is investigated. The internal series resistance of the battery under test is experimentally determined. The electrical performance of the battery under discharging condition through resistive load and its series resistance are also experimentally obtained. The open-circuit condition of the battery during charging and discharging are investigated and analyzed. Mathematical models for internal series resistances under charging and discharging conditions are determined.
Keywords: Microcontroller, Photovoltaic, BATTERY.

INTRODUCTION

The processes taking place during discharging of a lead acid cell are described by migrating to the negative electrode H2SO4 ions and react with the lead to produce PbSC > 4 and ions. This reaction releases two electrons. On the other hand, at the positive electrodes the lead of the PbOj is also converted to PbSO4 and water is formed. The above processes are reversed during the charging process [Rond. D.A.J. 2008].

Although specialized Photovoltaic (PV) batteries are now becoming available on the market, most of them that are currently installed in PV systems are standard components originally intended for conventional application, or adapted from them to suit the particular mode of operation envisaged for the PV system [Kkalhammer. F.R. 2001]. The battery storage configuration has a great effect on the capacity. The capacity can be improved by using the parallel configuration with shallow cycle batteries, the dual configuration with shallow cycle and the dual configuration with deep cycle batteries [Margaret. Casacca, 2006].

A mathematical model is built up after a series of experimental tests for lead acid battery for specifying its performance. The mathematical functions of the battery components were developed through examinations of the graphic plots of the experimental data, manufactures specifications. Ohm's law is used to calculate voltage drops across series resistance and current drops through parallel resistors [Ziyad M. Salameh, *et al*., 2012 and Margaret A. Casacca and Ziyad M. Salameh, 2007].

The discharge performance of starved-electrolyte sealed-lead cells and batteries is one of their strength. Taking advantage of this asset requires understanding the influence that use parameters and environmental factors may have on the resulting discharge. The discharge should be allowed to continue long enough to take advantage of the battery's long voltage plateau on discharge, but the discharge should be terminated before the possibility of over discharging the battery occurs [Technical Marketing Staff of Gates Energy Products, Inc.2002]. Lead acid battery perform best when properly charged. The charger is usually walking the line between the potential performance problems associated with undercharge and the threats to battery life from high overcharge currents. High overcharge currents may decrease battery life, either through loss of electrolyte by venting or loss of grid material through oxidation [Reasbeck. P. and J.G. Smith2009].

In this paper the electrical performances of lead acid battery (6V, 16 Ahr) supplied by solar cells array are experimentally obtained. The experimental results are used for determining the internal series resistance under charging and discharging conditions. Mathematical models for these resistances are built up in order to apply them practically.

THE PHOTOVOLTAIC CELL ARRAY

The fundamental power conversion unit of a PV system is the 'solar cell'. For practical use, they are usually assembled into modules. About 36 cells are typically interconnected in series in order to give a charging voltage for a 12V battery. For high power requirement, the modules are interconnected in series/parallel to form a DC power producing unit array known as generator, Fig.(1). And its specifications is illustrates in table.(1).

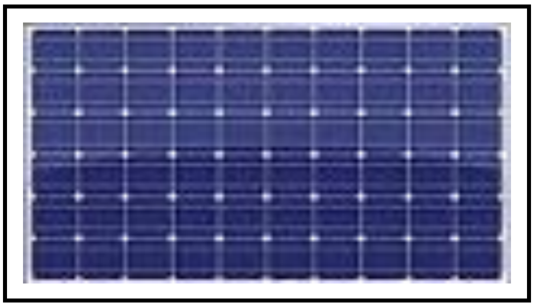

Table.(1) The photo of Photovoltaic

Table.(1) : The Specifications of Photovoltaic Module

Parameters	Symbol	Typ	Unit
Open Circuit Voltage	Voc	21.3	V
Maximum Power voltage	Vpm	17.1	V
Short Circuit Current	Isc	5.31	A
Maximum Power Current	Ipm	4.67	A
Maximum Power	Pm	80	W
Encapsulated Solar Cell efficiency	ηc	14.11	%
Module Efficiency	ηm	12.60	%

The Battery-Storage element:

An electric battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each battery consists of a negative electrode (anode) that holds charged ions, a positive electrode (cathode) that holds discharged ions, an electrolyte that allows ions to move from anode to cathode during discharge and (return during recharge) and terminals that allow current to flow out of the battery to perform work. The specifications of the battery which used are listed in Table (2).

Table (2): The specifications of the lead-acid battery.

Characteristics		Specifications
Maximum voltage,	(volts)	6
Maximum current,	(Amps)	16
Number of plates:		7
Dimensions: Length	(cm)	20
Width	(cm)	14
Height	(cm)	16

The battery used to store electricity generated by solar cells throughout the day during experiments to improve PV. The battery capacity is measured every hour since sunrise until sunset. The batteries are also used in power supply applications such as houses and projects.

Also, compared batteries were used connect with PV without development.

Auto Range Multi-meter:

Was employed to measure both voltage and current output for the photovoltaic array during daylight hours and during laboratory experiments and PV applications, the general and electrical specifications of auto range multi-meter are summarized and listed in Tables (3) and (4) respectively.

Table (3): The general specifications

Measurement	Specifications
Zero Adjustment :	Dc volts (5 ranges)-auto/Manual range Dc current-Manual range (3 ranges). Automatic.
Operating temperature:	0 °C to 50 °C (32° F to 122 °F).
Operating Humidity :	Max. 80% RH.
Power supply :	2X1.5 v AAA /UM 0.4 sizes Battery.
Power consumption :	Approx. Dc 0.7 mA
Dimension :	HWD 158 X 75 X 32 mm (6.3 X 3.6 X 1.3")
Weight :	250 g/0.5 ib (including battery).

Table (4): The electrical specifications

Ac/Dc Current	**Ac Frequency Response: 40HZ-400HZ Sine wave spec. Tested on 60HZ/50HZ**			
Range	Accuracy	Resolution	Voltage Drop (in case of fs)	Overload circuit protection
20 mA	DOA ±(1.2 + 11) ±(1.5%+5d)	10 uA	AcA: Ac200 mv DcA: Dc200 mv	0.5 A Fuse
200 mA		100 uA		Un Fused 20A. 20 sec
15A		10 mA		

Battery Performance Recording Device:

The device used to measure the performance of the batteries , measure the charging voltage, the charging current and also the charging time. The device is equipped with paper to record data are plotted where all the measurements with high accuracy and the following figure shows a photograph of the device, fig.(2). The general specifications of the device is illustrates in table.(5).

Fig. (2): The photograph of the Battery Recorder Data.

Table.(5) : The general specifications of the device(Kipp and Zonen)

Manufacturer:	Kipp & Zonen
Model:	BD 40 02 / 04
Power Supply:	110-120 VAC - 0.5 A - 60 Hz
Specifications:	Kipp and Zonen BD40 Single Pen Chart Recorder chart speed from 10mm/sec o1mm/min, adjustable pen speeds, manual pen controls and rear communication orts.
Speed Range:	0.1, 0.2,0.5,1,2,5,10 mm/s OR mm/min or 0-100MV (1,2,5,10,20,50,100).

To estimate the value of the internal resistance of the battery at different different levels of solar radiation, the battery was connected with solar cells through the device of determination the performance of battery, also connected with voltmeters and ammeter in parallel in order to estimate the internal resistance and the performance of the battery, the following figure(fig. 3) shows the photograph of the system during a laboratory tests.

Fig. (3): the photograph of the system during a laboratory tests.

RESULTS

Battery Behavior During Charging:

The charging current of the battery is measured against charging time during the period of charging. Fig.(4) represents the previous relationship which is recorded directly by a recorder connected through the experimental circuit used. The charging current of battery under test is dependent upon the state of charge of the battery and the insolation level. Initially the current increases with increasing the insolation level. At the end of charging it decreases to a minimum level. The final level of charging current is required to energize the losses within the battery.

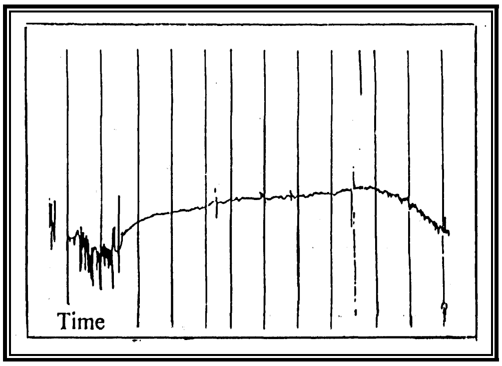

Fig. (4): Battery Charging Current Energized from Solar Cells Array Against Time, Velocity of the Chart Recorderis 0.5 mm/min.

By the aid of computer program, the energy stored in the battery as well as the percentage ampere hour stored in it during charging period and for each hour are obtained. The percentage ampere hour stored in the battery is given by:

$$\% \text{ Amper hour} = \frac{\text{Ampere hour stored in battery}}{\text{Battery capacity}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Fig.5 illustrates the relationship between charging current in ampere against percentage ampere hour stored in the battery (Pah). The charging current is initially increased till the Pah reaches to 30% capacity, then it decreases. As the Pah reaches 75%, the charging current is rapidly decreased. This relationship gives the point at which the battery must be disconnected from energy supply (solar cells array). This point is at 75% Pah. The experimental results show that at the previous point more bubbles of gases are shown in the battery. These bubbles are very dangerous because they oxidize the grids of battery plates. So that, at this point the voltage regulator of battery must be operate and remove the energy supply from the battery.

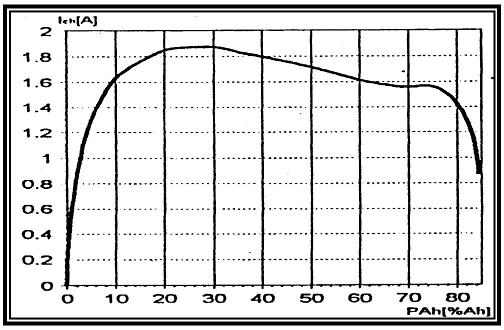

Fig.(5): Charging Current Against Percentage Amper Hour Stored.

Fig.6 also gives the point at which the battery must be disconnect from the charging source. The figure represents the battery voltage against Pah. The voltage steadily increases till 60% Pah, then it rapidly increases till 75% Pah and reaches to its maximum value. The last figure illustrates that the disconnection point is also at 75% Pah.

Fig. (6): Battery Charging Voltage Against Percentage Amper Hour Input to it.

The ampere hour (Ah), percentage ampere hour (Pah) input to the battery as well as solar energy incident upon solar cells array against charging time having similar characteristics shown in figures(7, 8) and (9).

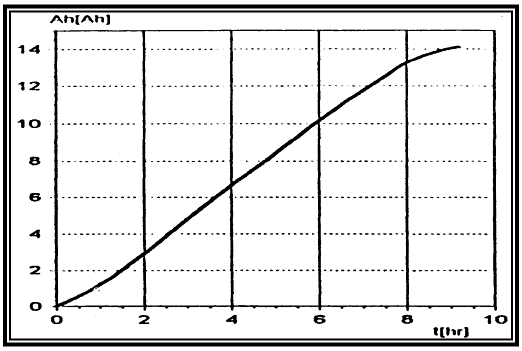

Fig. (7): Amper Hour Input in the Battery Against Charging Time.

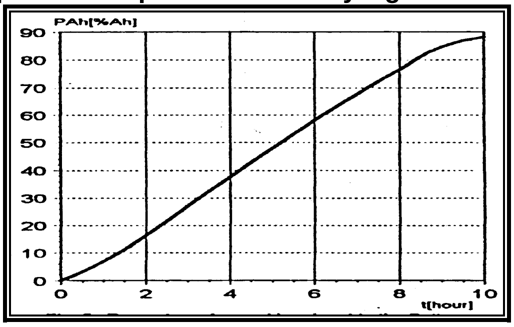

Fig. (8): Percentage Amper Hour Input to the Battery Against Time.

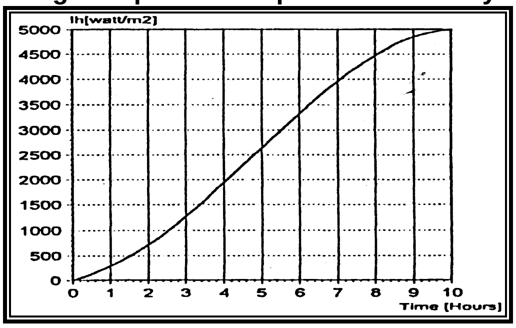

Fig. (9): Solar Energy Incident During Sun Shine Periods Upon Horizontal Solar Cells Array.

Open Circuit Conditions During Charging

The battery behaviors under open circuit conditions are experimentally investigated. The battery is recharged from solar cells array. The recharging current against time is recorded directly by recorder as shown in figs.10. lb - 10.8b for eight periods. The recharging operation period is 14.6 hr. The battery reaches to full charge after 10.25 hr. At selected instances, Which take place at the end of each of last period, the battery is opened and its terminal voltage against time is recorded. Figs.10. la - 10.8a illustrate the recorded open circuit voltage of battery against time at different instants of charging. All figures represent that the battery voltage is dropped down after that it exponentially decays to steady state value, VM. These recorded curves are the bases from which the battery behaviors are obtained.

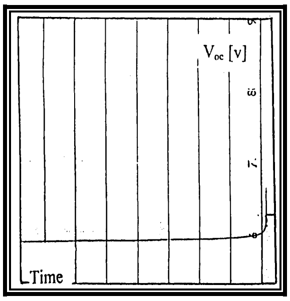

Fig. 10.1(a)

Fig. 10.1(b)

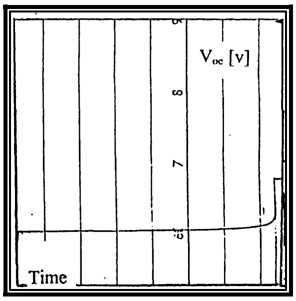

Fig. 10.2(a)

Fig. 10.2(b)

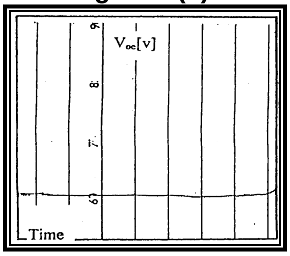

Fig. 10.3(a)

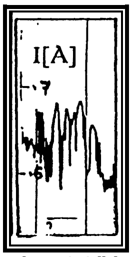

Fig. 10.3(b)

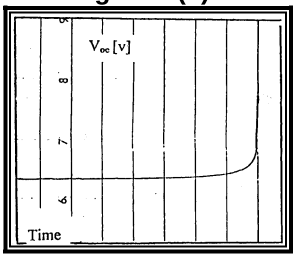

Fig. 10.4(a)

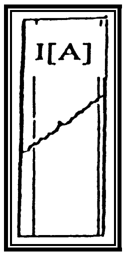

Fig. 10.4(b)

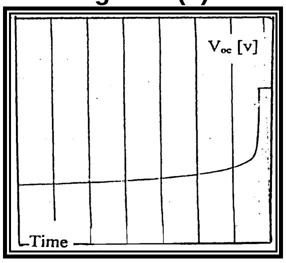

Fig. 10.5(a)

Fig. 10.5(b)

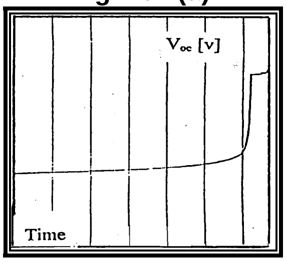

Fig.10.6(a)

Fig. 7.6(b)

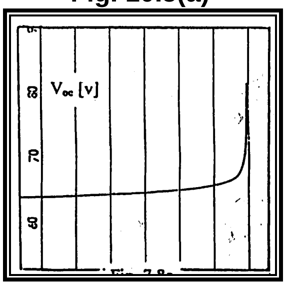

Fig. 10.7(a)

Fig.10.7(b)

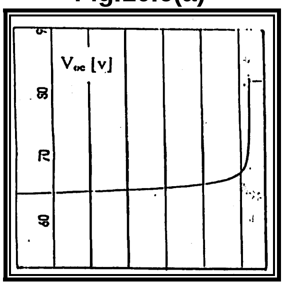

Fig. 10.8(a)

Fig. 10.8(b)

Fig. (10): Battery Charging Current and its Open-Circuit Voltage. Figure 10.1a-10.8a are Charging Current Periods, Velocity of the Chart Recorder is 0.5mm/Min. Figures 10.1b- 10.8b Are Open-Circuit Voltage Starting at the END of Current Periods , Velocity of Chart Recorder is 5mm/Min.

Fig.(11) represents battery open circuit voltage, directly after making open circuit, against charging time. It indicates (hat the open circuit voltage, Voc, is exponentially increasing and reaches to steady state condition after approximately 10 hr (storing time) The last time is the time after which the battery becomes full charge. The open circuit voltage of battery under charging is reached finally to steady state value. This value is dependent upon the batten/ state of charge. Fig.(12) illustrates the steady slate value of battery voltage under open circuit condition against time of charging. The value of VSB increases and reaches to constant value after 10 hr of charging. At this point the battery is readied to full charge condition. On the other hand, the battery reaches to steady state condition after time called time constant.

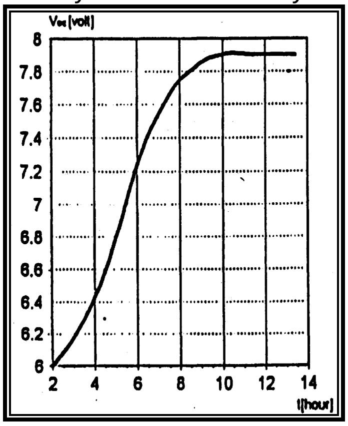

Fig. (11): Open Circuit Voltage of Battery during Charging Against Charging Time.

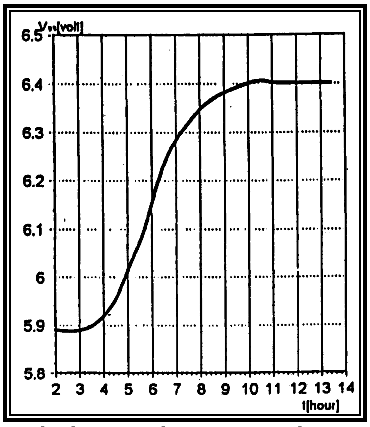

Fig. (12): Steady State Voltage of Battery during Open Circuit Condition Against Charging Time.

The time constant against charging time is represented in fig. (13) Initially the time constant increases as increasing battery state of charge or charging time. After 4 hr of charging, the battery rapidly reaches to steady state condition till 10 hr of charging. After 10 hours of charging. This time becomes constant. This means that the battery is fully charged. The more important factor which can be obtained from the last experiment is the battery series resistance, R*. This resistance is obtained by measuring the terminal voltage of battery before and directly after open circuit of the battery at different state of charging conditions. The differences between the two measured values gives voltage drop across internal series resistance of the battery, Ibef R«. By measuring the current before open circuit condition I^r the value of series resistance at this condition of state of charge is obtained.

Fig. (14) illustrates the battery series resistance under charging condition against state of charge of battery, represents by charging time. The value of this resistance initially increases till charging time becomes 6 hours, then it steeply decreases.

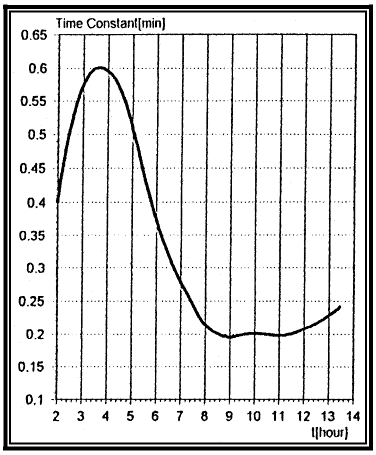

Fig. (13): Time Constant of Overcharging Capacitor of Battery Against Charging Time.

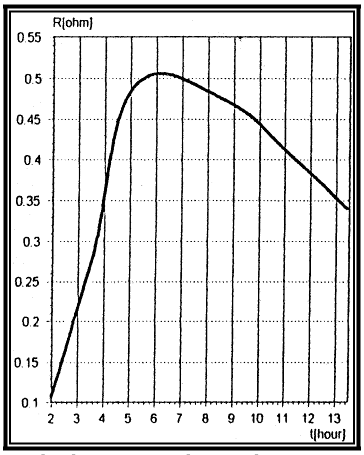

Fig. (14): Internal Resistance OF battery during Charging Against Time.

Discharging Behavior:

The battery is discharged at constant current to obtain the effect of state of charge upon its voltage. Fig. (15) represents the relationship between battery terminal voltage and discharging time. This figure depends upon the level of discharging current. As the discharging current increases, the discharging time decreases and vice versa. During discharging period (9 hr) the battery is opened several times for few minutes.

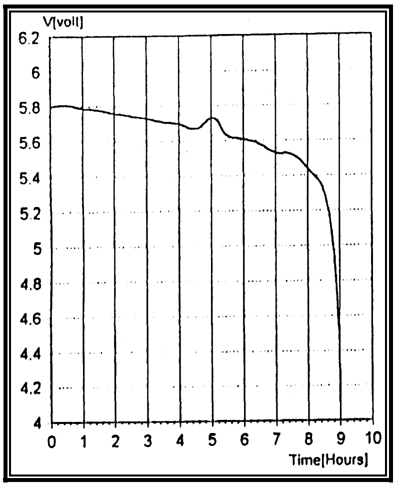

Fig. (15): Discharge Voltage Against Time.

The terminal voltage of the battery is recorded and represented by Fig. (16) Directly after open circuit condition, the open circuit voltage of battery is measured.

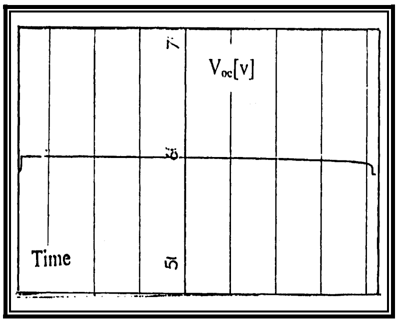

Fig. (16a)

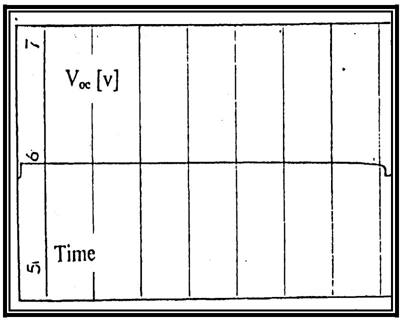

Fig. (16b)

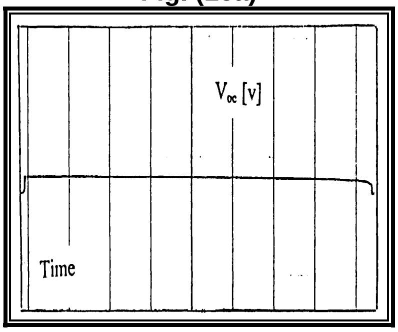

Fig. (16c)

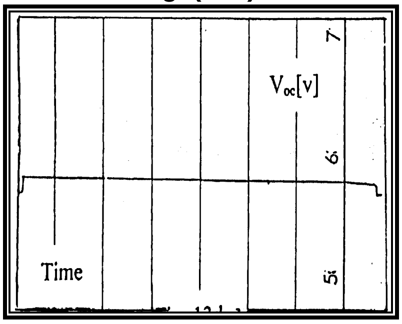

Fig. (16d)

Fig. (16): Battery Open Circuit Voltage During Discharging Condition at Specific Time Periods, Velocity of the Chart Recorder is 5mm/Min.

Fig. (17) represents the open circuit voltage of battery against discharging time. It indicates that the time at which the load must be disconnected from the battery is about 7.5 hr.

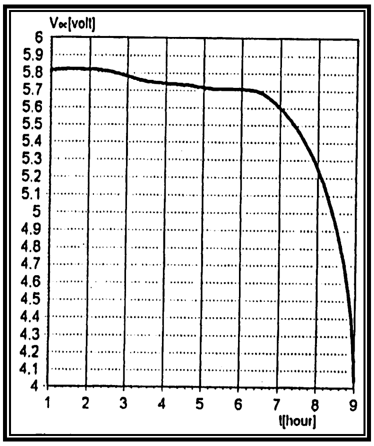

Fig.(17): Open Circuit Voltage of Battery under Discharging Condition Against Discharging Time.

Fig. (18) illustrates the steady state discharging voltage against discharging time. It takes the same behavior as previous parameters (V, Voc against time). The internal resistance of battery against discharging time is shown in Fig. (19). This resistance increases as the discharging also increases. This is due to the accumulation of $PbSO_4$ on battery plates during discharging process.

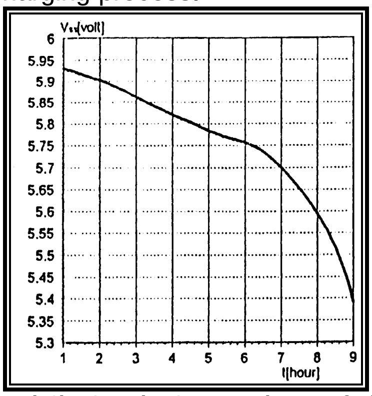

Fig. (18): Steady State Voltage of the Battery under open Circuit Condition Against Discharging Time

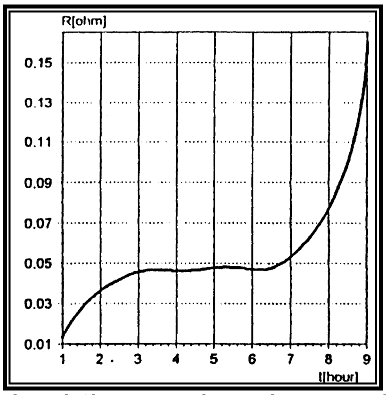

Fig. (19): Internal Resistance of Battery under Discharging Condition Against Time.

The results from figures 11 and 16 are modeled mathematically and their mathematical models are as follows:

$R_{ch} = -9.886*10^{-2} + .1058222\ f_{ch}$ $2<t_{ch}<6$ **..**(2)

$R_{ch} = .51868+8.56308*10^{-3}\ t_{ch}-1.6388*10^{-3}\ t_{ch}^2$ $6<t_{ch}<13$ **...................**(3)

Where:

T_{ch} : is the charging time in hours and

R_d, : is the series resistance of battery during charging.

The model for discharging resistance R_d is written as follows:

$R_d = -2.1469*10^{-2}+4.1075*10^{-2}\ t_d-6.30636*10^{-3}\ t_d^2$ $1<t_d<3$ **......................**(4)

$R_d = 0.05$ $3<t_d<$ **...**(5)

$R_d = 0.8552832 - 0.245358 t_d + 0.0186783 t_d^2$ $6<t_d<$ **.................................**(6)

Where:

t_d : is the discharging time of battery in hours.

CONCLUSIONS

In this paper the electrical performance of lead acid battery during charging and discharging conditions are experimentally obtained. The point at which the battery must be disconnected from charging supply or load is determined from these performances. The battery behavior during open circuit condition intervals through out charging and discharging are also obtained. The internal series resistance of battery during charging and discharging are experimentally determined. Mathematical models for these resistances are built up.

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اسلوب جديد من اجل تحديد المقاومة الداخلية للبطاريات

حمدي محمد نور

قسم بحوث القوى والطاقة - معهد بحوث الهندسة الزراعية - دقي - جيزة.

حيث أن البطارية من العناصر المهمة في أي معدة زراعية (الجرارات والمعدات المختلفة التي تحتوى علي بطاريات) وبالتالي فإن أدائها الكهربي يعتمد اعتماد أساسي علي قيمة مقاومتها الداخلية والتي تتمثل في المقاومة الكهربية لالواحها الإلكترونية الموجودة بين هذه الألواح فالمعرفة الدقيقة لمقاومتها الداخلية يؤدى إلي معرفة الأداء الكهربي الدقيق لها. وبالتالي فإن أي حمل كهربي يوصل بالبطارية مثل وحدة التسوية بالليزر .... فإن أداءه الكهربي يتأثر بأداء البطارية سواء الحامضية منها أو الجافة وتعتبر البطارية عنصر أساسي في منظومة القوى الفوتوفولتية الذاتية والتي تعتبر من منظومات القوى في الطاقات المتجددة المناسبة للاستخدام في الزراعة وخاصة الموجودة مها في المناطق الصحراوية. كما أنها من المنظومات المناسبة أيضا بالنسبة للمعدات الخاصة بالمشاريع الزراعية.

الهدف من البحث

يهدف البحث إلي المراقبة المعملية للأداء الكهربي للبطارية الحامضية باستخدام جهاز لتسجيل النتائج (جهد الشحن والتفريغ - الزمن) وذلك لحساب قيمة المقاومة الداخلية للبطارية ومعرفة أدائها الكهربي في أثناء عمليتي الشحن من الخلايا والتفريغ بفعل الحمل، حيث أن معرفة سلوك هذه المقاومة يؤدي إلي الاستخدام الأمثل للبطارية أثناء عمليتي الشحن والتفريغ مما يؤدي إلي طول عمرها الافتراضي حيث أن البطاريات بأنواعها من العناصر المهمة في تشغيل كافة المعدات الزراعية والجرارات حيث ان معرفةالمقاومة الداخلية للبطاريات تساعد على تصميم المنظومة الفوتوفولتية بكفاءة.

كما يهدف البحث أيضا إلى اقتراح طريقة عملية لاستنتاج قيمة هذه المقاومة في اثناء عمليتي الشحن والتفريغ للبطارية. عمل عدد أثنين نموذجين رياضيين تم فيهما وضع صورة رياضية موضح بهم قيمة المقاومة الداخلية للبطارية بالأوم دالة في زمن الشحن والتفريغ بالساعة .

تعتبر المقاومة الداخلية للبطاريات بأنواعها من العوامل المؤثرة تأثيراً كبيراً علي أدائهم الكهربي في أثناء عمليتي الشحن والتفريغ وقد تم في هذا البحث قياس الأداء الكهربي لبطارية رصاص حامضية (والتي تعتبر من أوسع الأنواع استخداما وانتشارا) معمليا لمعرفة أدائها الكهربي في أثناء عمليتي الشحن والتفريغ، ولتقدير قيمة المقاومة الداخلية في أثناء عمليتي الشحن والتفريغ فقد تم مراقبة جهد البطارية في أثناء عمليتي

الشحن والتفريغ وذلك باستخدام جهاز لتسجيل قيمة جهد البطارية لحظة بلحظة في أثناء العمليتين. وقد تم فصل كل من الحمل (أثناء عملية التفريغ) ومصدر الشحن (في أثناء عملية الشحن) عن البطارية وقد تم مراقبة جهدها لحظيا بتحليل أداء هذا الجهد اللحظي باستخدام جهاز التسجيل فقد أمكن تحديد قيمة مقاومتها الداخلية وقد لوحظ أن هذه المقاومة ذات قيمة متغيرة تتوقف على زمن الشحن والتفريغ، وقد لوحظ أيضا أنها تتزايد باستمرار بزيادة زمن التفريغ وعلى العكس من ذلك لأن قيمة المقاومة الداخلية للبطارية في تناقص مستمر مع زيادة زمن الشحن. وقد تم تفسير هذا الأداء فيزيائيا على أن كمية كبريتات الرصاص تتراكم تزايدياً في أثناء عملية التفريغ وتضمحل إلى أدنى مستوى لها أثناء عملية الشحن وفي هذا البحث قد تم عمل عدد أثنين نموذجين رياضيين تم فيهما وضع صورة رياضية موضح بهم قيمة المقاومة الداخلية للبطارية بالأوم دالة في زمن الشحن والتفريغ بالساعة.

وهذا البحث يتم فيه استنتاج دقيق لقيمة المقاومة الداخلية لبطاريات تكون موصلة بمنظومة قوى فوتوفولتية حيث يتم اقتراح طريقة عملية لاستنتاج قيمة هذه المقاومة في اثناء عمليتي الشحن والتفريغ.

وقد أوضح البحث أن قيمة هذه المقاومة والتي تمثلها البطارية (الألواح الإلكتروليتية) ليست ثابتة كما هو مشاع سابقا ولكنها متغيرة وتتوقف على تياري الشحن والتفريغ.

وأوضح البحث أيضا أن هذه المقاومة تنخفض قيمتها في أثناء عمليتي الشحن وتصل إلى أقل قيمة لها عندما تكون البطارية مشحونة شحنا تاما. أما في أثناء عملية التفريغ فقد أوضح البحث أن قيمتها تكون في ازدياد مضطرب كلما زادت عملية التفريغ وتصل قيمتها إلي أقصى قيمة لها عندما تكون البطارية فارغة تماما من أي شحنه كهربية.

وعلى هذا فقد أوضح البحث مما لا يدع مجالا للشك أن المقاومة الداخلية لأي بطارية هي دالة ي تيار الشحن والتفريغ.