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# Comparative Study of Commonly Used Batteries for Solar PV Applications

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## Abstract

The renewable energy source fluctuations could be reduced by applying the energy storage techniques, by storing the excess power generation for making it accessible for the daily life applications. Moreover, the photovoltaic systems could be more flexible, reliable as well has power cost reduction with the help of energy storage techniques. The most widely used energy storage technologies are the batteries which immediately convert the chemical energy contained in their active materials into electric energy via the electrochemical oxidation-reduction (redox) reaction. In this sense, the proposed study aimed to shed further light on selecting the most advanced rechargeable battery type and material based on their effectiveness and economic feasibility. The following storage batteries were chosen to be tested; Lithium (Lithium – polymer, Lithium – ion) and others Valve regulated lead acid batteries. Their charging/discharging characteristics were carried out based on their mode of operations. For charging, the constant current- constant voltage mode was used, while for the discharging, the constant current mode was applied. From which their electrical and performance parameters were calculated, based on it, it could be concluded that, Li-poly battery was the most suitable one for using in smart electronic devices and remote-control vehicles, owing to its high energy density, high specific energy, high power density, high specific power, low internal resistance, in addition to its very slim geometry which is attributed to gelled polymer electrolyte.

**Keywords:** Lithium (Li), Lithium-polymer (Li-poly), battery, lithium-ion (Li-ion) battery, valve regulated lead acid battery (VRLA).

## 1.0 Introduction

Rechargeable electrochemical batteries are closed systems which could convert the stored chemical energy to electrical ones with high efficiency depending on the operating conditions [1, 2]. They have only minor advances in terms of volume and size over the last few decades

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[3].These batteries could be electrically recharged to their original state by passing current through them in the opposite direction [4]. Also, they can boost the operating system efficiency totally and providing economic savings throughout the system's life cycle. The reliability of electricity delivered from both renewable and conventional sources can be enhanced using these batteries as energy storage medium [5]. The most used storage batteries are Nickel batteries (since 1950's) and Lead acid battery (since 1980's). The relatively new battery technology is Li-ion batteries (since 1990's) [5, 6].

Lithium (Li) which is the lightest of all metals can be considered as an important component of battery electrolytes and electrodes due to its high electrode potential. It provides the largest energy density per weight due to its low atomic mass [7]. Rechargeable battery constructed using lithium metal as an anode are capable of providing both high voltage and excellent capacity, resulting in an extraordinary high energy density, high efficiency and long life cycle. Li-ion batteries could be classified into two main categories namely; rechargeable and disposable (primary). Rechargeable one has a higher energy density than the disposable ones [3, 8, 9].

## 2.0 Methodology and circuit setup

The following types of the rechargeable chemical battery which are considered as versatile technologies can be design to play a vital role that perfectly fitting local market [5]. Figure (1) illustrates some of the rechargeable chemical batteries namely; VRLA (12 V/ 3.4 Ah), Li-ion (12 V/ 1.5 Ah) and Li-poly (11.1 V/ 1.5 Ah), respectively.


VRLA Li-ion Li-polymer

Fig. (1): Different rechargeable battery types.

The present work is aimed to selecting the most suitable material for smart life applications by studying the electrical performance parameters of the proposed rechargeable battery types. The charging/ discharging characteristics are carried out based on the most widely-used strategy namely; constant current- constant voltage and constant current modes of operations, respectively [10, 11].

## 2.1 Technical Characteristic Parameters

The following performance parameters of the tested batteries [12- 14] can be summarized in the following table (1):

Table (1): The calculated equations of technical parameters of the different tested batteries.

| Parameter | Equation |
|---|---|
| State of Charge (SoC) | $SoC = (VOC / V_{max}) \times 100\ \%$ |
| Depth of Discharge (DoD) | $DoD = 100\ \% - SoC$ |
| C – rate | $C - rate = I_{dis} / C_{nom}$ |
| Capacity | $Capacity = I_{dis} \times t$ |
| Internal resistance ($r_{in}$) | $r_{in} = (V_{no} - V_L) / I_L$ |
| Energy Density | $Energy\ Density = (V_{nom} \times C) / v$ |
| Specific Energy | $Specific\ Energy = (V_{nom} \times C) / w$ |
| Power Density | $Power\ Density = (V_{nom} \times I) / v$ |
| Specific Power | $Specific\ Power = (V_{nom} \times I) / w$ |

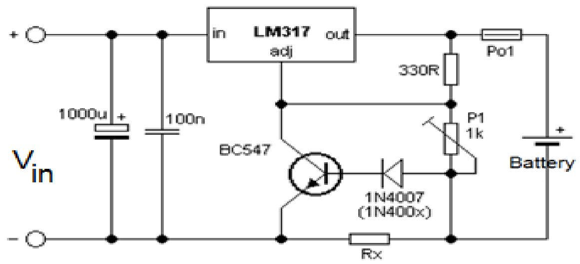
## 2.2 Experimental Circuit Setup

Figure (2) illustrates the batteries experimental circuit setup (a) charging and (b) discharging.

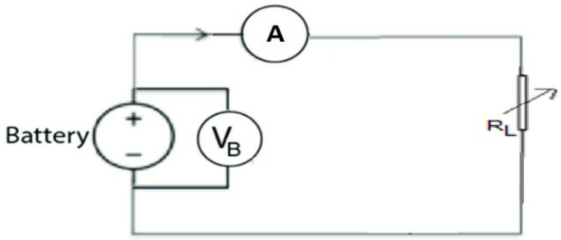
i. Consider the charging circuit (Fig. 2a). It consists of active elements (positive voltage regulator with adjustable output type LM317, NPN transistor type BC547, PN diode type 1N4007) and passive elements (electrolytic capacitor 1000 F, capacitor 100 nF, fixed resistors, etc.) and potentiometer of 1.0 kΩ). The LM317 offers relatively accurate voltage stabilization. The target voltage is set with potentiometer P1. Current stabilization is provided by a shunt resistor (Rx) and an NPN transistor. The mechanism of operation could be summarized as follows; when the voltage drop across Rx reaches about 0.95V (all voltage drops across NPN transistor and diode), the transistor starts to turn on. This reduces the voltage at pin Adj. (from LM317) and thus stabilizes the current. The charging current depends on the shunt resistor Rx, which is selected based on the battery type. The value of Rx could be calculated using Eq. (1) as:

$$Rx = 0.95 / I_{max} \quad (1)$$

ii. Discharging circuit (Fig. 2b), the batteries discharging characteristics are studied at fixed current values (certain C- rate) which is selected using the variable resistor ($R_L$). In this concern, the battery is discharged until its voltage is lower than the cut-off voltage. At this point, it is imperative to stop the discharging process and recharge the battery. Over - discharging/charging can accelerate battery degradation [15].



(a)



(b)

Fig. (2): Batteries experimental circuit setup (a) charging and (b) discharging.

## 3.0 Results and Discussions

### 3.1 Charging Characteristic Curves

Figure (3) shows the charging characteristic curves for the tested batteries based on CC/CV charging mode, with charging current rate of (C/10). For VRLA is 0.34 A and for Li-ion and Li-poly is 0.15 A. The current value is chosen, to conserve the battery life. It is to be noted that, their characteristics have the same trend. Consider VRLA battery (Fig. 3a), during CC charging mode, the voltage increases from its cut off voltage (11.20 V) up to 12.80 V within 8.0 h, where CV charging mode is started, after that the battery charging targeted voltage (topping charge = 13.50 V) is reached. At this point, the current starts to decrease asymptotically approaches zero (0.001 A).

Moreover as an example for Li-poly battery (Fig. 3c), during CC charging mode, the voltage increases from its cut off voltage (10.6 V) up to 12.0 V within 7.42 h, where CV charging mode is started, after that the battery charging targeted voltage (topping charge = 12.60 V) is reached. At this point, the current starts to decrease asymptotically approaches zero (0.001 A). It is to be noted that, the batteries charging time is more for VRLA (30 h) compared to Li-ion (22 h) and Li-Poly (19.5 h), respectively. Which is may be attributed to both battery type and capacity.

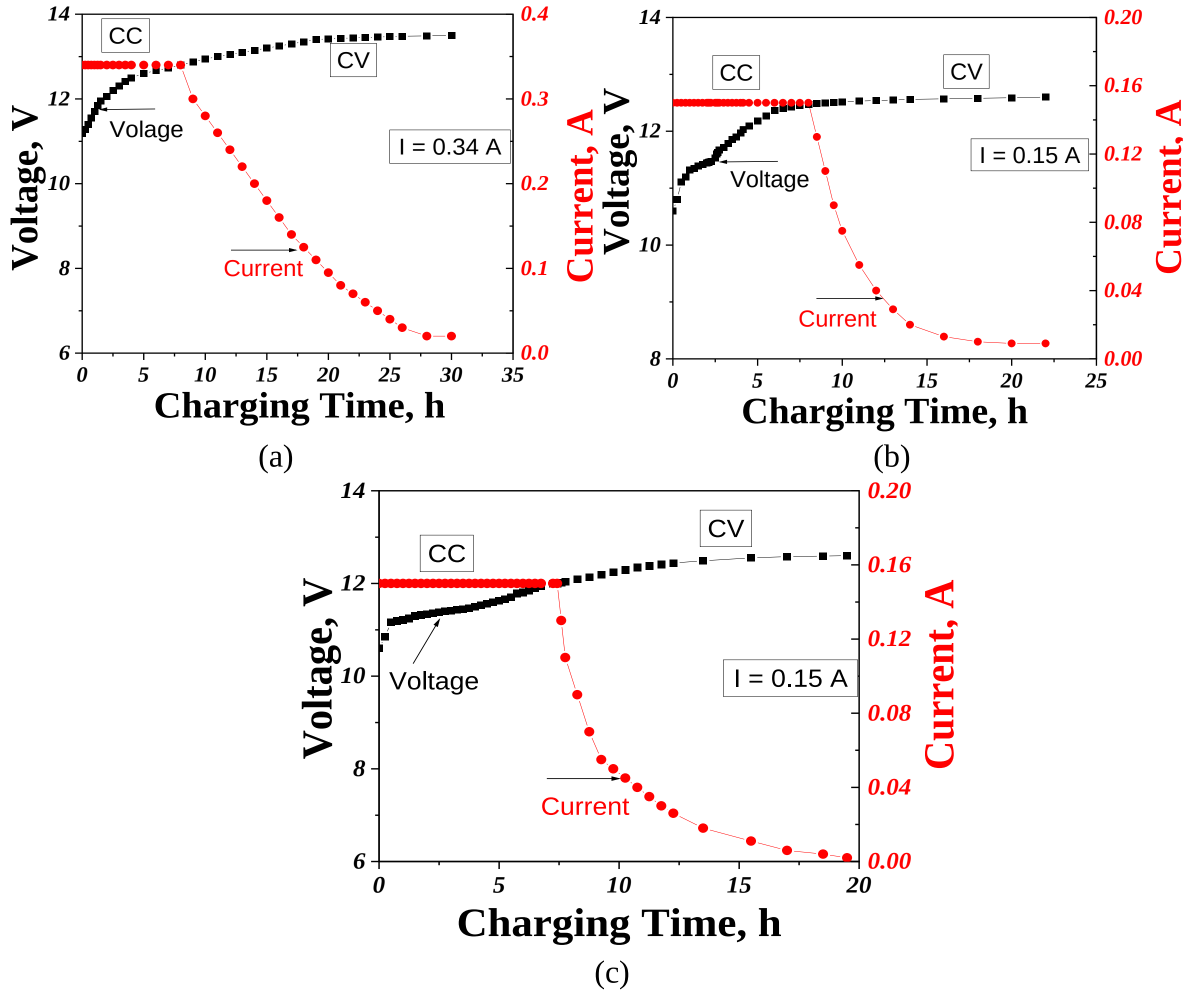



Fig. (3): Charging characteristic curves for different batteries
(a) VRLA, (b) Li-ion and (c) Li-poly.

Concerning the tested batteries performance parameters, their state of charge (SoC) and depth of discharge (DoD) are shown in Fig. (4). It is noticed that from Fig. (4 a), For VRLA battery, its SoC increases from 83 % up to 100 % during 30 h of the total charging time. While for both Li-ion and Li-poly batteries, their SoC increase from 84 % up to 100 % during around 22 h and 19.50 h, respectively. Moreover, their depth of discharge (DoD) which are plotted in Fig. (4 b), are shown to be the complement of their SoC.

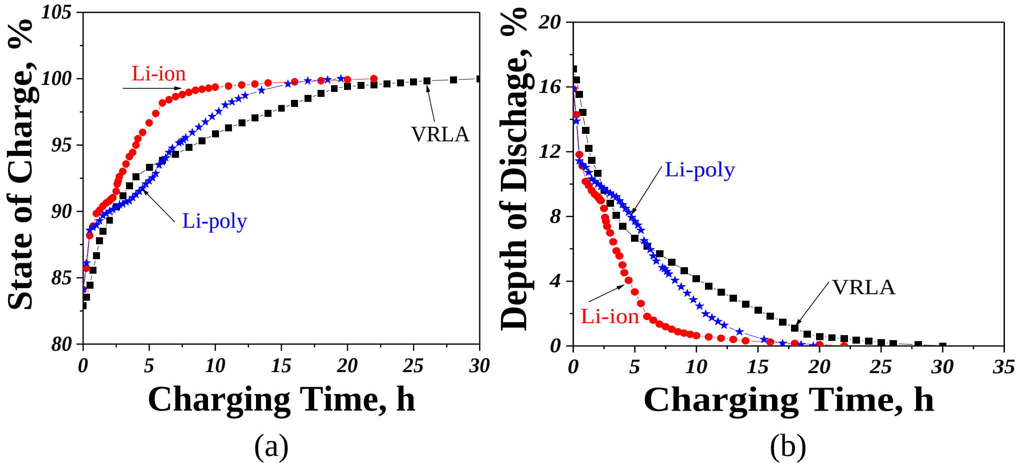



Fig. (4): Batteries performance parameters; (a) state of charge and (b) depth of discharge.

### 3.2 Discharging Characteristic Curves

The influence of the different battery C-rate values on the discharging characteristic curves applying CC discharging mode are shown in Fig. (5). The selected C-rate value is chosen to conserve the battery life [16, 17]. From which, it is clearly shown that, for the different tested batteries; their discharging times are inversely proportional to their C-rate values, where the maximum discharging time are reported to be; (20 h, 13.25 h and 14.45 h) at the minimum C-rate values (0.05 C, 0.08 C and 0.07 C) for the tested batteries, respectively.

Furthermore, the battery capacity is decreased because of the battery energy internal losses, in the form of heat. During lifetime of a battery, the capacity decreases in comparison to the capacity at ‘beginning of life’ [18]. Accordingly, it could be concluded that to conserve the battery efficiency and lifetime, low discharging current levels (i.e. lower C-rate) are proposed.

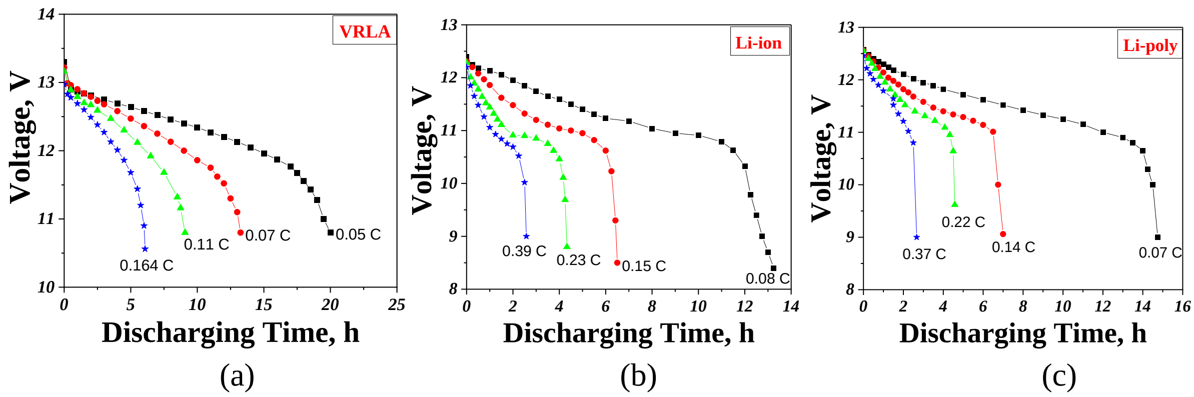



Fig. (5): Influence of battery C-rate values on discharging curves for;

(a) VRLA, (b) Li-ion and (c) Li-poly.

## 3.3 Battery Technical Parameters

The battery technical parameters (Energy density, specific energy, power density, specific power and internal resistance) are summarized and illustrated in Table (2) and Fig. (6). It is clear from the figure that Li-poly records the highest values for the mentioned parameters and VRLA is the lowest. Considering the calculated internal resistance ($r_i$) if the different tested batteries which is illustrated in Fig. (7). It is clearly shown that, VRLA has a higher internal resistance value (1.06 Ω) than Li-poly type (0.28 Ω), referring to the better efficiency and thermal stability of Li-poly battery.

Table (2): Technical parameters of the different tested batteries

| Battery type | Nominal voltage, V | Capacity, Ah | Energy density, Wh/l | Specific energy, Wh/kg | Power density, W/l | Specific power, W/kg | Internal resistance, Ω |
|---|---|---|---|---|---|---|---|
| **VRLA** | 12.70 | 3.40 | 72.30 | 34.50 | 10.60 | 5.08 | 1.06 |
| **Li-ion** | 11.10 | 1.33 | 158.00 | 136.50 | 61.60 | 45.50 | 0.80 |
| **Li-poly** | 11.10 | 1.48 | 304.00 | 151.40 | 112.50 | 50.00 | 0.28 |

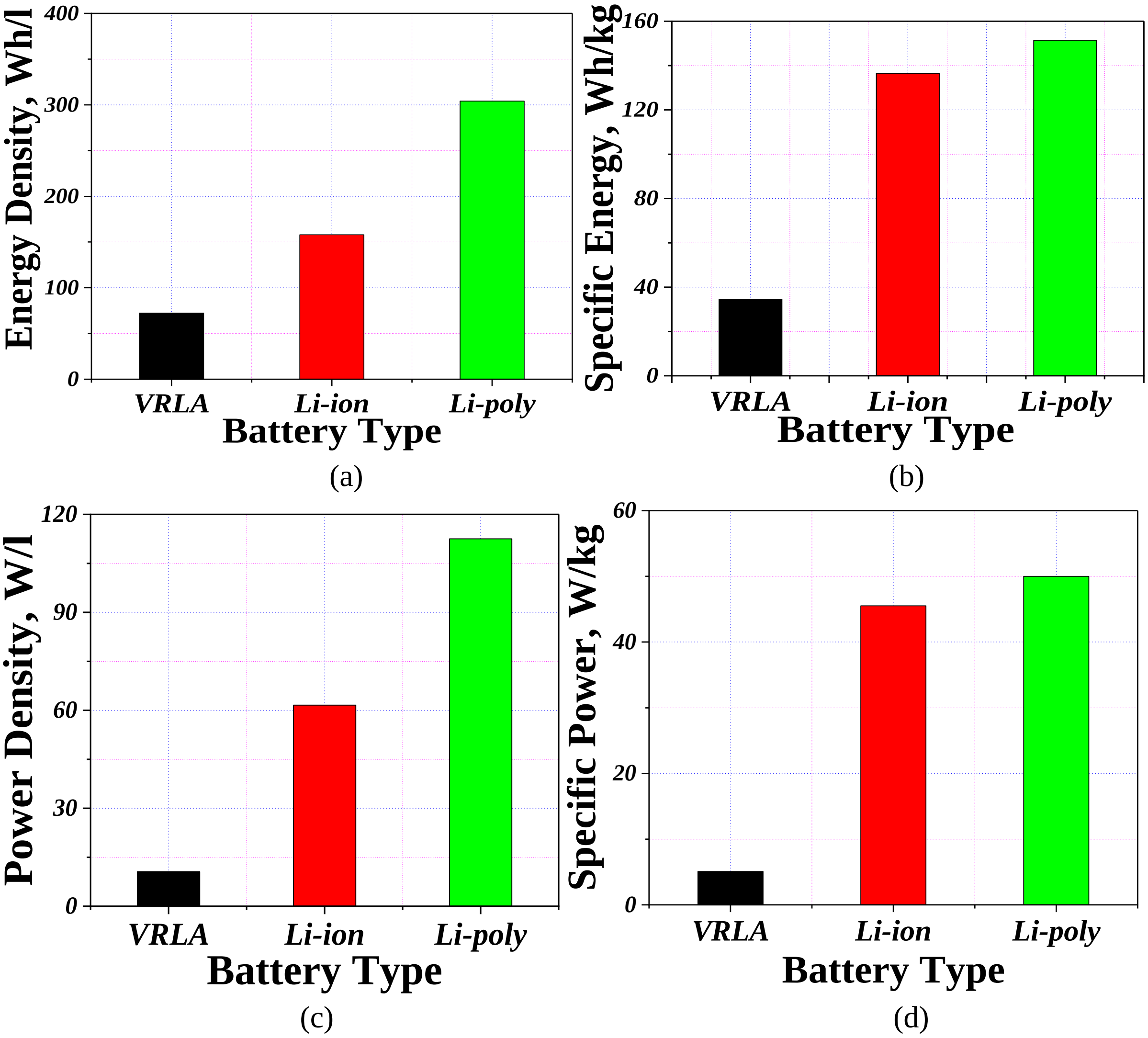



Fig. (6): Batteries technical parameters; (a) energy density, (b) specific energy, (c) power density and (d) specific power.

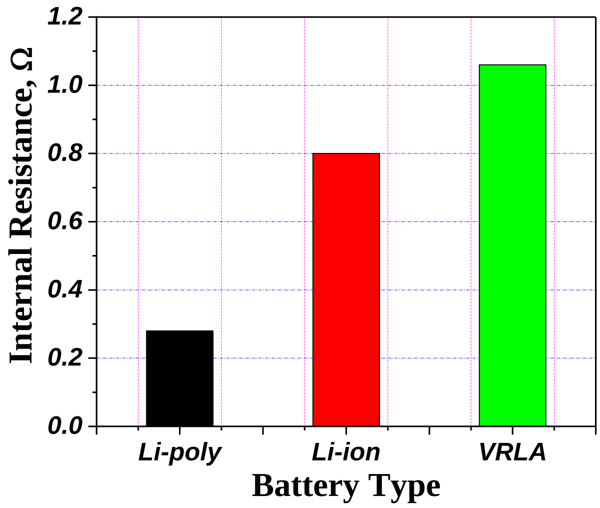



Fig. (7): Calculated internal resistance of the tested batteries.

## 4.0 Conclusions

From the experimental work, results analysis and interpretation, it could be concluded that Li-Poly battery could be considered as the most advanced rechargeable batteries, the matter which was attributed to its advantages of technical parameters including:

- high energy density (304 Wh/l),
- high specific energy (151.4 Wh/kg),
- high power density (112.5 W/l),
- high specific power (50 W/kg),
- low internal resistance (0.28 Ω),
- light weight,
- low memory effect,
- longer life span compared to the other batteries.

Finally, as a result, it is commonly used in smart electronic devices and remote-control vehicles due to its very slim geometry.

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# الملخص العربى

## دراسة مقارنة للبطاريات الأكثر شيوعًا لتطبيقات الخلايا الشمسية

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**نظرًا للتغييرات التي تطرأ على مصادر الطاقة المتجدده والتي من أهمها الطاقة الشمسية، مما يؤدي إلى القصور في استخاماتها الحياتية اليومية فإنه يمكن الحد من تلك التغيرات من خلال تطبيق تقنيات تخزين الطاقة الكهربية المتولدة منها وذلك لإمكانية استخدامها لاحقًا. وتعد الخلايا الشمسية المكون الرئيسي في أنظمة تحويل الطاقة الشمسية إلى طاقه كهربيه نظيفه وحفاظًا على تلك الطاقه المتولدة فإنه يتم تخزينها بتطبيق تقنيات تخزين الطاقة للإستفادة منها.**

**وتعتبر البطاريات هي الأكثر شيوعًا لتخزين الطاقة الكهربية وذلك بتحويل الطاقة الكيميائية الموجودة بداخلها إلى طاقة كهربائية عبر تفاعل الأكسدة والاختزال الكهروكيميائي. وفي هذا الصدد، فإن الدراسة المقترحة تهدف إلى إلقاء المزيد من الضوء على إختيار البطاريات الأكثر تطوراً والقابلة لإعادة الشحن من حيث الطراز ومادة التصنيع وذلك على أساس فعاليتها وجدواها الاقتصادي. حيث تم اختيار وإختبارعدد من بطاريات التخزين: ليثيوم (بوليمر/ أيون) وغيرها من بطاريات الرصاص الحمضية (ذات الصمامات المنظمة) وأمكن حساب كلًا من المعاملات الكهربية والآداء لكل البطاريات قيد الدراسة إعتمادًا على منحيات الشحن/التفريغ لكلٍ منهم .**

**حيث توصلت الدراسة العمليه إلى أن بطاريات الليثيوم - بوليمر هي الأكثر ملاءمة للاستخدام في الأجهزة الإلكترونية الذكية ومركبات التحكم عن بعد، وذلك لإرتفاع قيمة كلًا من: كثافة الطاقة، الطاقة النوعية وكثافة القدرة، القدرة النوعية إضافةً إلى إنخفاض قيمة المقاومة الداخلية لها، مما يعزى إلى طبيعة مادة الإلكتروليت البوليمرية الجيلاتينية لها.**