Chapter Three
Solar Photovoltaic System

Introduction: Photovoltaic power generation is a method of producing electricity, using solar cells. A solar cell is a device that /converts solar optical energy (solar radiation) directly into electrical energy. It is essentially a semiconductor device fabricated in a manner which generates a voltage when solar radiation falls on it.

Semiconductor Materials and Doping

A few semiconductor materials such as silicon (Si), cadmium sulphide, (CdS) and gallium arsenide (GaAs) can be used to fabricate solar cells. Semiconductors are divided into two categories: intrinsic (pure) and extrinsic, An intrinsic semiconductor has negligible conductivity, which is of little use. To increase the conductivity of an intrinsic semiconductor, a controlled quantity of selected impurity atoms is added to it to obtain an extrinsic semiconductor. The process of adding the impurity atoms is called doping. a pure semiconductor, electrons can stay in, one of the two energy bands the conduction band and the valence band, The conduction band has electrons at a higher energy level and is not fully occupied, while the valence band possesses electrons at a lower-energy level but is fully occupied The energy level of the electrons differs between the two bands and this difference is called the band gap energy

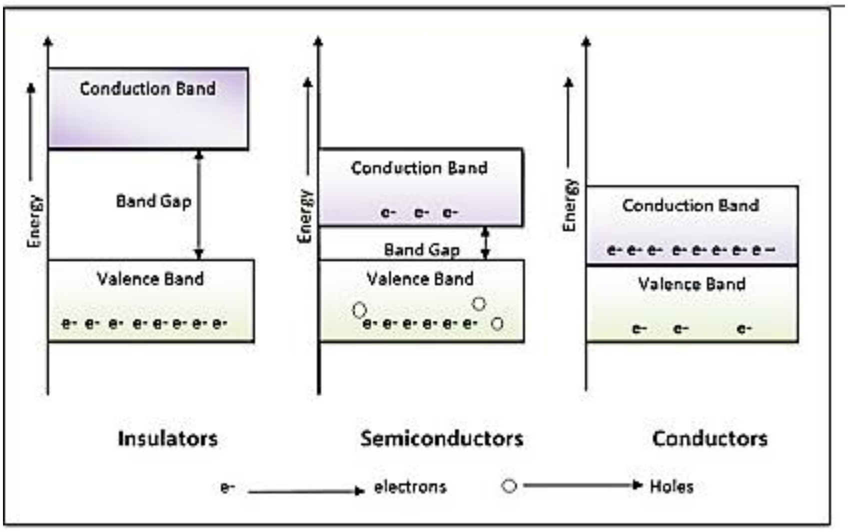


Figure (3-1): Energy bands in materials

P-N Junction

When n-type and p-type materials joined, a junction is formed. The number of elections in the n-type material is large; so when an n-type material is brought into contact with a p-type material, electrons on the n-side flow into holes of the p-material. Thus, in the vicinity of the junction, the n-material becomes positively charged and the p-material negatively charged. The process of diffusion of carriers continues till the junction potential reaches an equilibrium value at the time of equal flow of electrons and holes from both directions. This is known as the unbiased condition of the p-n junction. In this condition, V is the contact potential (i.e., not an externally imposed potential) developed between the p-n junction. The contact potential so developed is a property of the junction itself

Figure (3-4): A p-n junction

When there is no illumination (dark) the flow of junction current I_j with imposed voltage V in a p-n junction is expressed by:

$$I_j = I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right] \qquad (3\text{-}1)$$

Where I_o is the saturation current (also called the dark current) under and e is the electronic charge, and the other variables carry usual meanings.

Photovoltaic Effect

The interface between the two layers (P and N) produces an electric field and forms the so-called a “cell junction”. When the solar cell (p-n junction) is exposed to sunlight, a certain percentage of the incoming photons are absorbed in the region of the junction, freeing electrons in the silicon crystal If the photons have enough energy, the electrons will be able to overcome the electric field at the junction and are free to move through the silicon and into an external circuit. The direction of the electric current is opposite to its direction if the device operates as a diode

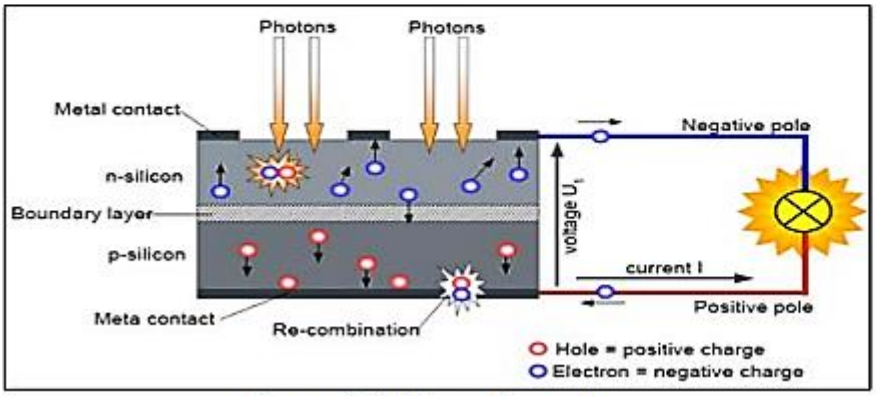


Figure (3-6) Solar cell operation

The electric current obtained I is the difference between the solar light generated current I and the diode dark current I_j, i.e.,

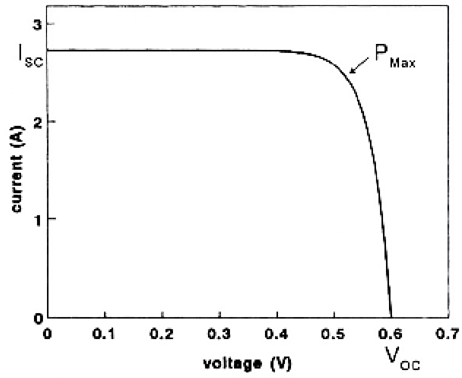
$$I = I_L - I_j \qquad (3\text{-}2)$$

$$I = I_L - I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right] \qquad (3\text{-}3)$$

This phenomenon is known as the **photovoltaic effect**

Efficiency of Solar Cells

Electrical characteristics of a solar cell are expressed by the current-voltage curves plotted under a given illumination and temperature conditions. The significant points of the curve are short-circuit current Isc. And open circuit voltage Voc. Maximum useful power of the cell is represented by the rectangle with the largest area.



The open circuit voltage, Voc, occurs on a point of the curve where the current is zero, so that Voc is equal to:

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{I_o} + 1\right) \qquad (3\text{-}4)$$

Where kT/q, is the equivalent thermal voltage, I_L, I_o, are photocurrent and reverse saturation current, respectively.

The short circuit current, Isc, occurs on a point of the curve where the voltage is zero. At this point, the power output of the solar cell is zero. The series resistance Rsi of the solar cell contributes highly on power loss as the current reaches its maximum limits. The point, Pm, on the knee of the curve, marks the value of current and voltage at which the module delivers the greatest power for a given level of sunlight.

$$\boxed{J_{sc} = J_p} \qquad (V_{sc} = 0)$$

Under standard test conditions (Irradiance 1000 W/m², air mass (AM 1.5), and Temperature 25°C), the maximum current (Im) and maximum voltage (Vm) at maximum output power (Pm) defined the rated power of the module. The other characteristics of solar module are conversion efficiency and Fill factor. The conversion efficiency is defined as the ratio of output electrical power to incident optical power. For maximum power output, we can write :

$$\eta = \frac{P_m}{P_{in}} \times 100\% = \frac{I_m V_m}{P_{in}} \times 100\% \qquad (3\text{-}5)$$

And the Fill factor, FF, is the ratio of the maximum output power to the product $I_{SC}.V_{OC}$:

$$FF = \frac{I_m V_m}{I_{SC} V_{OC}} \qquad (3\text{-}6)$$

$$J = J_p - J_0(e^{V/kT} - 1) \quad (9.19a)$$

Solving for the terminal voltage, we have

$$V = kT \ln\left(\frac{J_p - J}{J_0} + 1\right) \quad (9.19b)$$

From Equation 9.19b it follows that the output voltage increases with the available photocurrent but decreases as the current drawn by the load increases.

Types of Solar cell

Based on the types of crystal used, soar cells can be classified as,

1. Monocrystalline silicon cells
2. Polycrystalline silicon cells
3. Amorphous silicon cells

1. The Monocrystalline silicon cell is produced from *pure silicon (single crystal)*. Since the Monocrystalline silicon is pure and defect free, the efficiency of cell will be higher.

2. In polycrystalline solar cell, *liquid silicon* is used as raw material and polycrystalline silicon was obtained followed by *solidification process*. The materials contain various crystalline sizes. Hence, the efficiency of this type of cell is less than Monocrystalline cell.

Amorphous Silicon

Amorphous silicon is obtained by *depositing silicon film on the substrate like glass plate.*

- The layer thickness amounts to less than 1μm – the thickness of a human hair for comparison is 50-100 μm.
- The efficiency of amorphous cells is much lower than that of the other two cell types.
- As a result, they are used mainly in low power equipment, such as watches and pocket calculators, or as facade elements.

Comparison of Types of solar cell

Material	Efficiency (%)
Monocrystalline silicon	14-17
Polycrystalline silicon	13-15
Amorphous silicon	5-7

بعض مشاكل استخدام الخلايا الشمسية هو تعرّض الألواح الشمسيّة للغبار: يجب تنظيف الألواح الشمسيّة باستمرار والمحافظة على نقائها؛ لأن الألواح تفقد 50% من طاقتها في حال عدم تنظيفها لمدة شهر.
لا يمكن الاستفادة من الطاقة الكهربائية المنتجة من التحويل خلال فترات الليل أو في الأجواء الغائمة والمغبرة؛ فالطاقة يتمّ تحويلها واستخدامها مباشرةً، وفي حال استخدام أجهزة لتخزين الطاقة سيتطلّب ذلك شراء أجهزة مكلفة، وستضيع فرصة الحصول على الطاقة بالمجان، وهي الفكرة الرئيسيّة للألواح الشمسية. غلاء أسعار الخلايا

الشمسية؛ فالخلايا الشمسية مرتفعة السعر، بسبب استخدام عناصر نادرة أثناء تصنيعها، لذلك تتجنّب بعض المؤسسات والشركات استخدامها

Connections of Photovoltaic Devices

Series connection of photovoltaic devices .A photovoltaic device could be a cell, module, panel, or an array. Photovoltaic devices are connected in series to increase the voltage Two similar photovoltaic devices connected in series Voltage: The voltage, V, across two similar series-connected PV devices, A and B, is equal to the sum of the individual device voltages

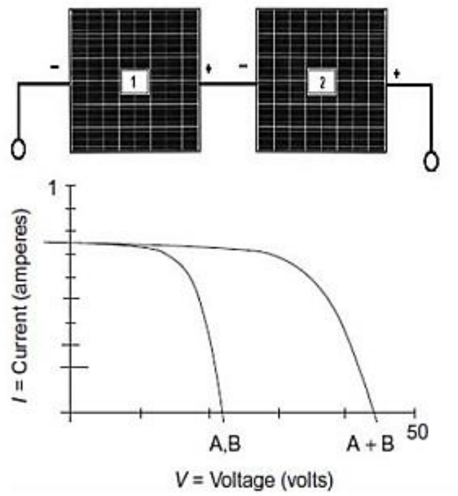
$V=V_1+V_2 \ldots$

$V_1=VA$

$V_2=VB$

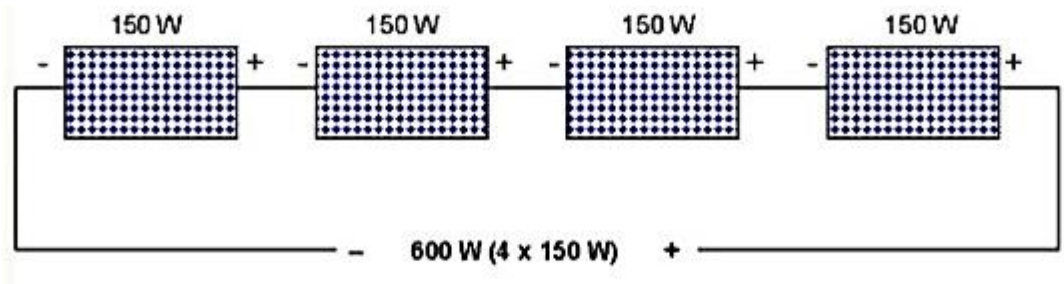
Current: The current, I, through the two similar series-connected PV devices is equal to
the current through either of the individual devices

$I=I_1=I_2$



Series Connection

1) Four similar PV devices connected in series



القدرة الكلية يتم حسابها ببساطة عن طريق الجمع الجبري لقدرة كل لوح شمسي، حيث أن جميعها • لها نفس القدرة، كالتالي

Total power = 150 + 150 +150 + 150 = 600 watt

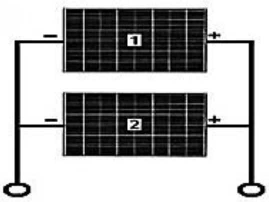
اما في حالة اختلاف القدرة للألواح الشمسية فيتم الحساب على أقل قدره فيهم كما هو موضح في • الرسم التوضيحي :

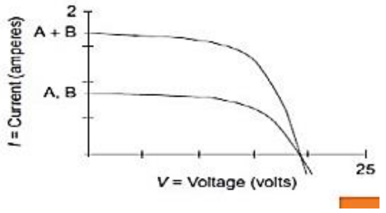
Tot.= 140 x 4 = 560 watt

ومن هنا يتضح لماذا يفضل عدم توصيل ألواح شمسية ذات مواصفات مختلفة

Parallel Connection of PV Devices photovoltaic devices are connected in parallel **to increase the current.** two Similar PV Devices Connected in Parallel

$V = V_1 = V_2$ … $I = I_1 + I_2$ …





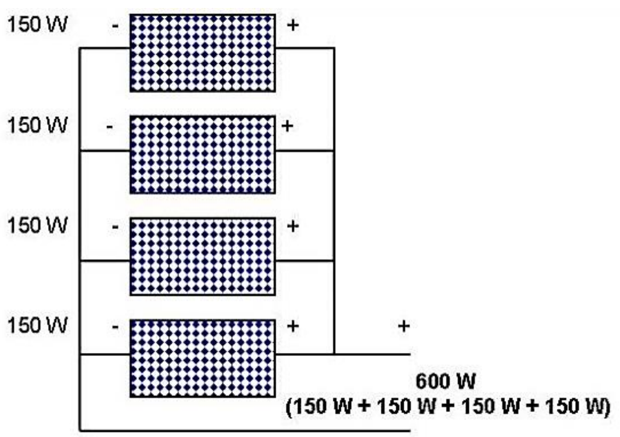
Parallel connection

الصورة أعلاه توضح لك طريقة التوصيل على التوازي حيث تحصل على جهد ثابت وتيار مضاعف

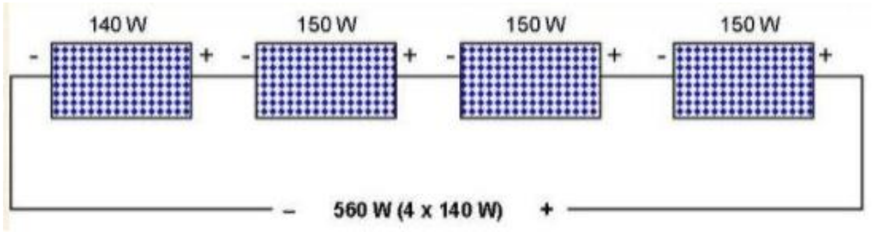
التيار الأكبر يسمح لك بشحن البطاريات بشكل أسرع، ولمضاعفة التيار يجب أن يتم توصيل الألواح .الشمسية على التوازي قم بتوصيل الطرف الموجب للوحة الشمسية الأولى مع الطرف الموجب للوحة الأخرى، أيضاً قم بتوصيل الطرف السالب لإحداهما مع الطرف السالب للأخرى. هذا سيعطيك جهد ثابت مع تيار .مضاعف)نتيجة جمع تياري اللوحين الشمسيين على عكس ربط اللوح ين على التولي حيث نحصل على جهد مضاعف

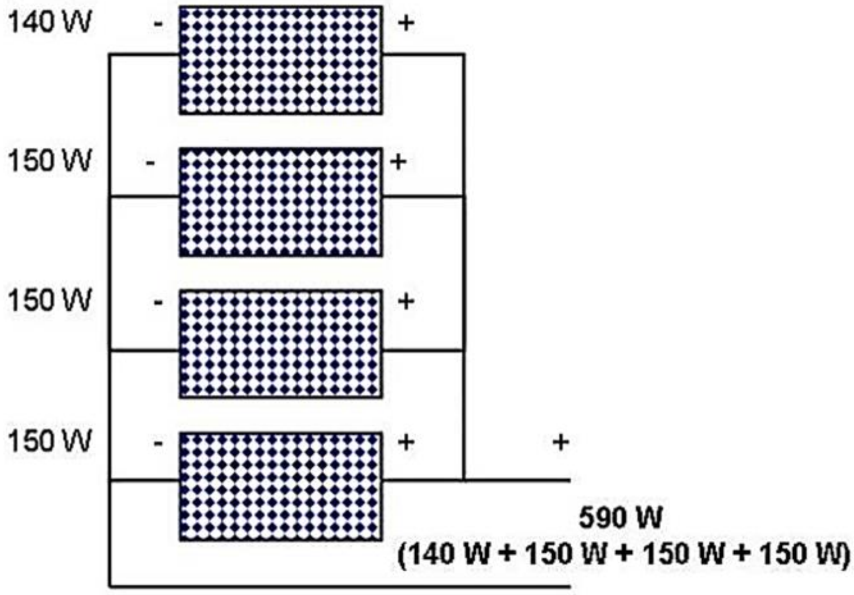
اذا كانت القدرة للوح الواحد متشابهة مع بقية الألواح

Tot. = 150 + 150 =150 + 150 = 600 watt



من الواضح أن القدرة الكلية لا تختلف عن التوصيل على التوالي لكنها تختلف في الفولت , أي أننا .سنحصل على جهد منخفض وتيار عالي
<u>في حاله اختلاف قدرة أحد الألواح فيتم الحساب عن طريق جمع القدرات جبريا</u>
مع الأخذ في الاعتبار في كل التوصيلات السابقة أن يكون الفولت لا يتعدى القيمة التي يتحملها تحت قيمه تحمل اللوح الشمسي مع مراعاة درجه الحرارة والعوامل العاكس)الإنفرتر(، وكونهُ أيضاً الجوية النتيجة مما سبق، أنه في حاله تطابق الألواح الشمسية في المواصفات القياسية لألواح فمن الأفضل التوصيل على التوالي حيث أنها تعطى أكبر فرق جهد وقدرة في نفس الوقت.
أما في حالة اختلاف أحدهم فمن الأفضل التوصيل على التوازي للحصول على أكبر قدره ممكنة حيث يتم جمع .القدرات جبريا كما تم التوضيح مسبقا وال يتم احتساب القدرة الكلية على أقلهم قدرة





Tot.= 140 + 150+ 150 +150 = 590 Watt

Solar cell modules and arrays

Since the solar cell is the smallest unit in photovoltaic systems, in addition to the fact that the voltage generated from it is very small, compared to the voltage of normal use of electrical .devices, the cells are therefore assembled to form a panel, module, or matrix

The following is a definition of these terms

PV cell unit

It is made of semiconducting and optically sensitive materials

By converting direct sunlight into electricity, this equipment is surrounded by an electrically conductive

Module It is a group of photovoltaic units that are combined and connected together in series

panel

It is a group of modules that are combined and connected together in series to obtain the necessary electrical power value

Array

It is the final form of a flat surface consisting of a group of panels that are gathered and connected together in parallel to obtain electrical energy. When installed, care must be taken to achieve inclination angles and orientation towards the sun, and not to be exposed to shadows throughout the period of the sun's surface

solar generator ((Solar Generator

Due to the relatively low efficiency of photovoltaic cells (does not exceed 17%), many photovoltaic modules (or arrays) are used to obtain large electrical capacity. The group .of these modules (or arrays) is known as a solar generator

The resulting **voltage depends on** the number of modules connected in series, while the current **depends on** the number of series of modules connected in parallel, according to the following equations

$$V_{out} = \Sigma Vn = V1 + V2 + V3 + \text{------} + Vn$$

$$I_{out} = \Sigma Im = I_1 + I_2 + I_3 + \text{-----} + Im$$

where

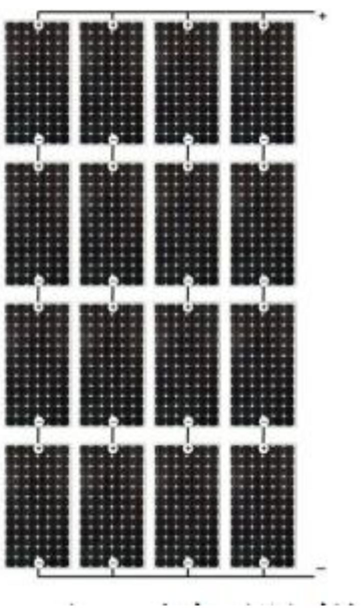
Number of modules connected in series (n) .

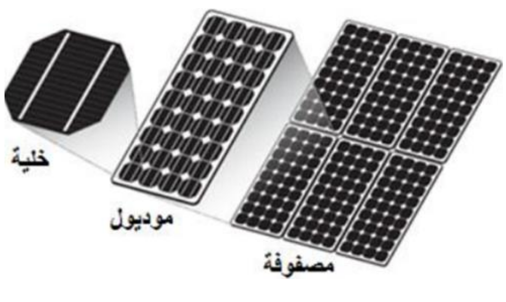
Number of modules connected in parallel (m)

The resulting power is calculated from the following equation:

$$Pout = \Sigma Vn \, \Sigma Im = (V1 + V2 + \text{------} + Vn)(I1 + I2 + \text{-----} + Im)$$

Figure shows a group of modules forming an array (or solar generator) consisting of 7 series of modules, each series consisting of 7 modules. Accordingly, the power output is the product of: four times the module current & four times the module voltage. shows (74) Solar generator consisting of 12 modules





1*Calculate the amount of power obtained from a solar site containing 500 solar panels, each panel It consists of 100 solar cells. Calculate the conversion efficiency of the product if you know the amount of solar energy What falls on one panel is equivalent to 1000 watts

2*Find the number of cells required to generate installed power for a product equal to 50 kilowatts / and the area What is required for the solar station if you know that one panel contains 50 solar cells and its area is 1 Square meters.

3*If the conversion efficiency of a solar station is 15% and the total power of the incident rays 1000 W/M^2. Calculate the amount of external power from a solar station with an area 120 m2