Benha University
Faculty of Engineering (Shoubra)
Power Engineering and Sustainable Energy Department
4th Year

Final Term Exam Model Answer
Date: 05/01/2019
Solar Cells Fundamentals
Duration: 2 Hours

- Answer all the following questions.
- Illustrate your answers with sketches when necessary.
- Total mark: 40 marks
- Number of questions: 3
- The exam consists of two pages.

## **Q.1** ***Write true or false with correcting the wrong statement*** ***[15 marks]***

1- A module in a solar panel refers to series arrangement of solar cells. (false, series and parallel arrangement)

2- A pyrometer is used for the measurements of both direct and diffused radiations. (True)

3- If every Egyptian household replaced 3 incandescent light bulbs with LED light bulbs, the Egyptian carbon dioxide emissions will increase. (false, decrease)

4- Edmond Becquerel is the first person who discovered the photovoltaic effect. (True)

5- Making coffee uses less energy than one hour of laptop use. (false, more)

6- The major principles of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (MPP). (True)

7- The voltage at which PV module can produce maximum power is called open circuit voltage. (false, (maximum power point) or (peak power voltage))

8- For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. (True)

9- The maximum theoretical efficiencies of solar sales could be around 98%. (false, 48%)

10-First solar cell was invented by Charles Fritts. (True)

11-Normally, PV module works better at hot temperature. (false, cold)

12-The input rating of the inverter should never be lower than the total watt of appliances. (True)

13-The fill factor for the following module's characteristics: $V_{MPP}$=34.6V, $I_{MPP}$ = 4.77A, $I_{sc}$=5.46A, $V_{OC}$=43.1V is about 90%. (false, 70%)

14-Shading of 10% of the surface area of a string may cause more than a 30% reduction in output. (True)

15-Blocking diodes are used to mitigate shading. (True)



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***Q.*2** ***[10 marks]***

a) Consider a 100-cm$^2$ photovoltaic cell with reverse saturation current $I_0 = 10^{-12}$ A/cm$^2$. In full sun, it produces a short-circuit current of 40 mA/cm$^2$ at 25°C. Find the open-circuit voltage at full sun and again for 50% sunlight. Plot the results. ***(4 marks)***

***Solution:***

The reverse saturation current $I_0$ is $10^{-12}$ A/cm$^2$ × 100 cm$^2$ = 1 × $10^{-10}$ A.

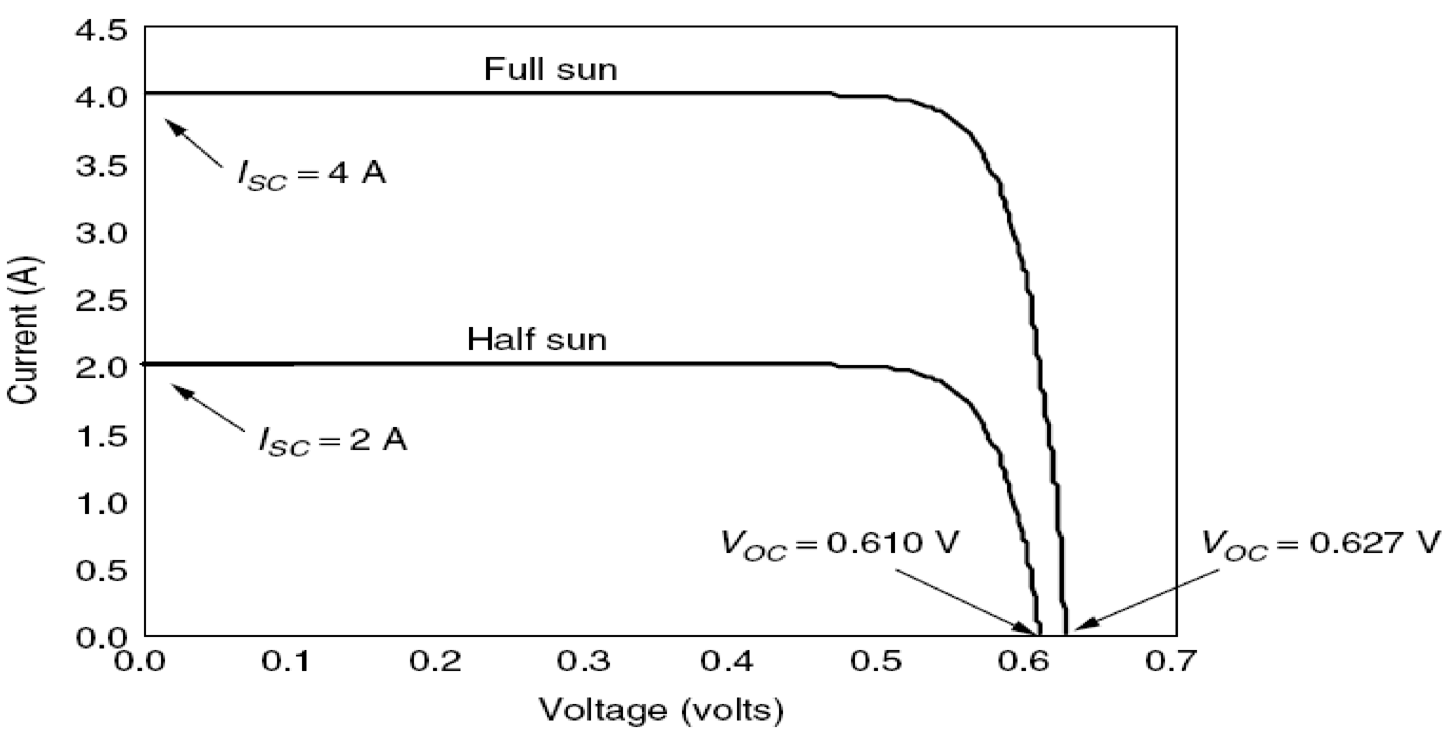
At full sun $I_{SC}$ is 0.040 A/cm$^2$ × 100 cm$^2$ = 4.0 A.

From the open-circuit voltage equation

$V_{OC} = 0.0257 \ln ((I_{SC} / I_0) + 1 = 0.0257 \ln ((4/10^{-10}) + 1) = 0.627$ V

Since short-circuit current is proportional to solar intensity, at half sun $I_{SC}$ = 2 A and the open-circuit voltage is

$V_{OC} = 0.0257 \ln ((2/10^{-10}) + 1) = 0.610$ V



b) 72-cell PV module has parallel resistance of 5.5 Ω per cell. In full sun, the output voltage is 34.6 V and the current is 4.77 A. If one cell is shaded and the current somehow stays the same. Determine: (i) the new module output voltage and power. (ii) the voltage drop across the shaded cell. (iii) the dissipated power in the shaded cell. ***(6 marks)***

***Solution:***

a) The drop-in module voltage will be

$\Delta V = (V/n) + IR_P = (34.6 / 72) + (4.77 \times 5.5) = 26.716$ V

The new output voltage will be 34.6 – 26.716 = 7.884 V.

Power delivered by the module with one cell shaded would be

$P_{module} = V\,I = 7.884 \text{ V} \times 4.77 \text{ A} = 37.6088 \text{ W}$

For comparison, in full sun the module was producing 165 W.

b) All of that 4.77 A of current goes through the parallel plus series resistance (0.005) of the shaded cell, so the drop across the shaded cell will be

$V_c = I\,(R_P + R_S) = 4.77 \times (5.5 + 0.005) = 26.259\ V$

(normally a cell in the sun will add about 0.5 V to the module; this shaded cell subtracts over 26.259 V from the module).

c. The power dissipated in the shaded cell is voltage drop times current, which is $P = V_c I = 26.259 \text{ V} \times 4.77 \text{ A} = 125.255 \text{ W}$

All that power dissipated in the shaded cell is converted to heat, which can cause a local hot spot that may permanently damage the plastic laminates enclosing the cell.

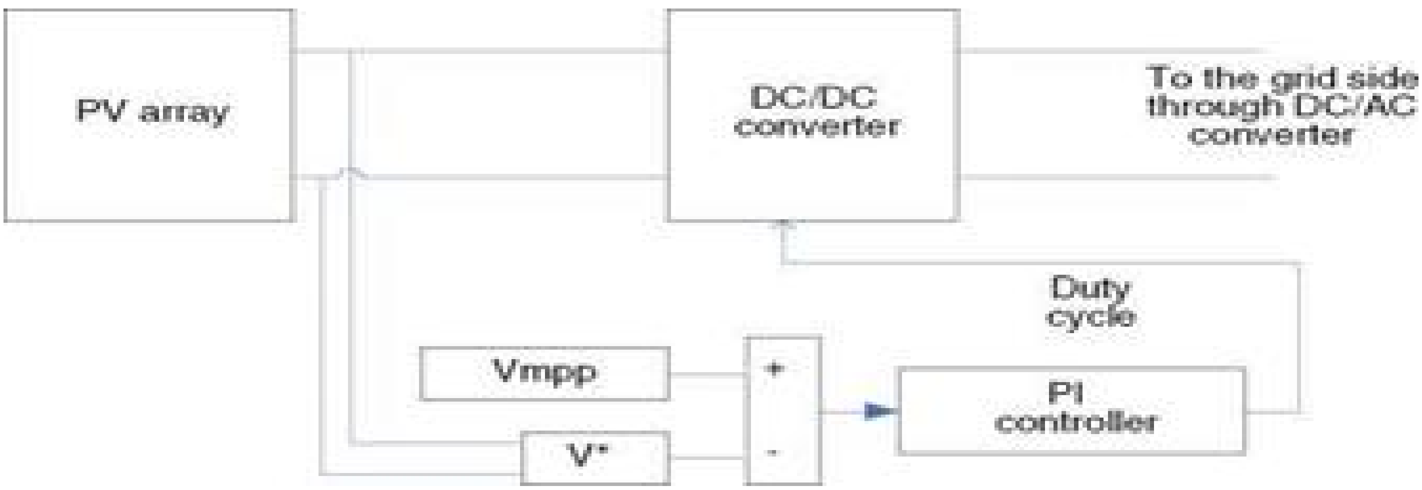
**Q.3** **[15 marks]**

a) Discuss in detail the MPPT systems of PV arrays and explain two commonly used techniques. **(5 marks)**

**MPPT Techniques**

1. Fractional open-circuit voltage.
2. Fractional short-circuit current.
3. Perturb and observe.
4. Incremental conductance

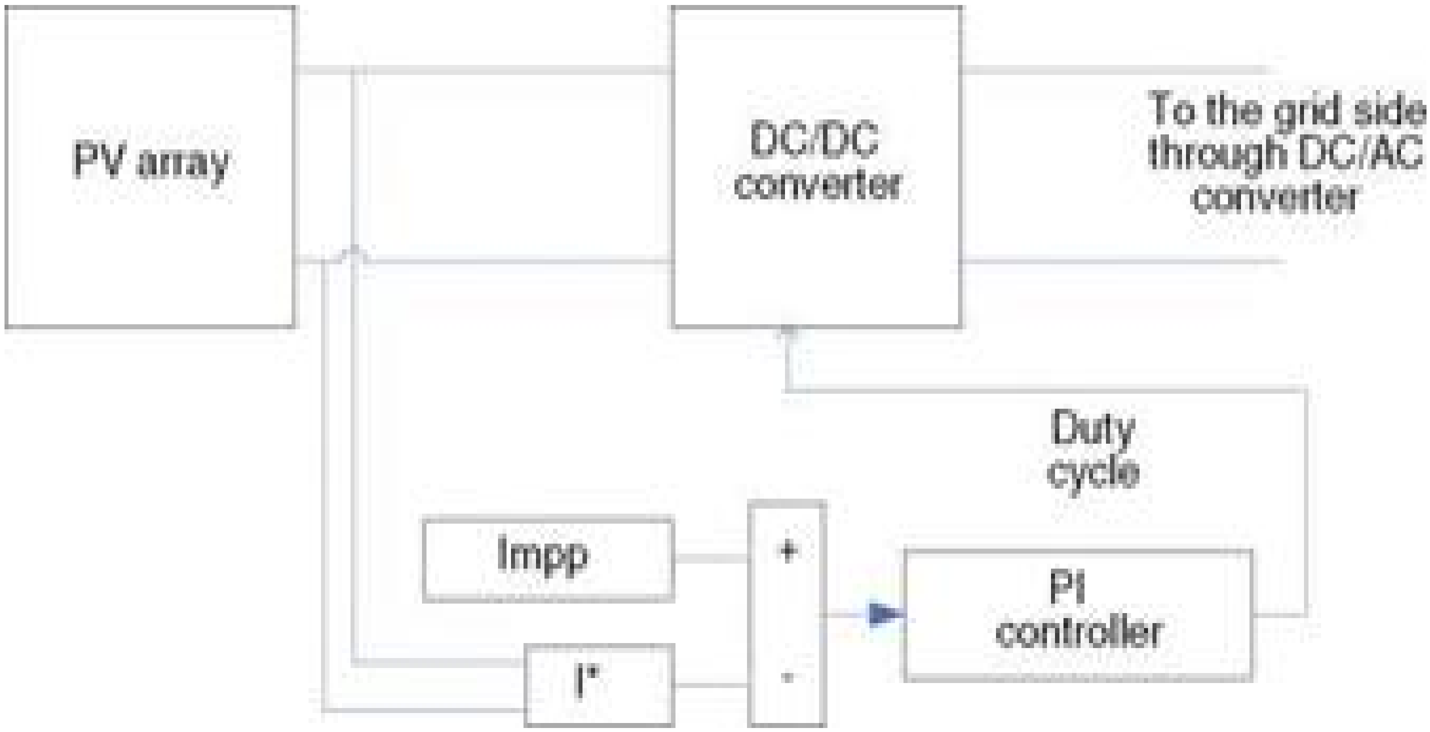
**Fractional open-circuit voltage (FOCV)**




- ❑ Fractional open-circuit voltage method sets the voltage value at the MPP equal to some fixed fraction of the measured open-circuit voltage.
- ❑ As the PV cells keep operating over longer periods, their open-circuit voltages are reduced and so are the values used for MPPT.
- ❑ Implementation of this method is simple.
- ❑ Its tracking efficiency is relatively low.
- ☐ $V_{MPP} \approx K\, V_{OC}$

**(K is the factor has been reported to be between 0.71 and 0.78)**

**Fractional Short-Circuit Current (FSCC)**

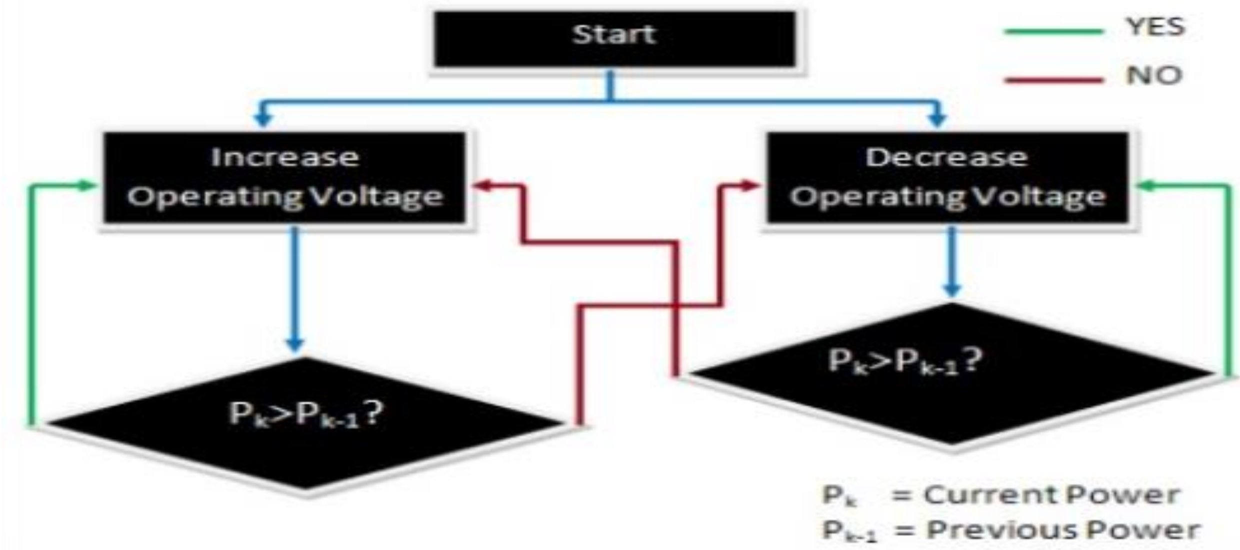



- ☐ FSCC is an unsophisticated but a swift technique of tracking the MPP.
- ☐ To track the power, this MPPT technique requires the value of SCC by isolating the PV array.
- ☐ The MPPT calculated using this technique is based on this equation ( $I_{mpp} \approx K\ I_{SC}$ ) which is an approximation, hence this method does not operate on true MPPT.

**(K is not constant. It's found to be between 0.78 and 0.92)**

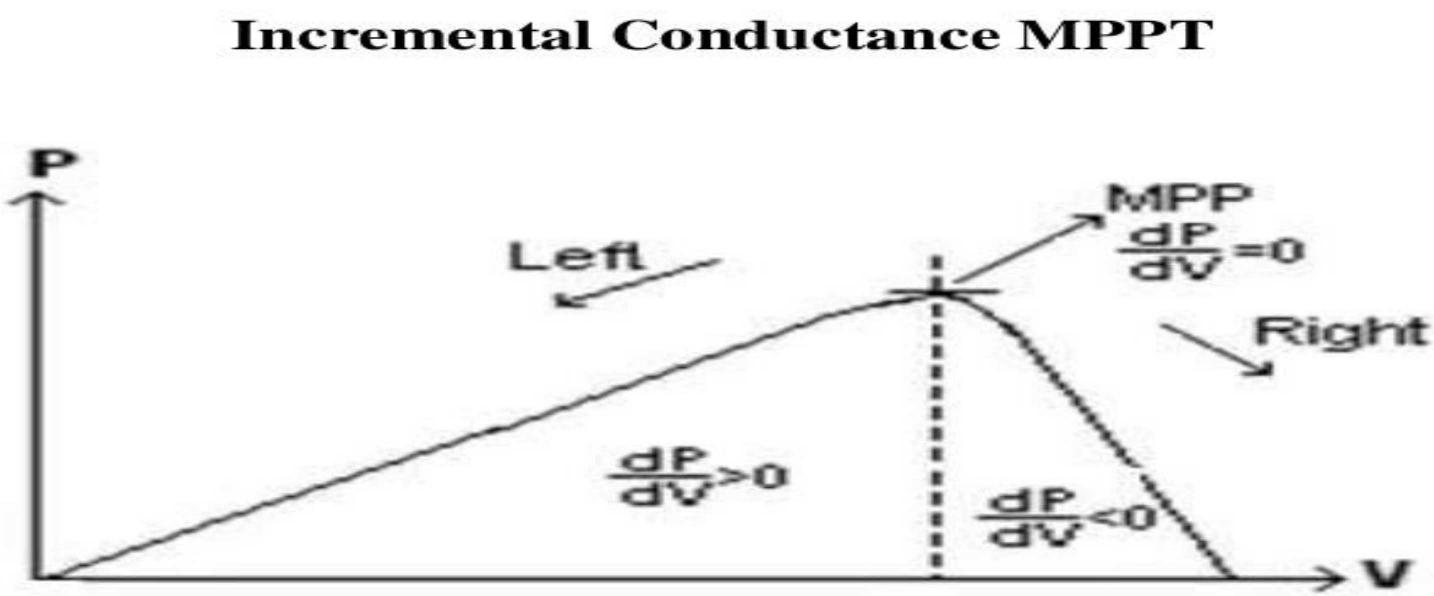
- ☐ This method is suitable to be implemented by using either the analog or the digital mode.
- ☐ The basic outline of this technique follows that the current at MPP ($I_{mpp}$) is closely located near the short circuit current Isc.
- ☐ Therefore, the operating point can be reached by multiplying Isc by the factor **k .**
- ☐ The constant "k" can be easily calculated from the specifications of the PV module and it is always less than 1.
- ☐ The constant k is a fixed value and therefore, can be used as a fixed entity in the algorithm.
- ☐ The accuracy of the method and tracking efficiency depends on the accuracy of K and periodic measurement of short circuit current.

**Perturb and observe (P&O)**




- ☐ Perturb and observe techniques, essentially, an application of the hill-climbing method.
- ☐ If an adjustment that increases the voltage raises the PV power output, then the voltage needs to be increased until the voltage increment no longer raises the power output.
- ☐ If the voltage increment lowers the PV power output, then in the next voltage adjustment reverse the sign of the disturbance.

**Incremental conductance (IC)**



b) Secondary school plans to get 25% of its electricity using photovoltaic array system on top of buildings where it is sunny. The total electrical load is 100 kW. The electrical characteristics of solar modules are: cell size: 12.55 × 12.55 cm, number of cells: 72, typical power: 150 Wp, minimum power: 145 $W_p$, voltage at typical power: 33.8 V, current at typical power: 4.45 A, short circuit current: 4.65 A, open circuit voltage: 43 V, module efficiency: 16.4 %, maximum circuit voltage: 1000 V. (i) Design the photovoltaic array system including (modules and inverter sizing). (ii) Design battery system for 2 hours daily. (iii) Estimate the required area for installing this PV system. ***(10 marks)***

Step (1): **Determine power consumption demands**

Total load use = 100 kW * 25 % * 8 hours = 200 kWh/day

Total PV panels energy required = 200 * 1.3 = 260 kWh/day

Step (2): **Size the PV panel**

Total $W_P$ of PV panel capacity needed = (260 kWh/day) / (8 hours/day) = 32.5 $kW_p$

Number of PV panels needed = 32.5 $kW_p$ / 150 $W_p$ = 217 modules

Step (3): **Inverter sizing**

For safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about 32 kW or greater.

Step (4): **Battery Sizing for 4 hours**

Total load use = 200 kWh/day

Nominal battery voltage = 12 V

Battery capacity = (200 kWh/day) / (0.85*0.6*12) = 32.68 kAh/day

Total Ah required for 2 hours per day = (32.68 kAh/day) * (2 hours / 8 hours per day) = 8.17 kAh

So the battery should be rated 12 V 66 kAh for 2 hours

Step (5): R**equired area for installing this PV system**

Area of one module = (12.55 cm × 12.55 cm) * 72 = 1.134 $m^2$

Required area by 217 modules = 1.134 $m^2$ * 217 = 246.078 $m^2$

Actual required area = 246.078 $m^2$ * 1.25 = 307.6 $m^2$

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*With our best wishes*