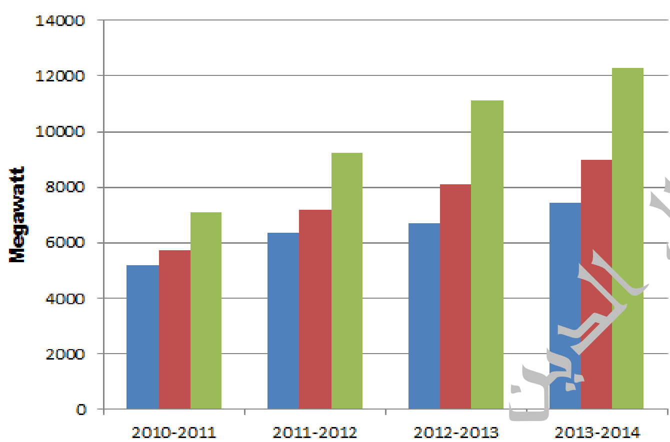
Tanta University

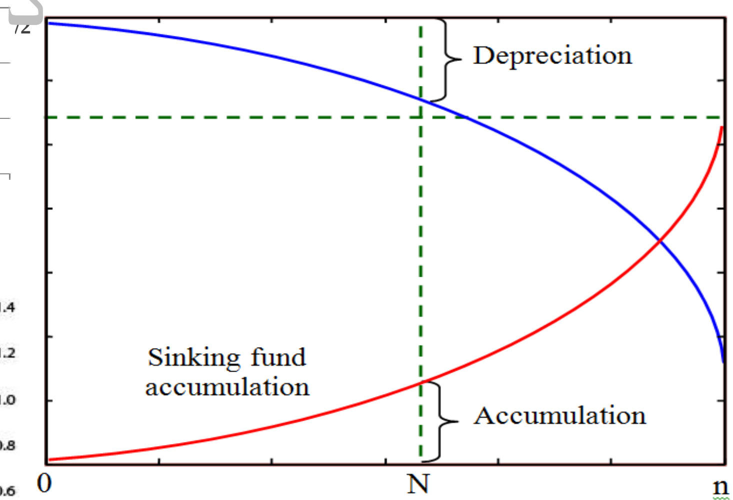
Electrical Power and Machines Engineering Department

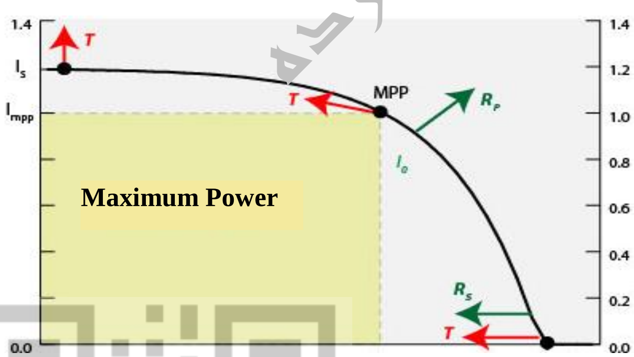
Faculty of Engineering

Economic Operation of Power Systems

Lab notes for 3rd year students







NAME	
CLASS	

CONTENTS

1- Computer program (1)

Optimal cross section area of conductors

1.1 Objectives

- To realize the effect of varying the cross section area of conductors on both the capital and running costs
- To recognize the meaning of optimization
- To familiarize students with the mathematical basis of calculating the optimal cross section area of conductors
- To write computer program to calculate the optimal cross section area of conductors under certain conditions

1.2 Background

There are many techniques that can be used to obtain the cross section area of the conductor. Any technique has to satisfy two main conditions: the first is the thermal capability of the conductor to carry out the rated current. The cross section area has to allow for the required current without excessive thermal power. This cross section area can be calculated using the current density of the overhead lines and free-to-air conductors. For underground cables, on the other hand, special tables can be used to find out the suitable cross section area depending on, e.g. the type of the cable.

The energy wasted in a transmission line can be calculated as follows:

$$W = \frac{I^2 \cdot R \cdot T}{1000} \quad kWh \qquad (1\text{-}1)$$

Where: T is the total operating time (h). If the tariff of kWh is "c" (L.E. / kWh), the cost of lost energy is calculated as:

$$C_{Le} = c\frac{I^2 \cdot R \cdot T}{1000} = c\frac{I^2 \cdot \rho \cdot L \cdot T}{1000 \cdot a} = \frac{K_1}{a} \qquad (1\text{-}2)$$

The fixed cost of the conductor (the price cost in addition to the installation cost) is directly proportional to the cross section area:

$$C_f = K_2.a.D \qquad (1\text{-}3)$$

Where: C_f is the fixed cost and D is the annual interest and depreciation. The fixed and running costs are illustrated as functions of the cross section area in Fig. 1-1. The total cost of the transmission line is calculated by adding the fixed cost to the cost of energy loss.

$$C_{tot} = \frac{K_1}{a} + K_2 \cdot a \,.D \qquad (1\text{-}4)$$

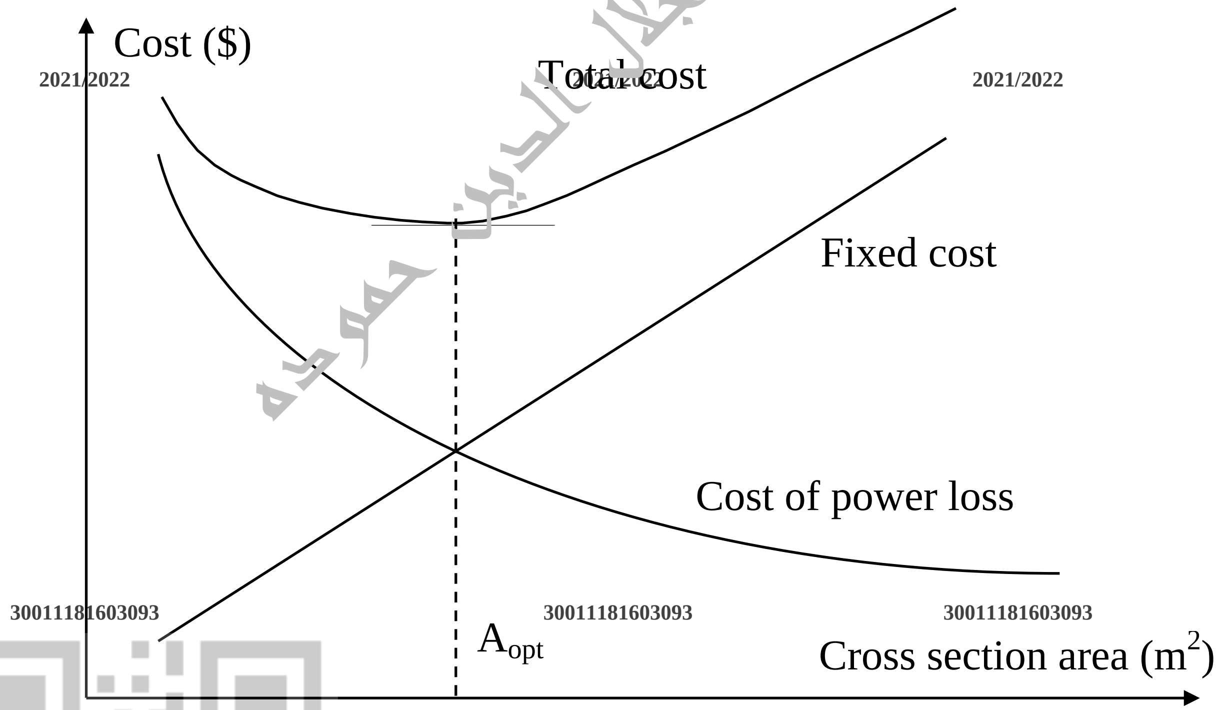


Fig. 1-1 Dependence of the cost of conductors on its cross section area

For minimum cross section area:

$$\frac{\partial C_{tot}}{\partial a} = 0 \Rightarrow -\frac{K_1}{a^2} + K_2 \cdot D = 0 \Rightarrow a = \sqrt{\frac{K_1}{K_2 \cdot D}} \qquad (1\text{-}5)$$

1.3 Applications

Taking the values of the constants for a certain cable as follows: $K_1=10^{-4}\$m^2$, $K_2=2*10^5\$/m^2$ and D=8%, write a MATLAB program to illustrate the variation of both the fixed and running costs with the cross section area of the cable. The figure has to include the total-cost curve. The area varies from 50 up to 100mm^2.

1.4 Results and discussion

- Describe the variation of the fixed, the running and the total costs with the cross section area of the cable.
- Extract the value of the optimal cross section area and the corresponding fixed and running cost
- Verify the obtained optimal cross section area by calculating its value using equation 1-5.

2- Computer program (2)
Depreciation cost

2.1 Objectives

- To realize the different methods of calculating the depreciation cost
- To have the capability of calculating the amount of set aside per year for the accumulation of the depreciable investment at the end of n^{th} year using the common tree methods
- To write computer program to calculate the annual unit depreciation using different methods

2.2 Background

The depreciation cost represents the annual cost required to the depreciation caused by the wear and tear of equipment and machines because of the normal operation. At the end of operating life, the equipment and machines have to be replaced.

It is required, then, to get aside certain amount of the income to collect sufficient money that is equal to the capital invested in these machines and equipment. The main symbols are as follows:

P= Initial investment value of all equipment (capital cost)

S= Salvage value at the end of the life time (Scrap value)

n= Life of the equipment in years

A= The amount set aside per year for the accumulation of the depreciable investment at the end of n^{th} year

r= Annual rate of compound interest on the investment capital

x= Annual unit depreciation

2.2.1 Straight line method

In the straight-line method, a fixed annual amount is set aside as in equation 2-1. Fig. 2-1 illustrates this method.

$$A = \frac{P - S}{n} \qquad (2\text{-}1)$$

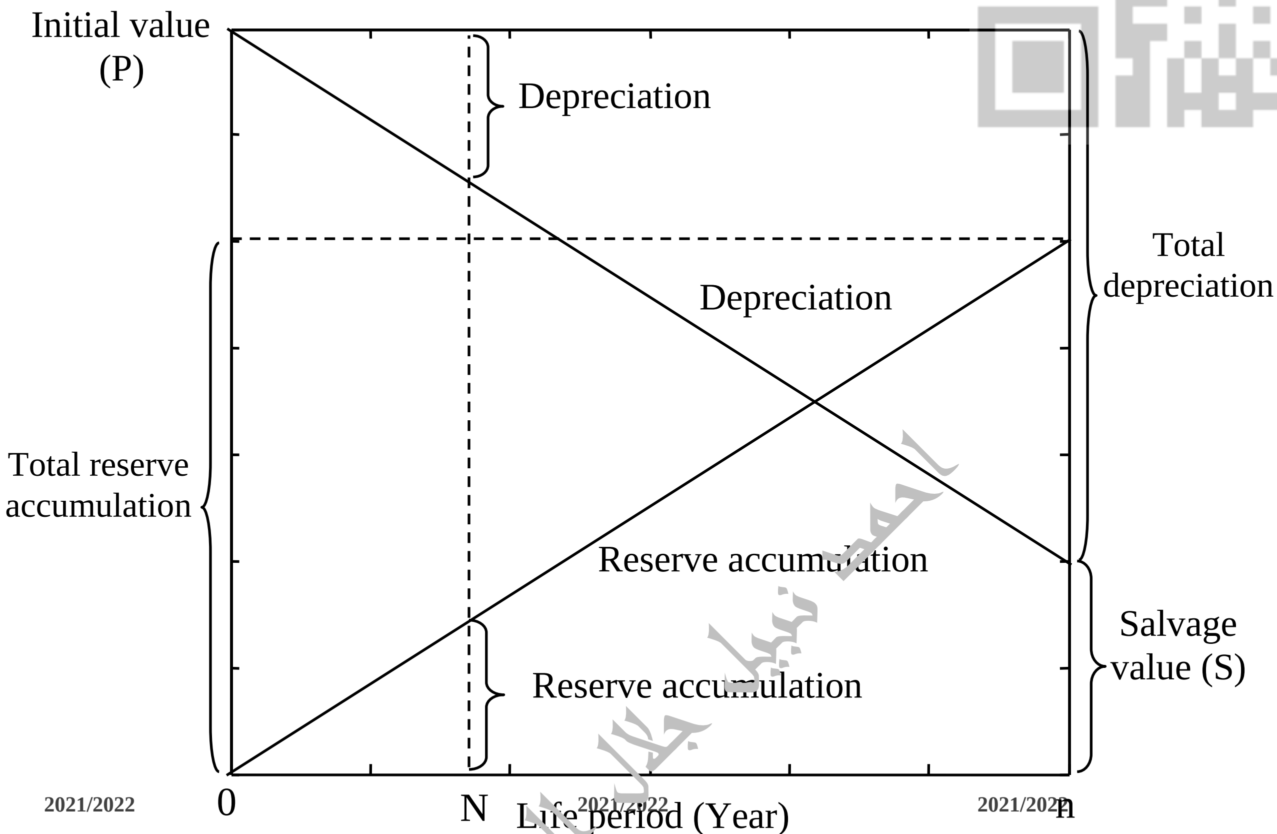


Fig. 2-1 Straight-line method of depreciation

2.2.2 Diminishing-value method

In the diminishing-value method, the amount set aside per year decreases with the life of the equipment, where a fixed rate of depreciation is applied as shown in Fig. 2-2. The value of the equipment and the amount of money set aside per year for the accumulation of the depreciable investment at the end of the n^{th} year are calculated as follows:

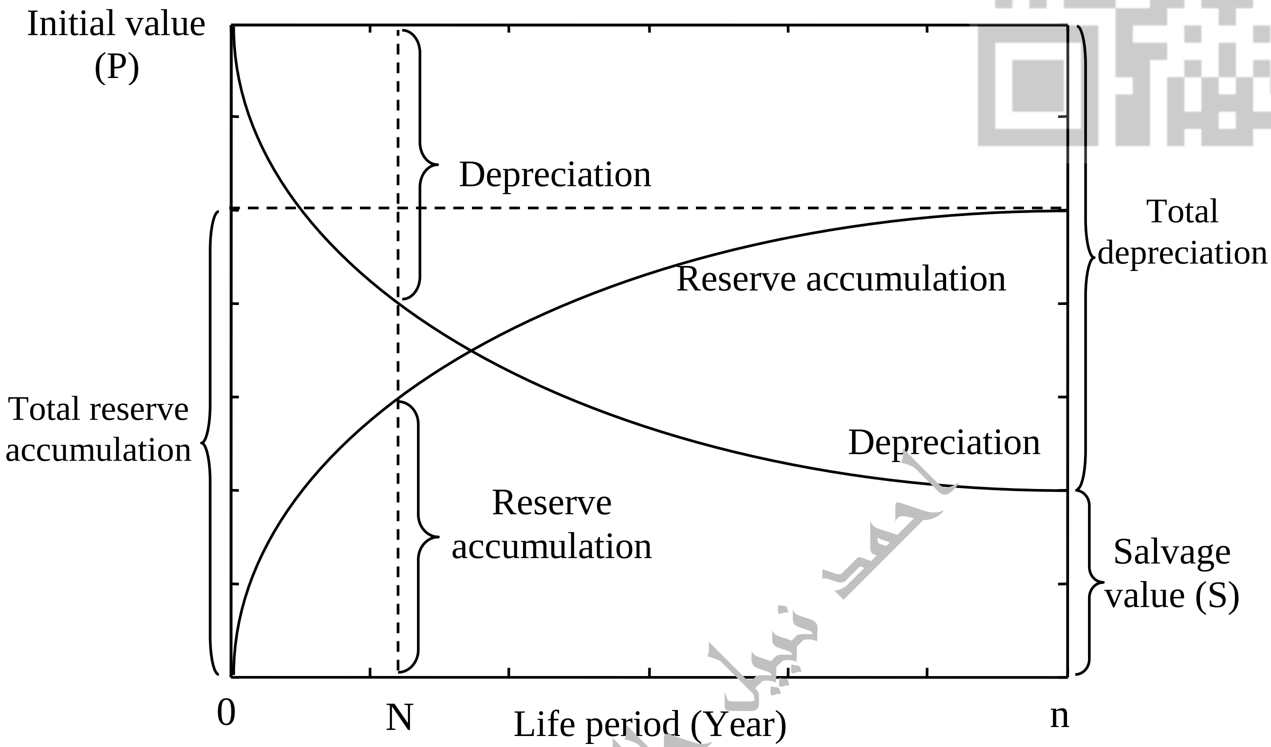


Fig. 2-2 Diminishing-value method of depreciation

$$\text{Value of the equipment} = P \cdot (1-x)^{n} \qquad (2\text{-}2)$$

$$\text{Set aside money} = x \cdot P \cdot (1-x)^{n-1} \qquad (2\text{-}3)$$

The annual unit depreciation can be calculated as follows:

$$x = 1 - \sqrt[n]{\frac{S}{P}} \qquad (2\text{-}4)$$

2.2.3 Sinking-value method

In the sinking-fund method, the amount of interest earned by the saved money is taken into account. The set aside per year consists of the annual payment and the earned interest. Fig. 2-3 illustrates the sinking-fund method.

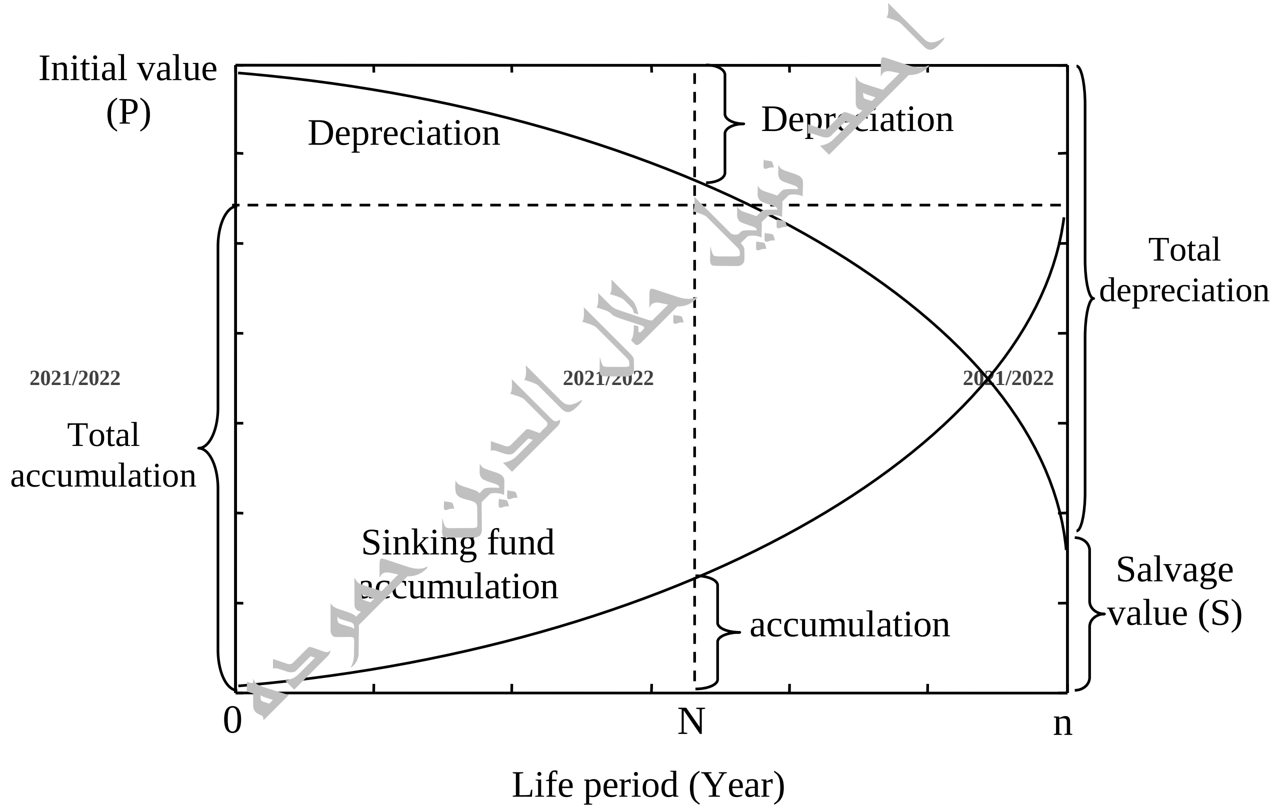


Fig. 2-3 Sinking-fund method of depreciation

The value of set aside money at the end of the nth year is given as: $A(1+r)^{n-1}$

The total amount of accumulation at the end of the n^{th} year is calculated as:

$$y = A\frac{(1+r)^n - 1}{r} \qquad (2\text{-}5)$$

And The amount set aside per year at the end of n^{th} year is:

$$A = \left(\frac{r}{(1+r)^n - 1}\right)(P - S) \qquad (2\text{-}6)$$

2.3 Applications

A distribution transformer has an initial cost of $1.56*10^6$ L.E. and a salvage value of $60*10^3$ L.E. at the end of the 25^{th} year. Write a MATLAB program to draw the depreciation and the reserve accumulation using the three methods of depreciation assuming that the annual rate of compound interest on the investment capital is 10%. Compare the depreciation using the three methods at the end of the:

a) 10^{th} year b) 15^{th} year

c) 20^{th} year and d) 25^{th} year

2.4 Results and discussion

- Conclude on the results obtained from each method
- Critic each method based on the obtained results
- Verify the values of depreciation using the three methods using those obtained from figures.

3- Computer program (3)

Incremental fuel cost

3.1 Objectives

- To familiarize students with the performance curve of the boiler-turbine-generator set
- To recognize the incremental heat rate and the incremental fuel rate

3.2 Background

The performance curve of the boiler-turbine-generator set is illustrated in Fig. 3-1. The incremental heat rate is defined as the ratio of input fuel to the corresponding output power with a unit of (Btu/MWh).

Fig. 3-2 illustrates a typical heat rate curve.

The incremental fuel rate is calculated using the following equation:

$$\text{Incremental fuel rate} = \frac{\Delta\,(\text{input})}{\Delta\,(\text{output})} \approx \frac{d\,(F)}{d\,(P)} \qquad (3\text{-}1)$$

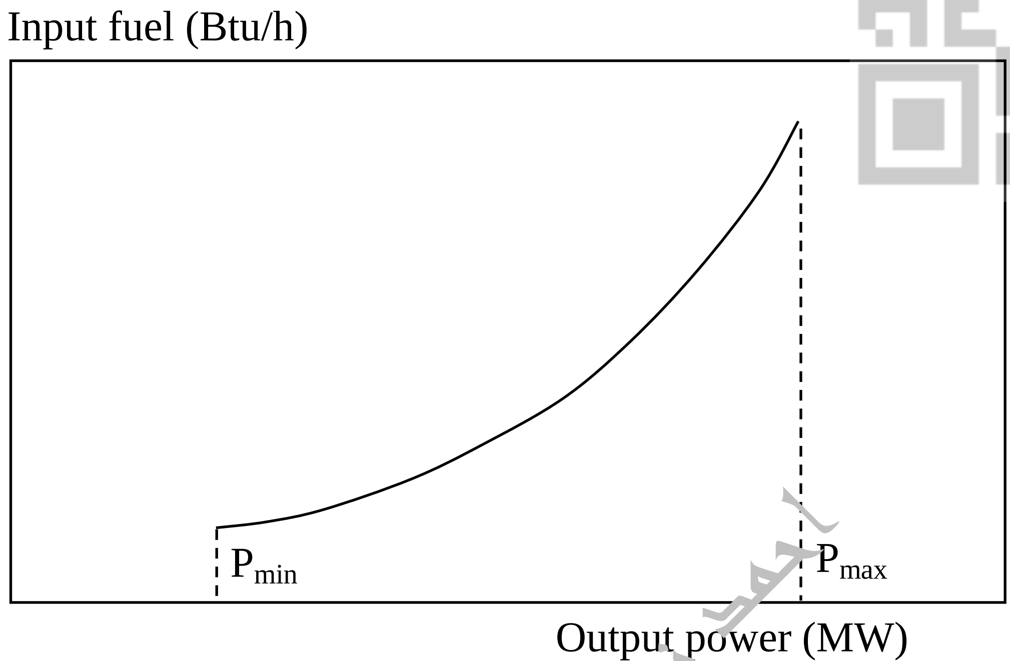


Fig. 3-1, Input-output curve of a generating unit

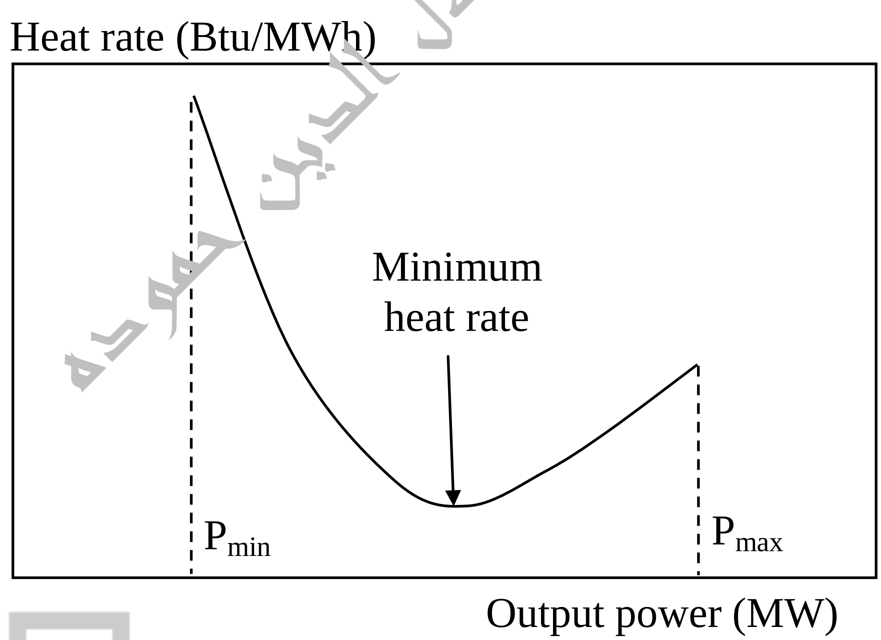


Fig. 3-2, Incremental heat rate curve

With F is the input fuel and P is the output power. The unit associated with incremental fuel rate is (Btu/MWh). To operate at the maximum fuel efficiency, the point of the minimum heat rate has to be defined. Multiplying the incremental fuel rate by the cost of fuel, the incremental fuel cost is obtained in terms of ($/MWh).

3.3 Applications

The input fuel in (Btu/h) for a power plant with min. and max. power of 10 and 100 MW respectively is given by: $F=(40+4*P + 0.012*P^2)*10^6$, where P is the generated power in (MW). Write a MATLAB program to plot the input-output curve of the plant. Calculate the heat rate and plot its curve against the output power. Assuming a fuel cost of $0.12*10^{-6}$ $/Btu, calculate the incremental fuel cost in $/MWh and plot its curve against the output power.

3.4 Results and discussion

- What is the minimum value of the input heat rate?

- What is the value of the incremental fuel cost corresponding to a generated power of 70MW?
- What is the value of the input fuel rate corresponding to a generated power of 50MW?

4- Computer program (4)

Economic load dispatch neglecting losses

4.1 Objectives

- To realize the meaning of the Economic load dispatch
- To evaluate the different methods used to solve the Economic load dispatch problem
- To apply the conditions of optimal load dispatch to distribute loads among generating units to achieve the optimal economic operation

4.2 Background

The cost function of thermal power plants is given as follows:

$$C = \alpha + \beta * P + \gamma * P^2 \qquad (4\text{-}1)$$

It is assumed that all generators are connected at the same bus without any losses in the transmission lines. The condition of optimal operation of the system in this case is given by the equation:

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2} = \dots = \frac{dF_n}{dP_n} = \lambda \qquad (4\text{-}2)$$

Where: λ is the Lagrange multiplier, F_i is the input fuel to i^{th} unit and P_i is the output power of the i^{th} unit. The optimal generated power from each unit is:

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i} \qquad i=1,2,\dots n \qquad (4\text{-}3)$$

The Lagrange multiplier is calculated from the relation:

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$$\lambda = \frac{P_D + \sum_{i=1}^{n} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{n} \frac{1}{2\gamma_i}} \qquad (4\text{-}4)$$

Where: P_D is the total load demand

The following steps can be followed to obtain the solution for the previous equations:

- Define the coefficients of the cost functions of all generating units (β_i and γ_i, i=1,2,…n)

- For a certain load demand, calculate the value of the λ according to equation (4-4).
- Depending on the calculated value of λ, compute the individual power P_1, P_2, ... P_n corresponding to incremental fuel cost of production as given by equations (4.3).
- Check for max. and min. output power for each plant. In case of violating the generation limits for any of them, the output power of that generator is fixed at its extreme limit
- The remaining load demand is calculated by subtracting the output power of the plant that operates at its extreme limit and the new demand is distributed among the remaining generators.

The following flow chart summarizes the proceedings.

4.3 <u>Applications</u>

The incremental fuel costs in \$/MWh for a plant consisting of three units are given by:

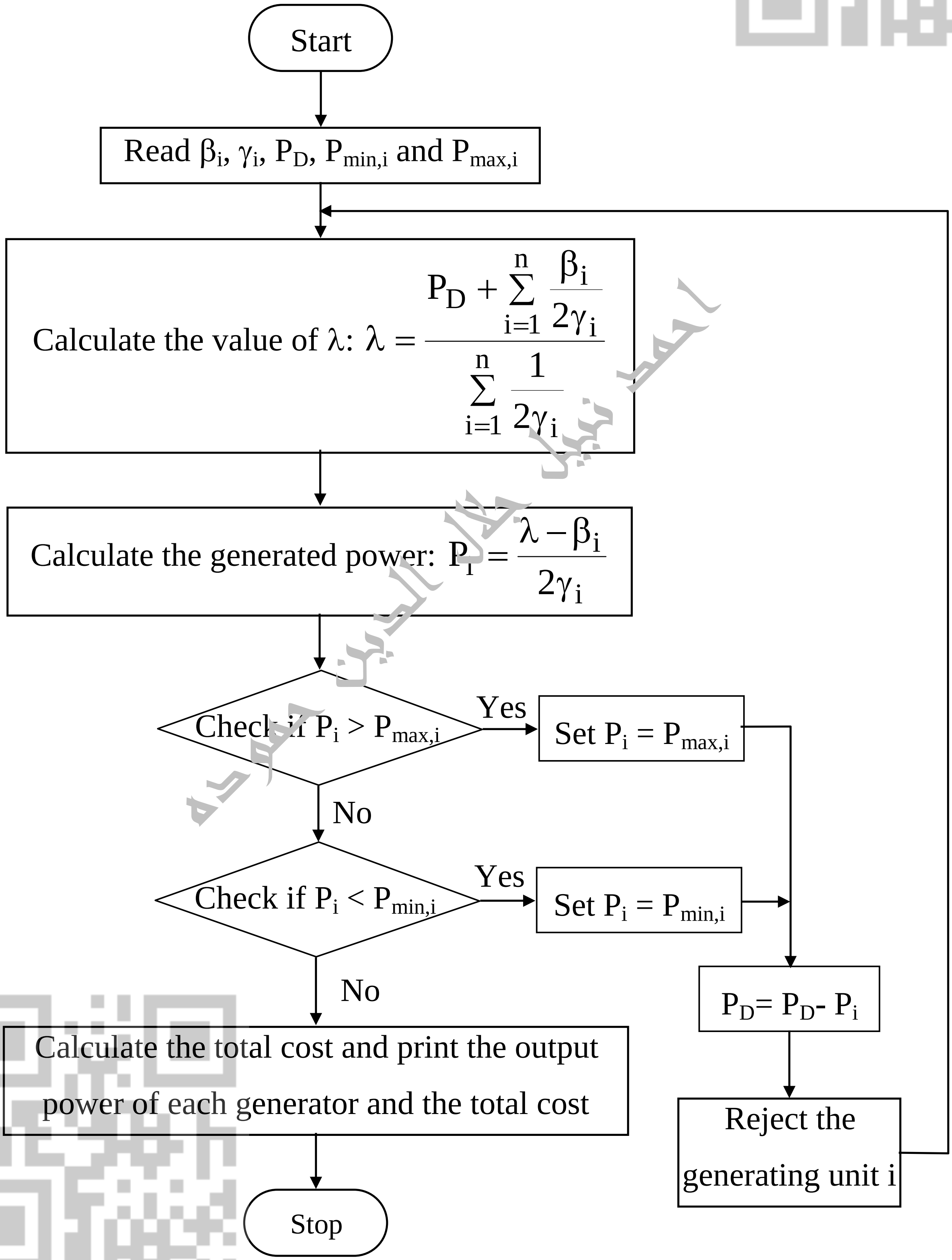
$$\frac{dF_1}{dP_1} = 0.008P_1 + 4 \qquad \frac{dF_2}{dP_2} = 0.01P_2 + 3 \qquad \frac{dF_3}{dP_3} = 0.007P_3 + 3.8$$

Assuming that all units are operating at all times and the load demand varies from 300 to 1500 MW, find the incremental fuel cost of the plant and the optimal allocation of load between the three units. The minimum and maximum loads on each unit are respectively 80 and 500 MW.

4.4 <u>Results and discussion</u>

- Fill out the following table:

P_D (MW)	λ	P_1 (MW)	P_2 (MW)	P_3 (MW)
300				
500				
700				
900				
1100				
1300				
1500				


Start
Read β_i, γ_i, P_D, $P_{min,i}$ and $P_{max,i}$
Calculate the value of λ: $\lambda = \dfrac{P_D + \sum_{i=1}^{n} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{n} \frac{1}{2\gamma_i}}$
Calculate the generated power: $P_i = \dfrac{\lambda - \beta_i}{2\gamma_i}$
Check if $P_i > P_{max,i}$
Yes
Set $P_i = P_{max,i}$
No
Check if $P_i < P_{min,i}$
Yes
Set $P_i = P_{min,i}$
No
$P_D = P_D - P_i$
Reject the generating unit i
Calculate the total cost and print the output power of each generator and the total cost
Stop

5- Computer program (5)
Economic load dispatch neglecting losses using iterative technique

5.1 Objectives

- To apply the iterative technique to distribute certain loads among generating units to achieve the optimal economic operation
- To compare between equation-solving technique and iterative technique in solving the optimal economic dispatch problem

5.2 Background

The problem is the same as described in the previous computer program. The difference lies only on the technique of solving the problem. In this case, an iterative method is used. The steps of the iterative solution are explained in the following:

- Assume a suitable value of λ that is greater than the largest value of β_i.

- Compute the individual power P_1, P_2, ... P_n corresponding to incremental cost of production from equations (4.3).
- Check for max. and min. output power for each plant. In case of violating the generation limits, the output power of that generator is fixed at its extreme limit.
- Check if the equality constraint $\sum_{i=1}^{n} P_i = P_D$ is satisfied.
- If not, modify the value of λ and repeat the above steps. The new value of λ depends on its previous value and the difference between load demand and the generated power. For example, if the total generation exceeds the total demand, the value of l has to be decreased and vice versa.
- If equality is satisfied, the optimal load dispatch is achieved and the results are saved.

The step change of λ in each step in the previous procedures is not fixed and can be defined using a suitable criterion. For example, the difference between load demand and the generated power can be normalized with respect to the load demand and the value of λ is increased or decreased with the half ratio. As an alternative, it is possible to define a step change of λ, i.e. Δλ and performing two steps. Then, an extrapolation is performed to find out a new suitable value of λ. The following flow chart summarizes the proceedings:

The active power generation constraints have to be taken into account while solving the economic dispatch problem. If the constraints of upper or lower power limits are violated for any generator, the power is tied to the corresponding limit as a fixed value while the rest of the demand is distributed over the other operating generators. The distribution of the rest of the demand over the other generators is carried out according to the equal incremental cost of production. This process is called re-dispatch analysis

5.3 <u>Applications</u>

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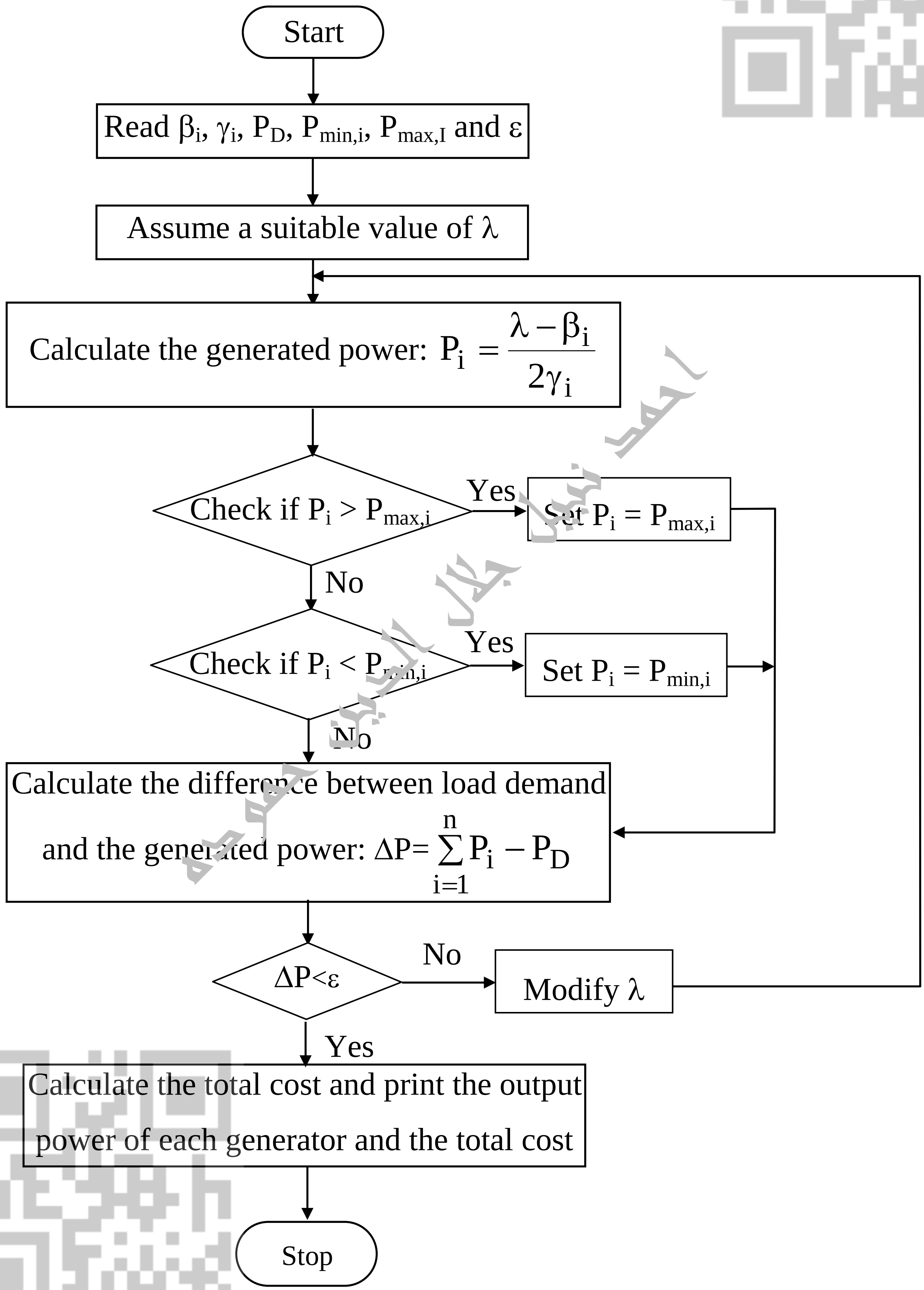
Use the iterative technique to solve the problem given in section 4-3 assuming a tolerance of 2%. The load varies between 300 and 1500MW.


Start
Read βi, γi, PD, Pmin,i, Pmax,I and ε
Assume a suitable value of λ
Calculate the generated power: $P_i = \frac{\lambda - \beta_i}{2\gamma_i}$
Check if Pi > Pmax,i
Yes
Set Pi = Pmax,i
No
Check if Pi < Pmin,i
Yes
Set Pi = Pmin,i
No
Calculate the difference between load demand
and the generated power: $\Delta P = \sum_{i=1}^{n} P_i - P_D$
ΔP<ε
No
Modify λ
Yes
Calculate the total cost and print the output
power of each generator and the total cost
Stop

5.4 Results and discussion

- Fill out the following table:

P_D (MW)	λ	P_1 (MW)	P_2 (MW)	P_3 (MW)
300				
500				
700				
900				
1100				
1300				
1500				

- Compare between results obtained using this technique and those obtained in the previous method
- Compare between times consumed in the calculations in the two methods.
- Compare between the simplicity of programming
- Correlate between the accuracy and the consumed time

6- Computer program (6)

Theoretical characteristics of photovoltaic

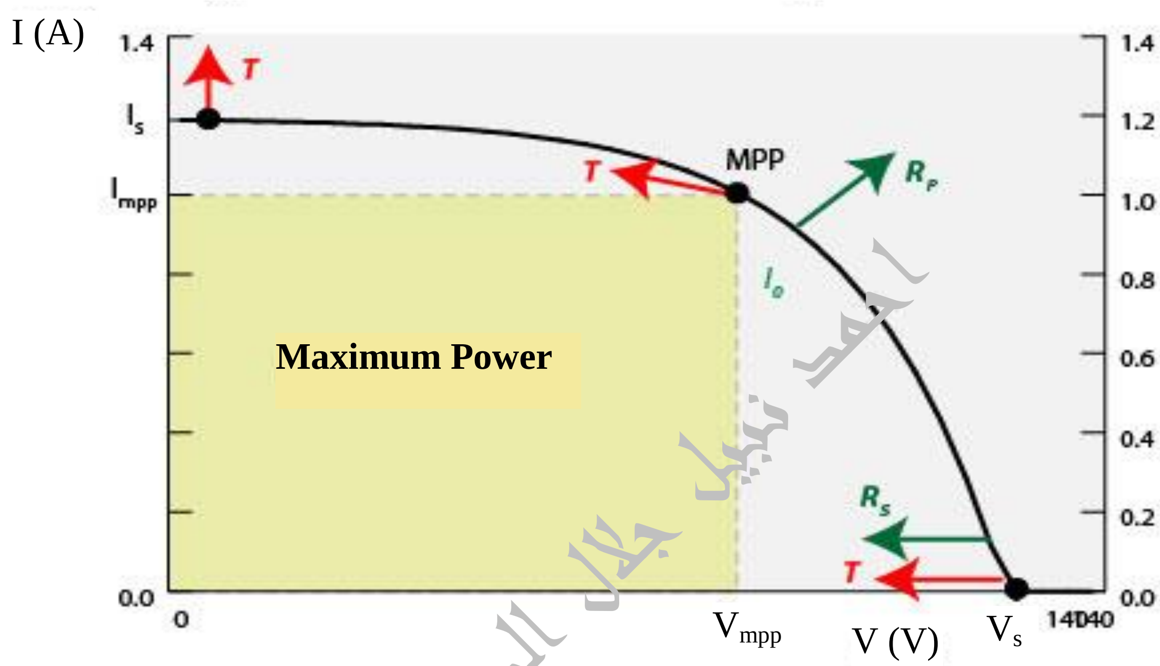
6.1 Objectives

- To draw the voltage current characteristics of the photovoltaic system
- To identify the parameters and variables affecting the characteristics
- To extract the important operating parameters from the curves such as the open loop voltage and the short-circuit current

6.2 Background

In a string of series-connected PV cells, the resultant string operating voltage V is always the sum of the individual cell operating voltages (V1, V2, V3, etc.). The current I passing through each cell in the series-connected string must be the same as the current in the external load circuit. The combined I–V characteristic of a system of series-connected cells can therefore be obtained by adding the voltages of individual cells at equal currents.

Typical I-V characteristics of photovoltaic



6.3 <u>Applications</u>

Write a MATLAB program to draw the voltage-current characteristics of a photovoltaic system having the following parameters:

Series resistance: 0.003 Ω;

Reverse saturation current: 0.000025 A;

Number of series cells: 36;

Number of shunt cells: 6;

Compilation factor: 1.66;

Photon current: 5.6;

Electric charge: $1.6e^{-19}$;

Boltzmans constant: $1.38e^{-23}$;

Absolute temperature: 300;

6.4 Results and discussion

- Plot the voltage current characteristics
- Extract the no load voltage and the short circuit current
- Define the point of the maximum power

7- Practical Experiment (1)

Typical V-I characteristics of photovoltaic

7.1 Objectives

The main objective of the experimental setup is to test the performance of the PV module under standard conditions. It is thus required to draw a typical V-I characteristic of the module. To achieve that, it is necessary to construct a laboratory arrangement that enables measuring the volt and current of the PV system under different loading conditions.

7.2 Required Equipment

1) A PV array (60W)
2) A regulator
3) Suitable variable resistive load
4) An Ammeter (3A)
5) A voltmeter (50V)
6) A Luxmeter
7) A Protractor

7.3 Procedures

1) Connect the PV array with regulator in series
2) Connect the regulator with variable load in series
4) Connect an Ammeter in series with the load to measure the current drawn by it
3) Connect a voltmeter in parallel with the regulator to measure the voltage of PV

5) Use a Luxmeter to measure the irradiation. Measure the value of the irradiation to ensure that it is suitable of the module
6) Use a Protractor to measure the tilt angle. Adjust the angle of the module (between 120 and 140)

7) Maintain the values of the irradiance and the tilt angle fixed at their standard values and without any shadow
8) Adjust the resistive load to the highest value and record the voltage and the current
9) Change the value of the resistive load and in each time record the voltage and the current in the following table:

7.4 Results

- Record the voltage and the current in the following table:

R(ohm)						
V(volt)						
I(ampere)						

- Plot the voltage-current characteristics

7.5 Questions

- What is the values of the no load voltage and the short circuit current
- What is the value of the maximum power on the curve

8- Practical Experiment (2) Variation of V-I characteristics with affecting factors

8.1 Objectives

The main objective of this experiment is to study the influence of some factors on the PV characteristics. Among these factors are:

- Different level of irradiance
- Shadow
- Tilt angle

To study the influence of these factors, two of them are maintained fixed and the third factor is changed. However, only the first two factors are studied in these experiments.

8.2 Required Equipment

1) A PV array (60W)
2) A regulator
3) Suitable variable resistive load

4) An Ammeter (3A)
5) A voltmeter (50V)
6) A Luxmeter
7) A Protractor

8.3 <u>Fixed tilt angle with different irradiation without shadowing</u>

The luxmeter is used to measure the variation of irradiance with fixed tilt angle (between 120 and 140) and then the values of voltage and current are recorded.

8.3.1 Procedures

1) Connect the PV array with regulator in series
2) Connect the regulator with variable load in series
4) Connect an Ammeter in series with the load to measure the current drawn by it
3) Connect a voltmeter in parallel with the regulator to measure the voltage of PV
5) Use a Luxmeter to measure the irradiation.
6) Use a Protractor to measure the tilt angle. Adjust the angle of the module (between 120 and 140)

7) Maintain the values of the tilt angle fixed at its standard values and without any shadow

8) Adjust the resistive load to the highest value and record the voltage and the current

9) Change the value of the resistive load and in each time record the voltage and the current.

10) Change the value of the irradiance and repeat steps 8 and 9. The irradiance can be changed by performing the test at different timing through the day. Alternatively, the array is subjected to a ***complete shadow*** to reduce the irradiation.

8.3.2 Results

- Record the voltage and the current in the following table:

Irradiance						
	V					
	I					
	V					
	I					
	V					
	I					
	V					
	I					
	V					
	I					

- Plot a family of curves representing the voltage-current characteristics under different irradiation values.

8.3.3 Questions

- What is the effect of changing the irradiation on the V-I characteristics of the module
- What is the effect of changing the irradiation on the maximum power
- What is the effect of changing the irradiation on the no load voltage and the short circuit current

8.4 Fixed irradiation and tilt angle with shadow

The array is subjected to a shadow either partially or completely. The shadow can be extended to 1/4, 1/2, 3/4 and the whole PV cell. At each time, the following procedures ate accomplished:

8.4.1 Procedures

1) Connect the PV array with regulator in series
2) Connect the regulator with variable load in series
4) Connect an Ammeter in series with the load to measure the current drawn by it

3) Connect a voltmeter in parallel with the regulator to measure the voltage of PV

5) Use a Luxmeter to measure the irradiation.

6) Use a Protractor to measure the tilt angle. Adjust the angle of the module (between 120 and 140)

7) Maintain the values of the tilt angle and the irradiation fixed at their standard values

8) Adjust the resistive load to the highest value and record the voltage and the current

9) Change the value of the resistive load and in each time record the voltage and the current.

10) Apply a certain shadow and repeat steps 8 and 9.

8.4.2 Results

- Record the voltage and the current in the following table:

Shadow	*Voltage and current*				
1/4	*V*				
	I				
1/2	*V*				
	I				
3/4	*V*				
	I				
4/4	*V*				
	I				

- Plot a family of curves representing the voltage-current characteristics under different Shadowing.

8.4.3 Questions

- What is the effect of changing the shadowing level on the V-I characteristics of the module
- What is the effect of changing the shadowing level on the maximum power
- What is the effect of changing the shadowing level on the no load voltage and the short circuit current