Session 4:

Solar Charge Controller & Regression

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SESSION CONTENT

1. **Maximum Power Point Tracking**

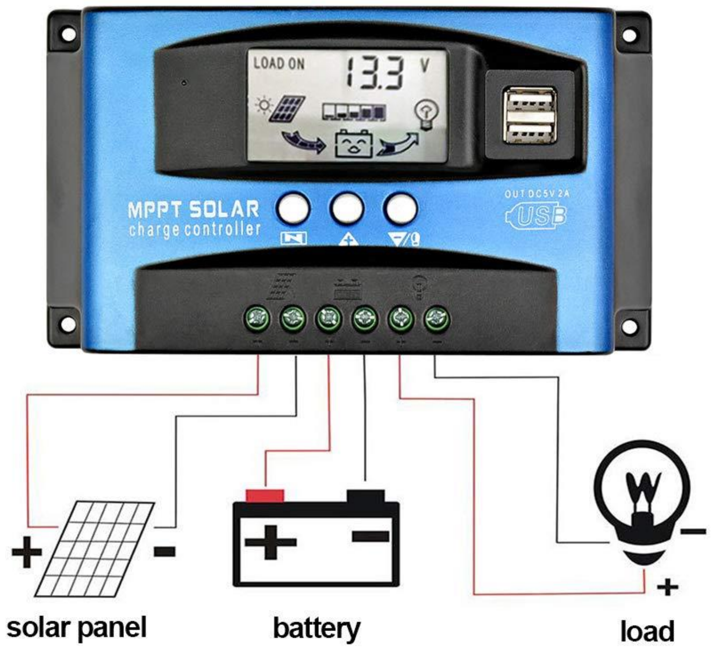
2. **Regression**

Introduction to MPPT

The major principle of Maximum Power Point Tracking (MPPT) is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point)

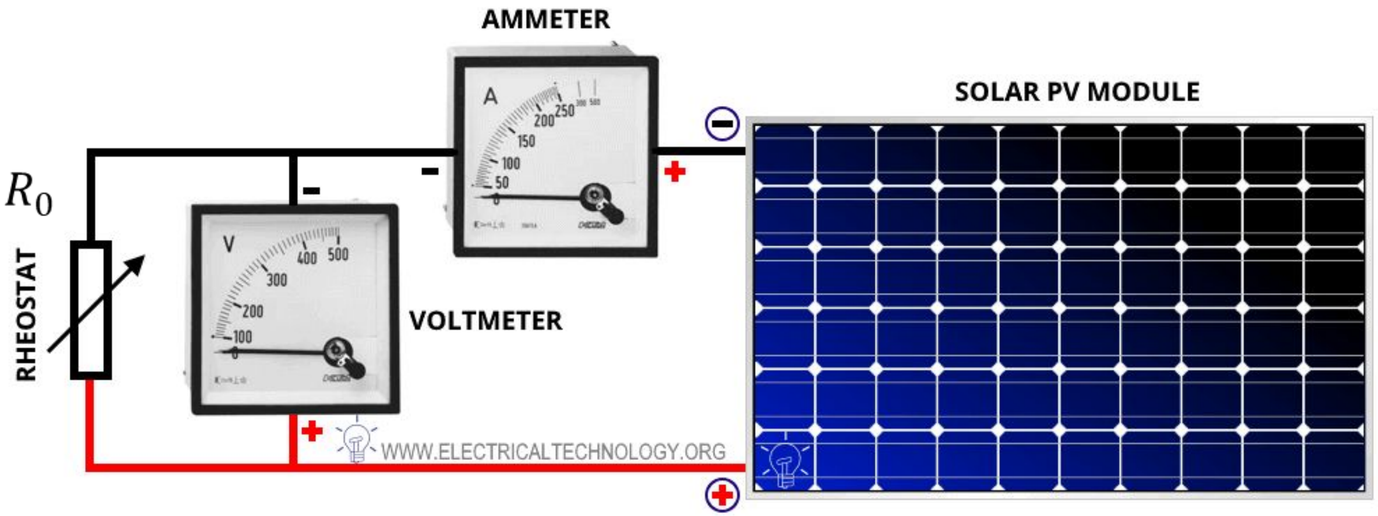
For PV modules, there is one single operating point at any given point in time where maximum power can be drawn. So the maximum power point tracking algorithm ensures that this point is always reached

MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get optimum current into battery

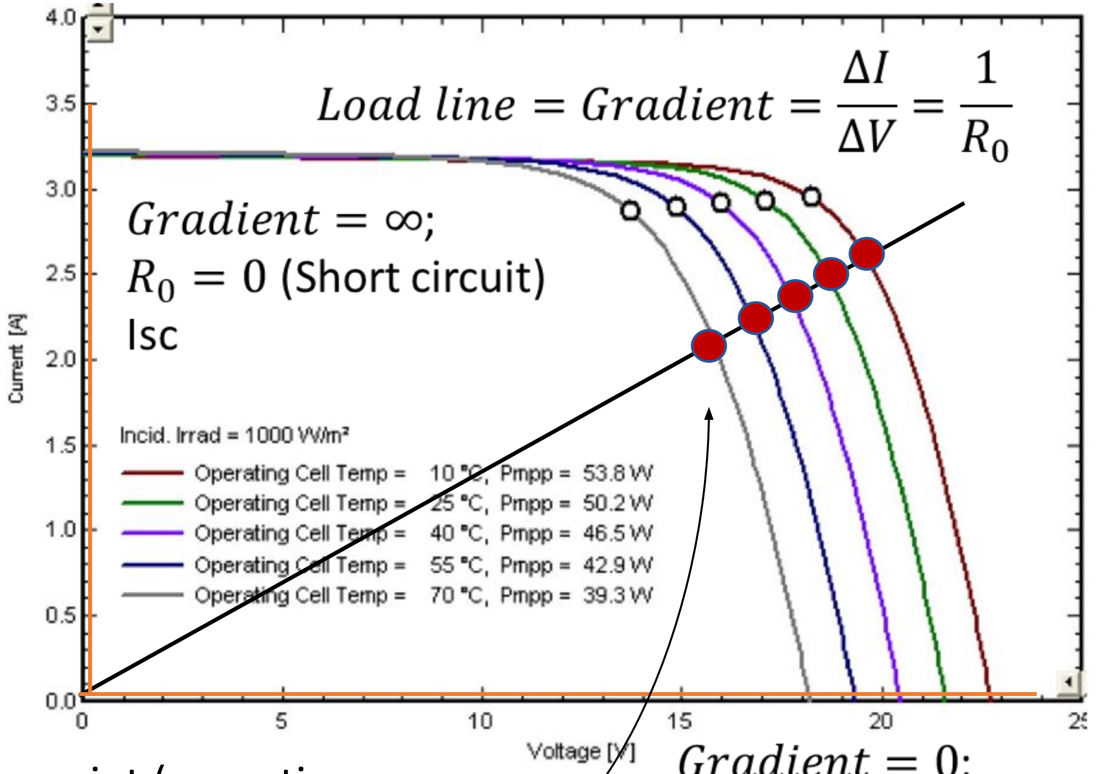


MPPT is most effective under these conditions:

- Cold weather: Normally, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.
- When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lower.



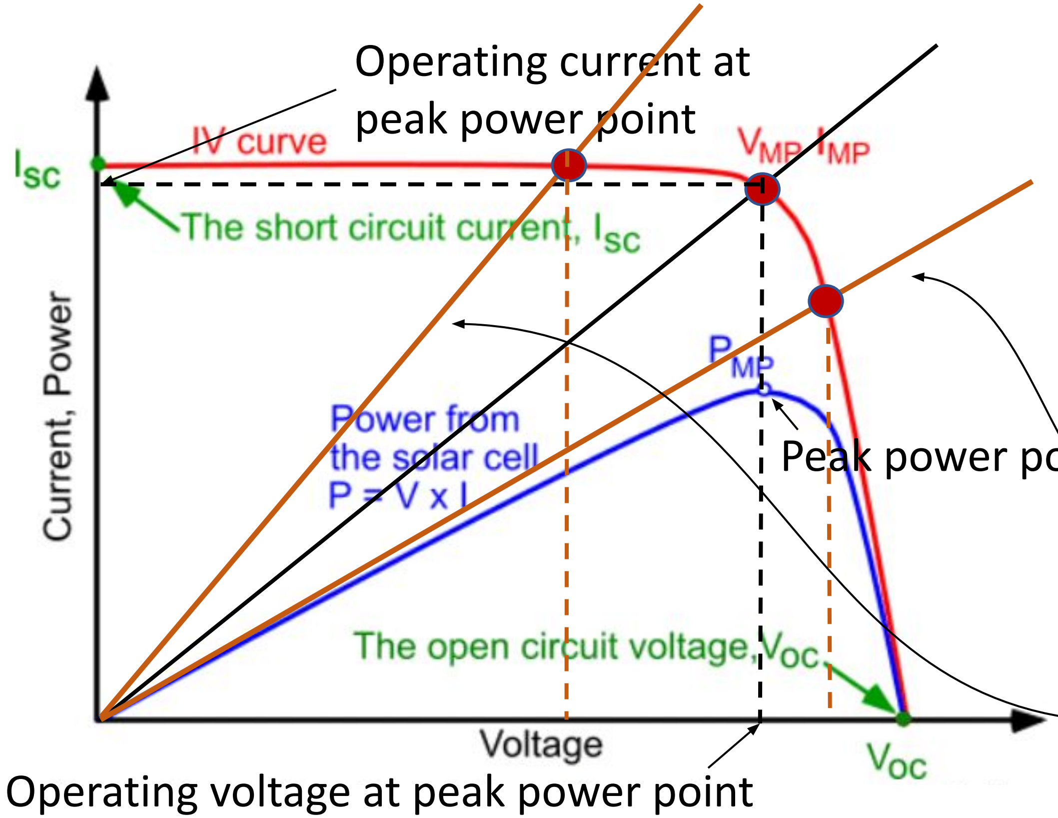
Measuring the I-V Curve of Solar Panel Module



$$Load\ line = Gradient = \frac{\Delta I}{\Delta V} = \frac{1}{R_0}$$

$Gradient = \infty;$
$R_0 = 0$ (Short circuit)
Isc

$Gradient = 0;$
$R_0 = \infty$ (Open circuit)
Voc



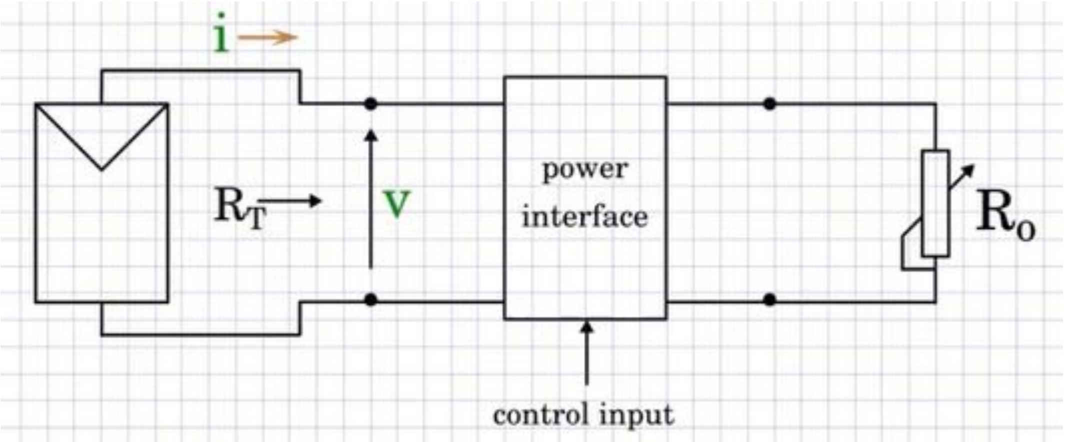
Any arbitrary point (operating point) represents the power being drawn by the PV = Intersection of load line with IV curve

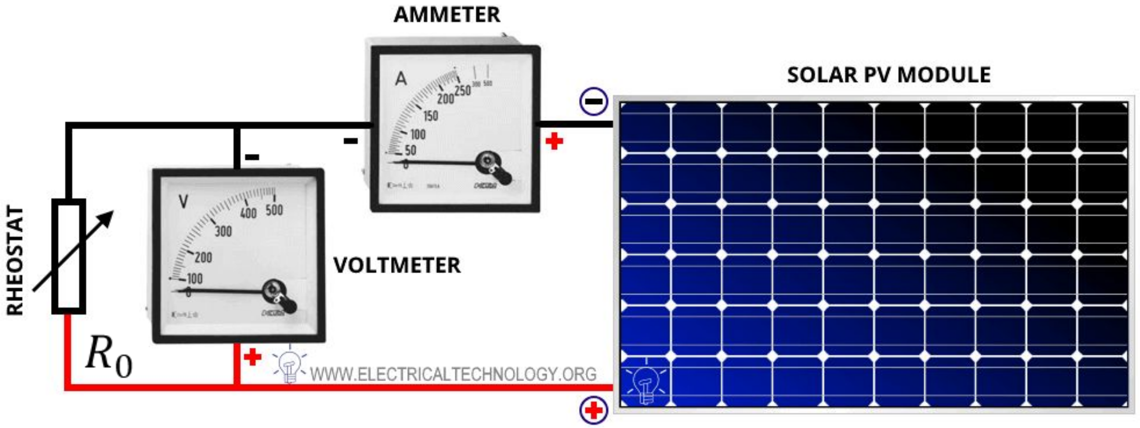
At a higher R_0 value, implying less steep load line, the operating point draws less power than the peak power from PV panel

At a lower R_0 value, implying more steep load line, the operating point draws less power than the peak power from PV panel

Objective: Operating point to be located such as to draw the maximum power from the PV panel

The problem is when R_0 changes (due to a change in the use of some electrical appliances) the load line changes right or left of peak power point





Measuring the I-V Curve of Solar Panel Module

The MPPT ensures that R_T is always at the peak power operating point irrespective of the value of R_0

Using a sensing technique, a reference i and V values are compared with the current and voltage values needed to attain R_T and minimize error. Feedback matches reference and the control input is acquired.

The MPPT works in such a way that whatever the value of R_0, the control input accordingly changes such that R_T remains constant

The power interface is a dc-dc converter that converts a source of direct current from one voltage level to another
(1) Boost (step-up); (2) Buck (step-down); (3) Buck-Boost (output voltage that is greater or less than the input voltage)

SOLAR MODULE/ARRAY MODEL

The photocurrent (phase current) mainly depends on the solar insolation and cell's working temperature, as described:

$$I_{PH} = [I_{SC} + K_I(T_C - T_{Ref})]\lambda$$

where I_{SC} is the cell's short-circuit current at a 25°C and 1kW/m^2, K_I is the cell's short-circuit current temperature coefficient, Tc is the cell's working temperature, T_{Ref} is the cell's reference temperature, and λ is the solar insolation in kW/m^2.

The cell's saturation current varies with the cell temperature, and is described as:

$$I_S = I_{RS}(T_C / T_{Ref})^3 \exp[qE_G(1/T_{Ref} - 1/T_C)/kA]$$

where I_{RS} is the cell's reverse saturation current at a reference temperature and a solar radiation, E_G is the bang-gap energy of the semiconductor used in the cell. The ideal factor A is dependent on PV technology, k (= 1.38 ×10−23J/K) is a Boltzmann's constant.

The equivalent circuit for the solar module arranged in N_P parallel and N_S series generates an output current of:

$$I = N_P I_{PH} - N_P I_S[\exp(qV/N_S kT_C A) - 1]$$

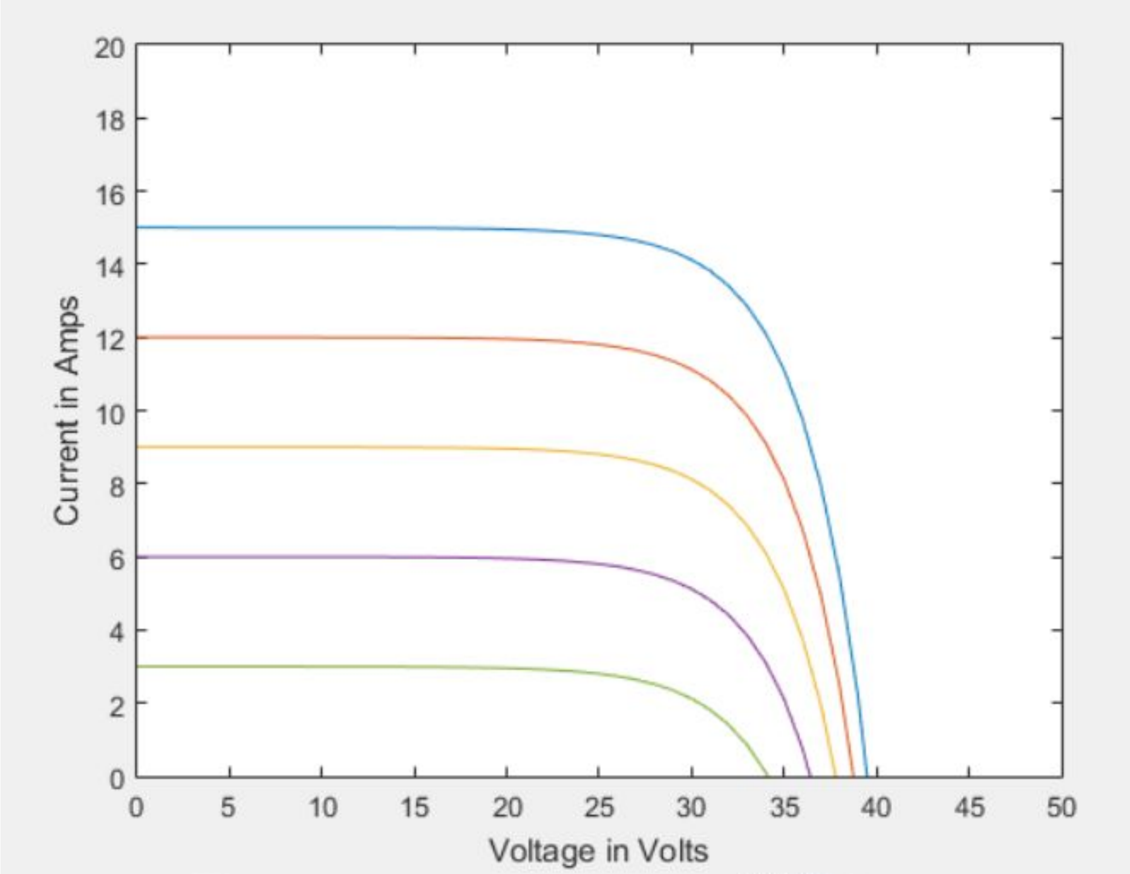
where q is the electron charge and V is the voltage of the solar module.

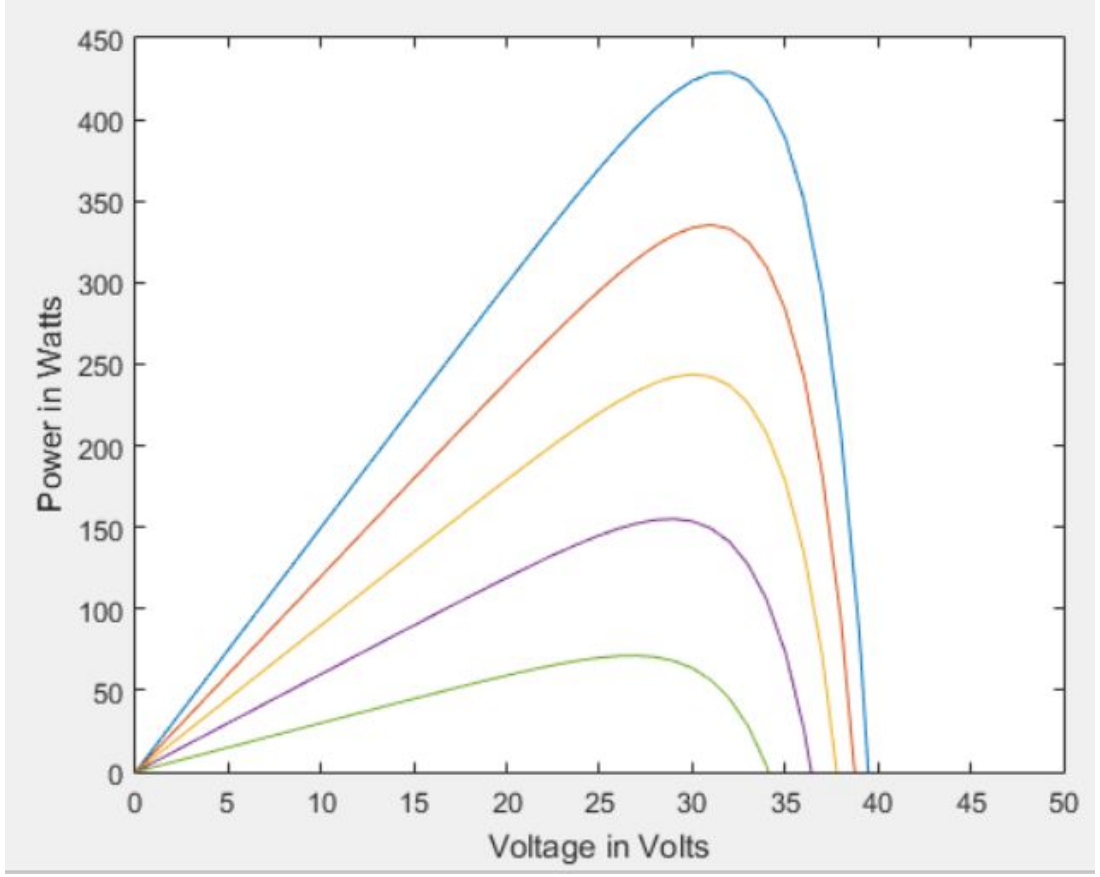
```matlab
clear all
close all
%Declaring variables
T=302;
Tr=298;
Tr1=40;
ki=0.00023;
Iscr=3.75;
Irr=0.000021;
A=2.15;
Eg0=1.166;
alpha=0.473;
beta=636;
S=[100 80 60 40 20];
K=1.38065*10^(-23);
q=1.6022*10^(-19);

Eg=Eg0-(alpha*T*T)/(T+beta)*q;
Np=4;
Ns=60;
V0=[0:1:300];
%finding values for all 5 values of sun
for i=1:5
    Iph=(Iscr+ki*(T-Tr))*((S(i))/100); %phase current
    Irs=Irr*((T/Tr)^3)*exp(q*Eg/(K*A)*((1/Tr)-(1/T))); %current through shunt resistor
    I0=Np*Iph-Np*Irs*(exp(q/(K*T*A)*V0./Ns)-1); %output current
    P0=V0.*I0; %output power
    figure(1) %voltage vs current plot
    plot(V0,I0);
    axis([0 50 0 20]);
    xlabel('Voltage in Volts');
    ylabel('Current in Amps');
    hold on;
    figure(2) %Voltage vs Power plot
    plot(V0,P0);
    axis([0 50 0 450]);
    xlabel('Voltage in Volts');
    ylabel('Power in Watts');
    hold on;
    figure(3) %Current vs Power plot
    plot(I0,P0);
    axis([0 20 0 450]);
    xlabel('Current in Amps');
    ylabel('Power in Watts');
    hold on;
end

[Max, Where] = max(P0);
Imax=I0(Where)
Vmax=V0(Where)
Pmax=max(P0)
```

MATLAB SIMULATION





Modify the code in line 'i=1:5' to i=1; i=2; …. i=5 and study the maximum power under various

The nonlinear nature of PV cell is apparent as shown in the figures, i.e., the output current and power of PV cell depend on the cell's terminal operating voltage and temperature, and solar insolation as well.

We observe from both figures that with increase of solar insolation, phase current of the PV module increases, and the maximum power output increases as well.

Table II Solarex MSX 60 Specifications ($1kW/m^2$, 25°C)

Characteristics	SPEC.
Typical peak power (P_p)	60W
Voltage at peak power (V_{pp})	17.1V
Current at peak power (I_{pp})	3.5A
Short-circuit current (I_{SC})	3.8A
Open-circuit voltage (V_{OC})	21.1V
Temperature coefficient of open-circuit voltage	-73mV/°C
Temperature coefficient of short-circuit current (K_I)	3mA/°C
Approximate effect of temperature on power	-0.38W/°C
Nominal operating cell temperature (NOCT)	49°C

Table I Factor A dependence on PV technology

Technology	A
Si-mono	1.2
Si-poly	1.3
a-Si:H	1.8
a-Si:H tandem	3.3
a-Si:H triple	5
CdTe	1.5
CIS	1.5
AsGa	1.3

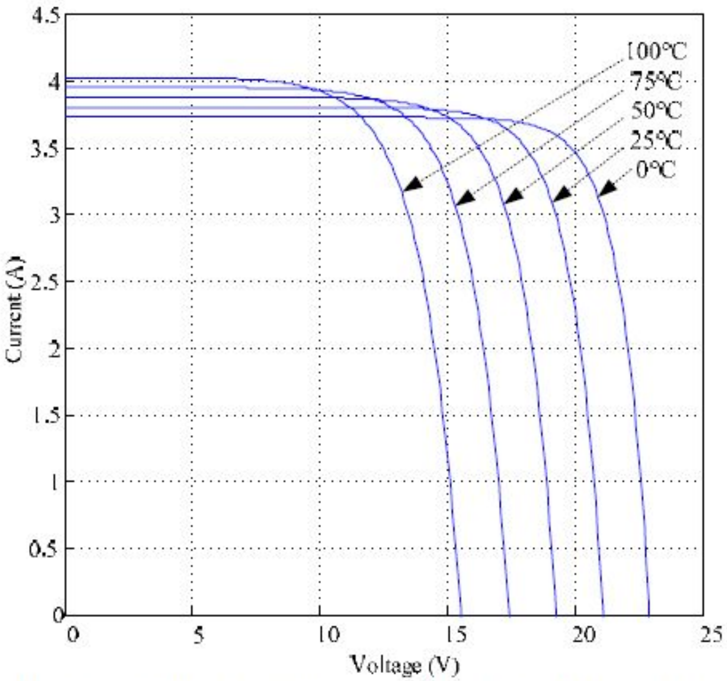


Fig. 7(a) I-V output characteristics with different T_c.

Such a model using the relevant solar cell parameters, operating temperature and insolation may be used to derive the peak power point and regulate the power interface to achieve this point

MPPT can thus be achieved and optimized power output from solar PV panel is derived

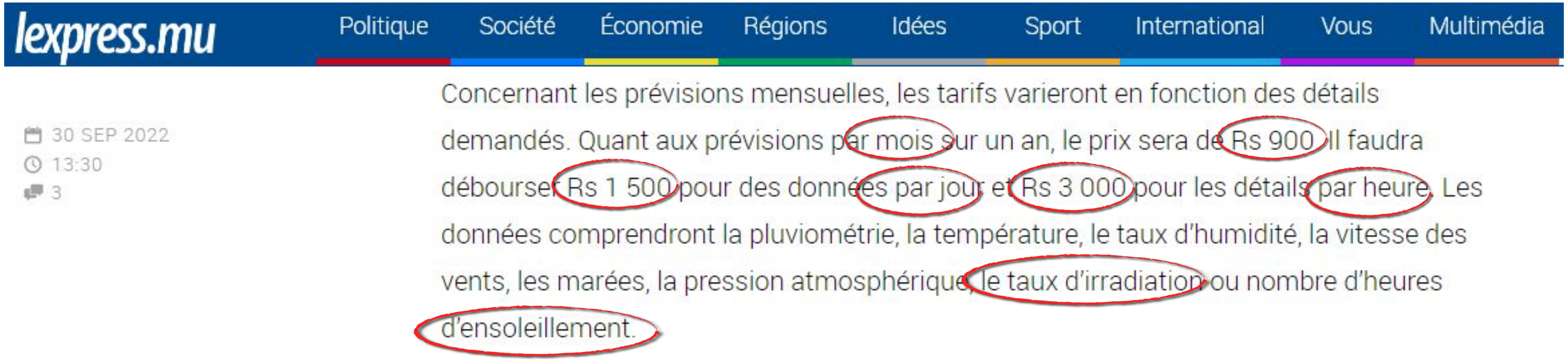
Affordable method for estimating solar radiation from temperature

Introduction to Regression Analysis

Context

COST FACTOR

Solar radiation data is sought by architects, agricultural sector, climatologists, researchers, and energy experts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Concernant les prévisions mensuelles, les tarifs varieront en fonction des détails demandés. Quant aux prévisions par mois sur un an, le prix sera de Rs 900. Il faudra débourser Rs 1 500 pour des données par jour et Rs 3 000 pour les détails par heure. Les données comprendront la pluviométrie, la température, le taux d'humidité, la vitesse des vents, les marées, la pression atmosphérique, le taux d'irradiation ou nombre d'heures d'ensoleillement.

MAINTENANCE FACTOR

Solar radiation instruments must be periodically cleaned with special microfiber cloth and cleaning liquids as the glass domes and windows of the instruments accumulate dirt that significantly reduce the reliability of the data

Moreover, the internal mechanism needs annual oiling of gears or adjustment of the internal clock (for tracking system)

Solar radiation data is not made readily available due to high cost, maintenance and calibration requirements on solar instruments

Davis Wireless Vantage Pro2™ Plus w/UV & Solar Radiation Sensors 6162 U.

Brand New

$1,017.10

List price: ~~$1,794.57~~ **43% off**

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EKO MS-60 a ISO 9060:2018 Class B (First class) pyranometer with analog output

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Solar radiation instruments are relatively expensive (on ebay)

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Brand New

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Top Rated Seller

Rs 690

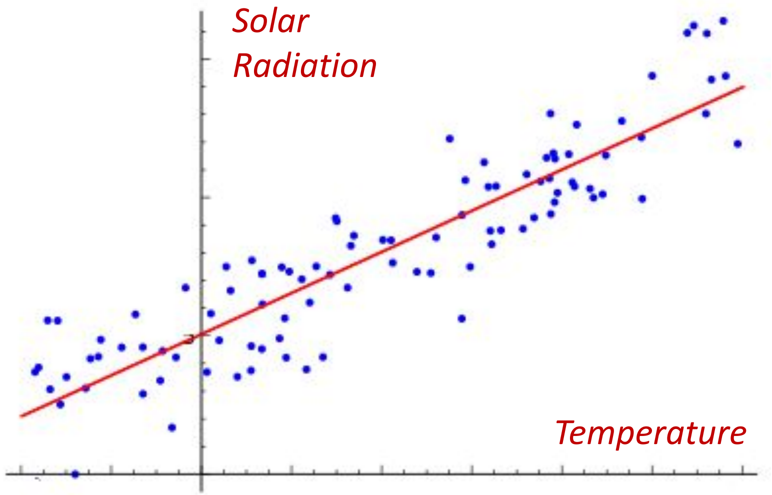
Sponsored

Temperature recorders are way cheaper (on ebay)

Estimation of Solar Radiation

Can we instead use temperature measurements to estimate solar radiation data? This will enable the use of cheaper and easy to maintain temperature instruments

- We can do this conversion because there exists a relationship between air temperature and solar radiation
- This relationship can be found using simple regression analysis
- Linear regression seeks to find the line of best fit through the data by searching for the regression coefficient (α_1) that minimizes the error in fitting
- The fitted line has the equation: $y = \alpha_1 x + \alpha_2$
- This may be written as:
  $Solar\ radiation = gradient\ (Temperature) + y\ intercept$



Temperature	Solar Radiation
27.65	312
28.25	410

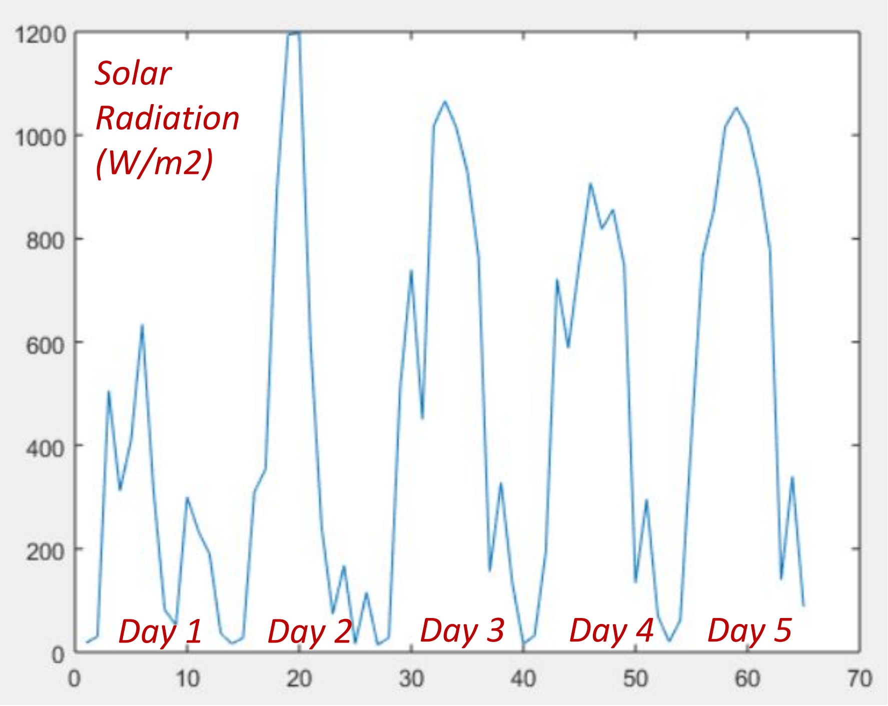
*SolarRadiation = 163 * (Temperature) - 4200*

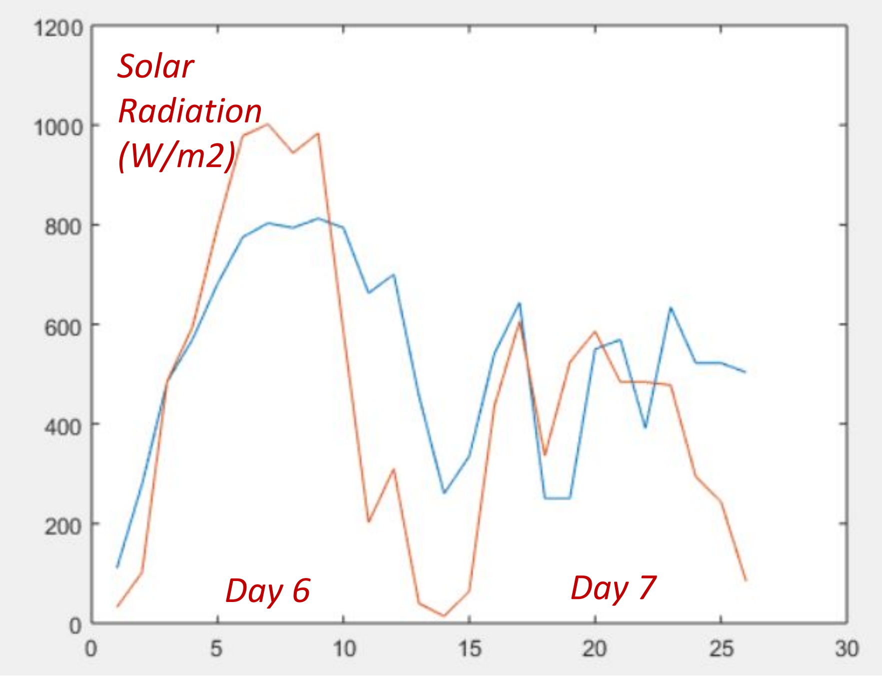
29.51	? (610.1)

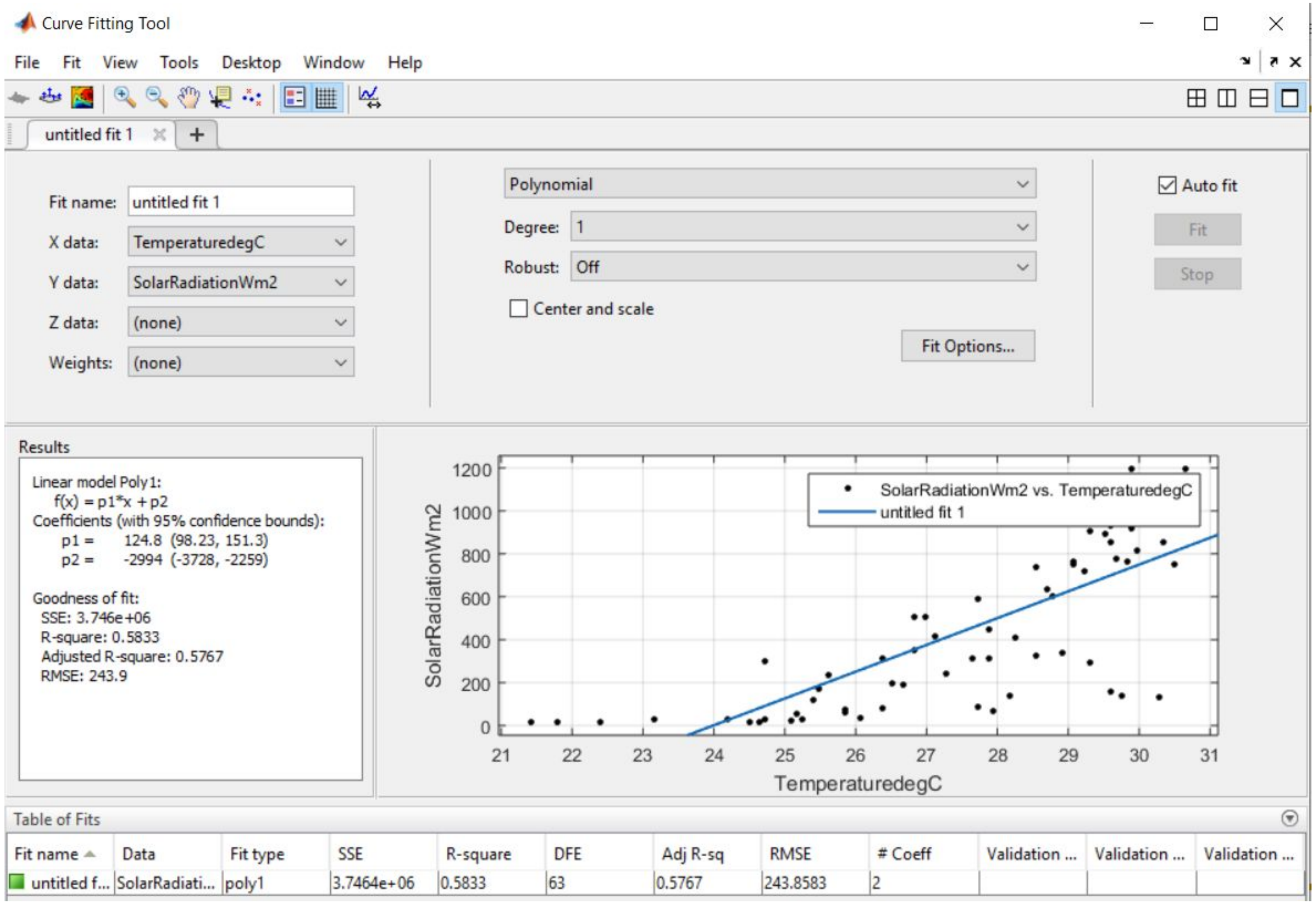
The idea is:
- Using available data of temperature and radiation to build the equation
- Using the equation formulated to estimate solar radiation based on temperature measurements

Practical Session on Estimating Solar Radiation

- Open MATLAB software and click on import data to transfer data of solar radiation and temperature from excel sheet (SRegressionPractical; Sheet 1) to MATLAB
- Select all data in the pop up window and click on import selection.
- In MATLAB workspace, type *'cftool'* and press enter. In the pop up window (Curve Fitting Tool), for X data select *'TemperaturedegC'* and for Y data select *'SolarRadiationWm2'*
- Observe the automatically fitted regression line. The regression line has the equation
  *SolarRadiation = 124.8 * (Temperature) - 2994*
- Use to equation formed to estimate the solar radiation for the 6th and 7th day based on recorded temperature measurements. First import the temperature data *'Temperature67degC'* for 6th and 7th day from (SRegressionPractical; Sheet 2) to MATLAB
- Type the following equation in the MATLAB workspace to estimate the solar radiation (Estimate) for the 6th and 7th day: *'Estimate = 124.8 .* Temperature67degC - 2994'*
- Compare the estimated trend with the real one imported from (SRegressionPractical; Sheet 3) by typing the following in the MATLAB workspace *plot(Estimate);hold on; plot(SolarRadiation67Wm2)*







- The more dataset is used to build the regression equation, the more accurate will be the estimated solar radiation using recorded temperature measurements

The End