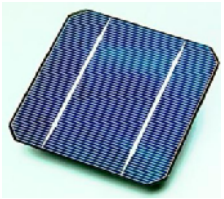

A Novel MPPT scheme for Solar Powered Boost Inverter using Evolutionary Programming

December 16, 2011

Presentation By

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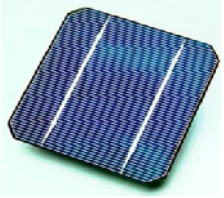
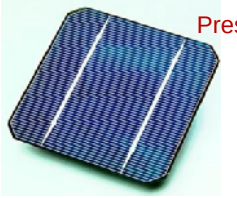
Paper Number : 111



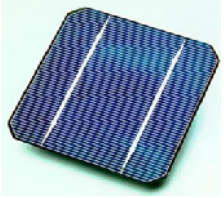
Objectives of This Paper

- Design and development of solar powered single stage boost inverter for RL load
- Design of accurate PV module and improved MPPT algorithm using Evolutionary Programming
- Comparison of closed loop controlling of boost inverter using-
  - PI controller
  - Sliding mode controller
  - MPPT algorithm

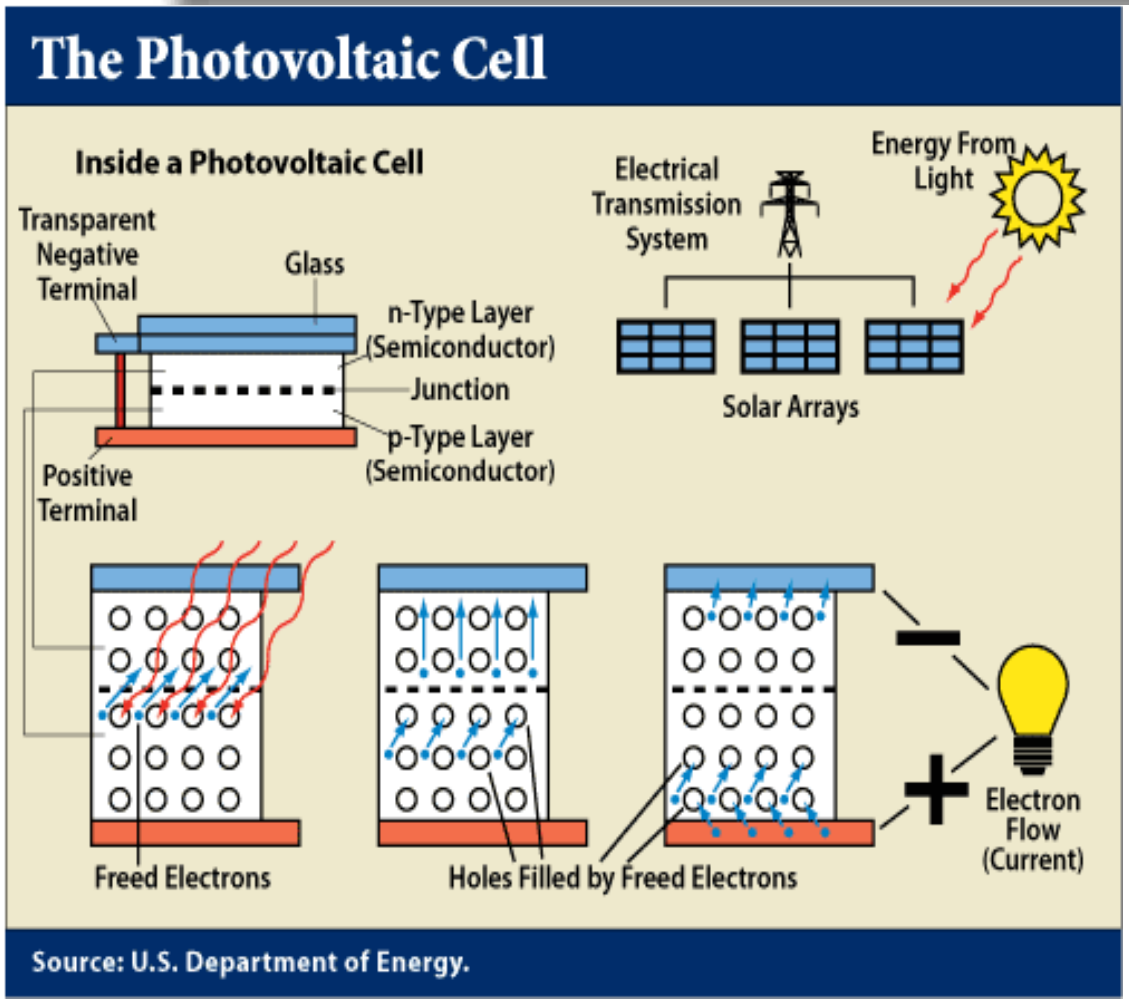


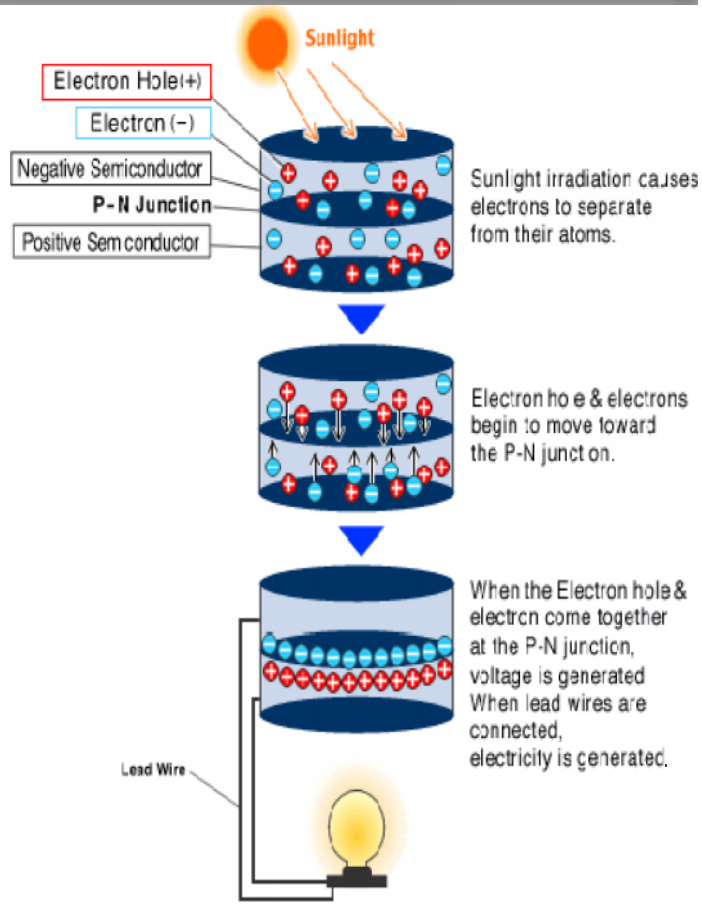
Contents of Presentation

- Simulation of accurate PV panel
- Simulation of improved maximum power point tracking algorithm using Evolutionary Programming
- Analysis and simulation of open loop single stage PV fed boost dc-ac converter
- Developing sliding mode control and PI control for PV fed boost inverter
- Comparison of the results and conclusion



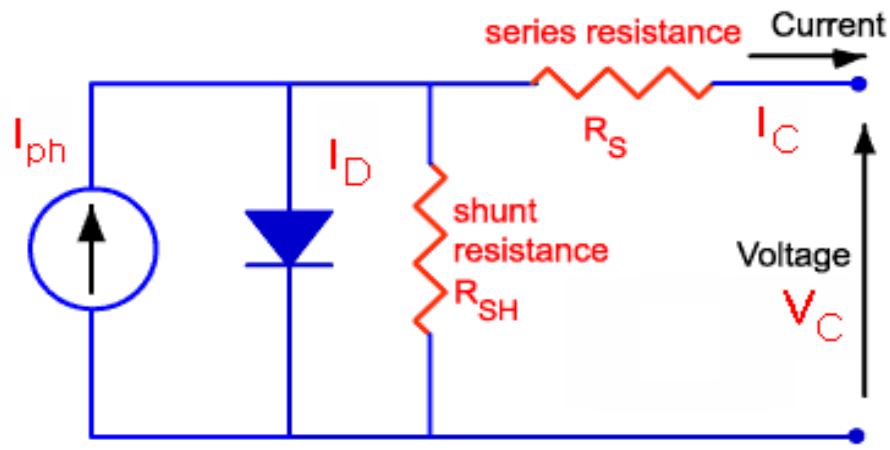
PHOTOVOLTAIC CELL WORKING PRINCIPLE

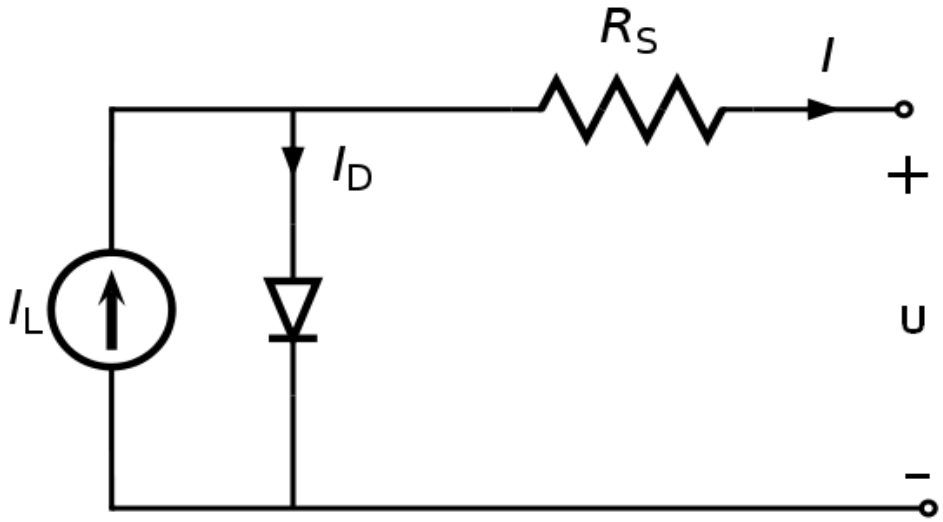




Workship the creator not his creation- Edmond Becquerel ,1889 Electricity From Sun

PHOTOVOLTAIC CELL MODELING





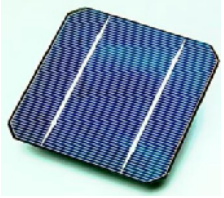
From the figure

$$I = I_L - I_D ----(1)$$

Where I=Output Current In Amps

I_l=light Current Or Photo Generated Current In Amps

I_D= Diode Current in amps



PHOTOVOLTAIC CELL MODELING Cont…

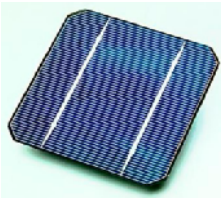
By Shockley equation, current diverted through diode is

$$I_D = I_o\left[\exp\left(\frac{U + IR_s}{nkT\ /\ q}\right) - 1\right]$$

Where I_o= Reverse Saturation Current
n= Diode Ideality Factor
K=Boltzmann's Constant
T= Absolute Temperature
q= Elementary Charge

For silicon of 25^0C nkT/q=0.0259 volts=α

$$I_D = I_o\left[\exp\left(\frac{U + IR_s}{\alpha}\right) - 1\right]$$



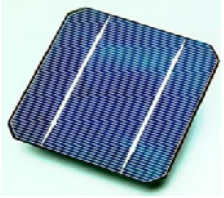
PHOTOVOLTAIC CELL MODELING Cont…

Substituting above equation in equation (1) we get

$$I = I_L - I_o\left[\exp\left(\frac{U + IR_s}{\alpha}\right) - 1\right] ----(2)$$

Where α=nkT/q is known as Thermal Voltage Timing Completion Factor

The four Parameters I_L,I_o,R_s and α need to be determined to Study the I-U characteristics of PV cells



PHOTOVOLTAIC CELL MODELING Cont…

LIGHT CURRENT I_L determination

$$I_L = \frac{\phi}{\phi_{ref}}\left[I_{L,ref} + \mu_{I,SC}\left(T_c - T_{c,ref}\right)\right]$$

Where ϕ = irradiance(W/m^2)

ϕ_{ref} = reference irradiance(1000 W/m^2 is used in this study)

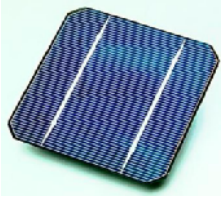
$I_{L,ref}$ = Light current at reference condition (1000 W/m^2 and 25 ^0c)

T_c = PV cell temperature

$T_{c,ref}$ = Reference Temperature ($25^0 C$ is used here)

$\mu_{I,SC}$ = Temperature coefficient of the short circuit current ($A/^0C$)

Both $I_{L,ref}$ and $\mu_{I,SC}$ can be obtained from manufacturer data sheet



PHOTOVOLTAIC CELL MODELING Cont…

SATURATION CURRENT I_O determination

$$I_o = I_{o,ref}\left(\frac{T_{c,ref}+273}{T_c+273}\right)^3 \exp\left[\frac{e_{gap}N_s}{q\alpha_{ref}}\left(1-\frac{T_{c,ref}+273}{T_c+273}\right)\right]$$

Where $I_{o,ref}$ = Saturation current at the reference condition (A)

e_{gap} = Band gap of the material (1.17eV for Si materials)

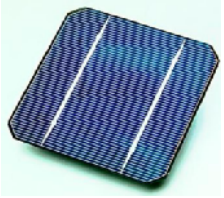
N_s = Number of cells in series of the PV module

q = Charge of the electron ($1.60217733 \times 10^{-19}$ C)

α_{ref} = The value of α at the reference condition

$$I_{o,ref} = I_{L,ref} \exp\left(-\frac{U_{oc,ref}}{\alpha_{ref}}\right)$$

$U_{oc,ref}$ = The open circuit voltage of the PV module at the reference condition(V) (Will be provided by manufacturers)



PHOTOVOLTAIC CELL MODELING Cont…

Calculation of α

$$\alpha_{ref} = \frac{2U_{mp,ref} - U_{oc,ref}}{\frac{I_{sc,ref}}{I_{sc,ref} - I_{mp,ref}} + \ln\left(1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right)}$$

Where

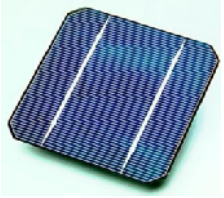
$U_{mp,ref}$ = Maximum power point voltage at the reference condition (V)

$I_{mp,ref}$ = Maximum power point current at the reference condition (A)

$I_{sc,ref}$ = Short circuit current at the reference condition (A)

α is a function of temperature, which is expressed as

$$\alpha = \frac{T_c + 273}{T_{c,ref} + 273}\alpha_{ref}$$



PHOTOVOLTAIC CELL MODELING Cont…

Calculation of Series Resistance R_s

Some manufactures provide value of R_s, if they do not provide
It can be calculated as follows

$$R_s = \frac{\alpha_{ref} \ln\left(1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right) + U_{oc,ref} - U_{mp,ref}}{I_{mp,ref}}$$

R_s is taken as constant here

Thermal Model of Photovoltaic cell

$$C_{pv}\frac{dT_c}{dt} = k_{in,pv}\phi - \frac{U \text{ x } I}{A} - K_{loss}\left(T_c - T_a\right)$$

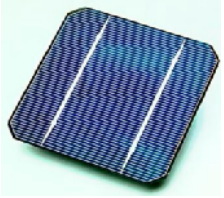
C_{pv} = The oveall heat capacity per unit area of the PV cell/Modul e $[J/(^0c.m^2)]$

$K_{in,pv}$ = Transmitta nce absorbtion product of PV cells

k_{loss} = Overall heat loss coefficien t$[W/(^0c.m^2)]$

T_a = Ambient te mperature(^0c)

A = Effective area of the PVcell/ Module(m^2)

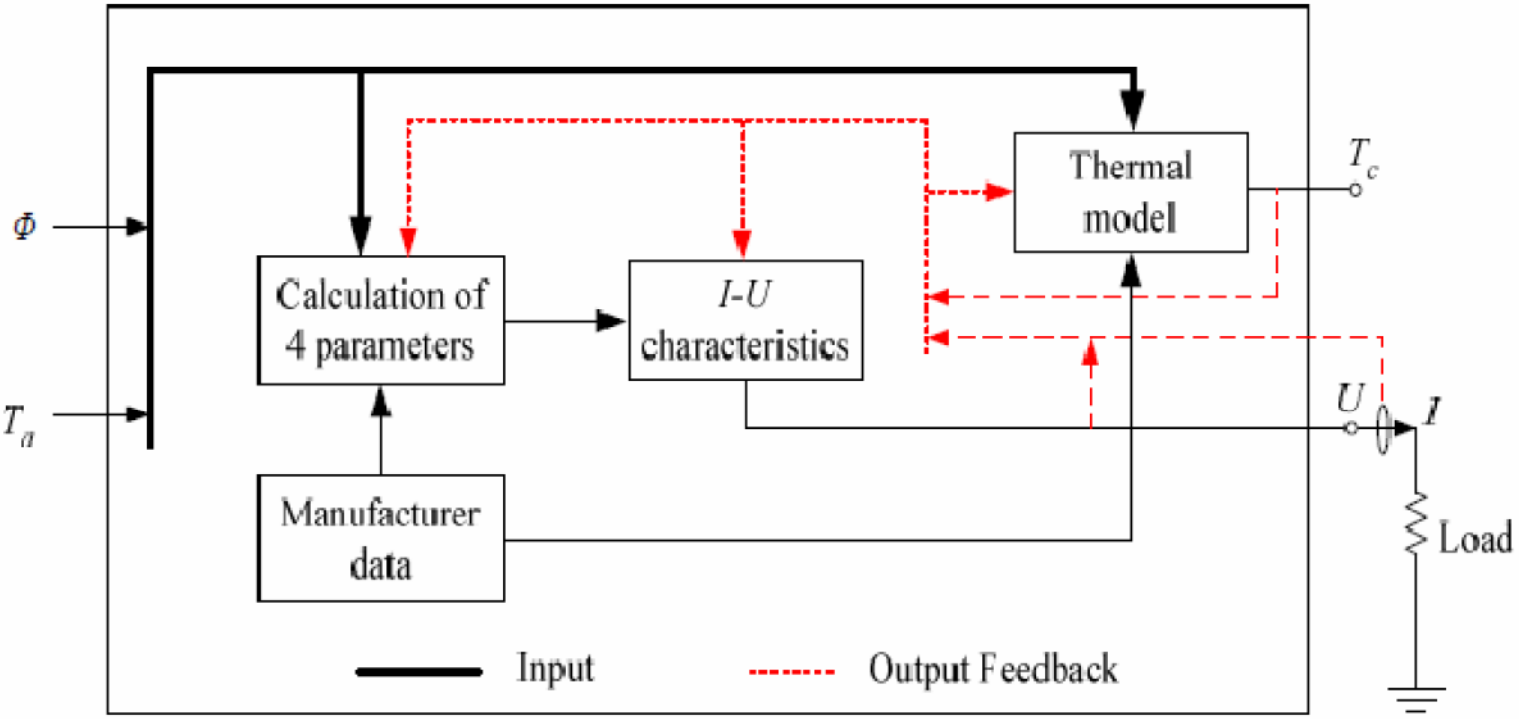


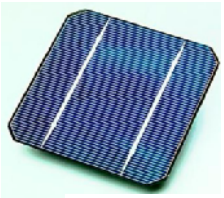
PHOTOVOLTAIC CELL MODEL PARAMETERS

$I_{L,ref}(I_{SC,ref})$	2.664 A
α_{ref}	5.472 V
R_s	1.324 Ω
$U_{oc,ref}$	87.72 V
$U_{mp,ref}$	70.731 V
$I_{mp,ref}$	2.448 A
Φ_{ref}	1000 W/m^2
$T_{c,ref}$	25^{0}c

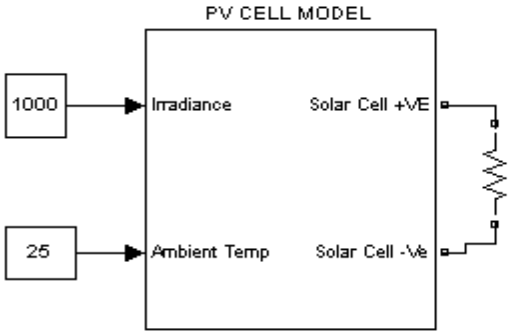
C_{PV}	5 X 10^4 J/ (^{0}c.m^2)
A	1.5m^2
$K_{in,pv}$	0.9
K_{loss}	30 W/ (^{0}c.m^2)

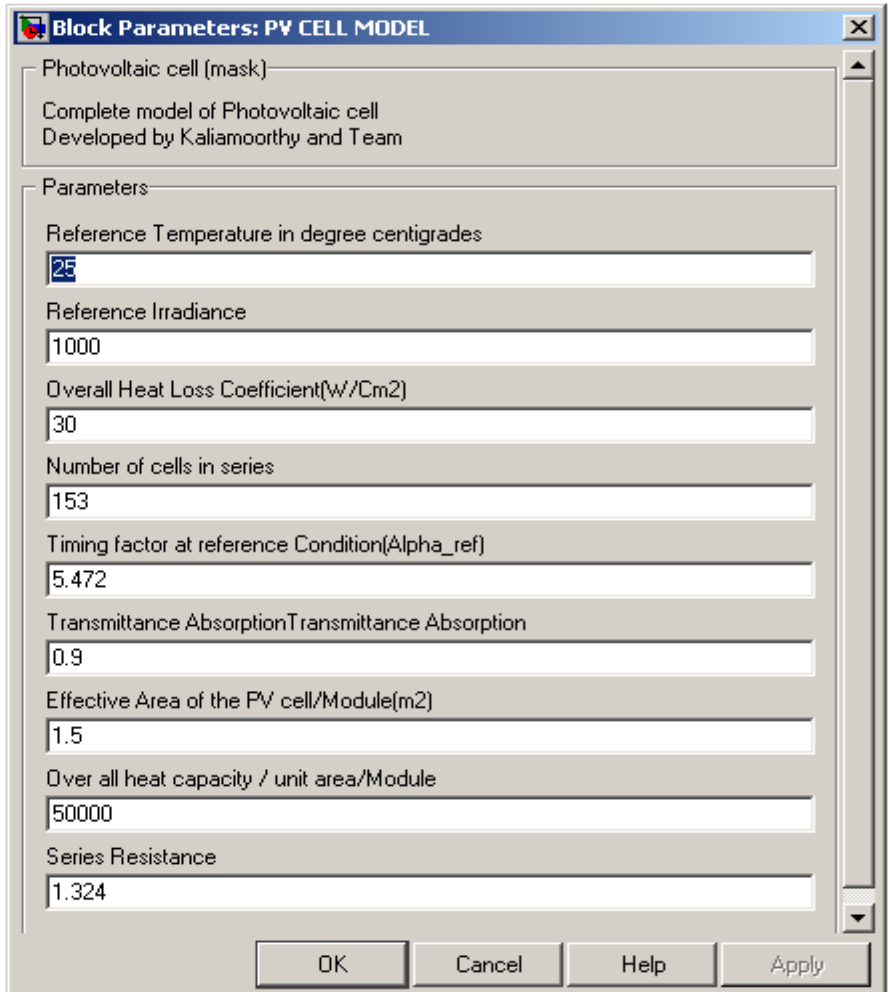
PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK

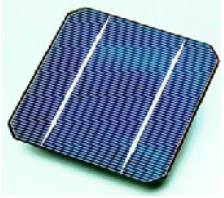




PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK

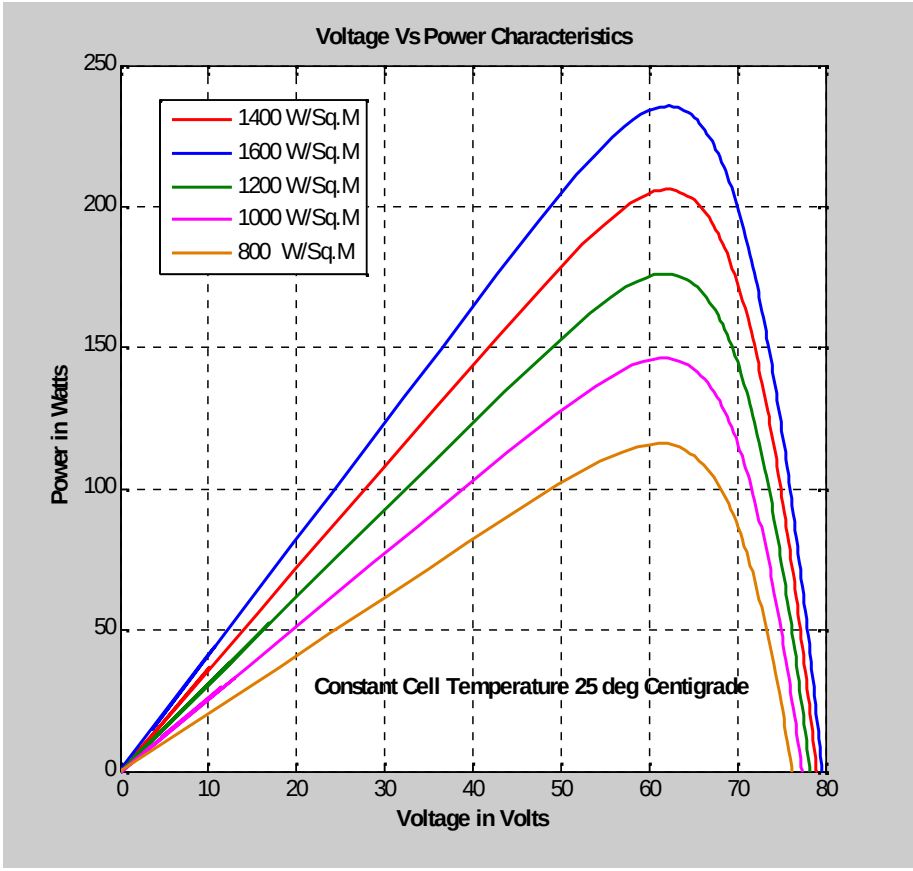


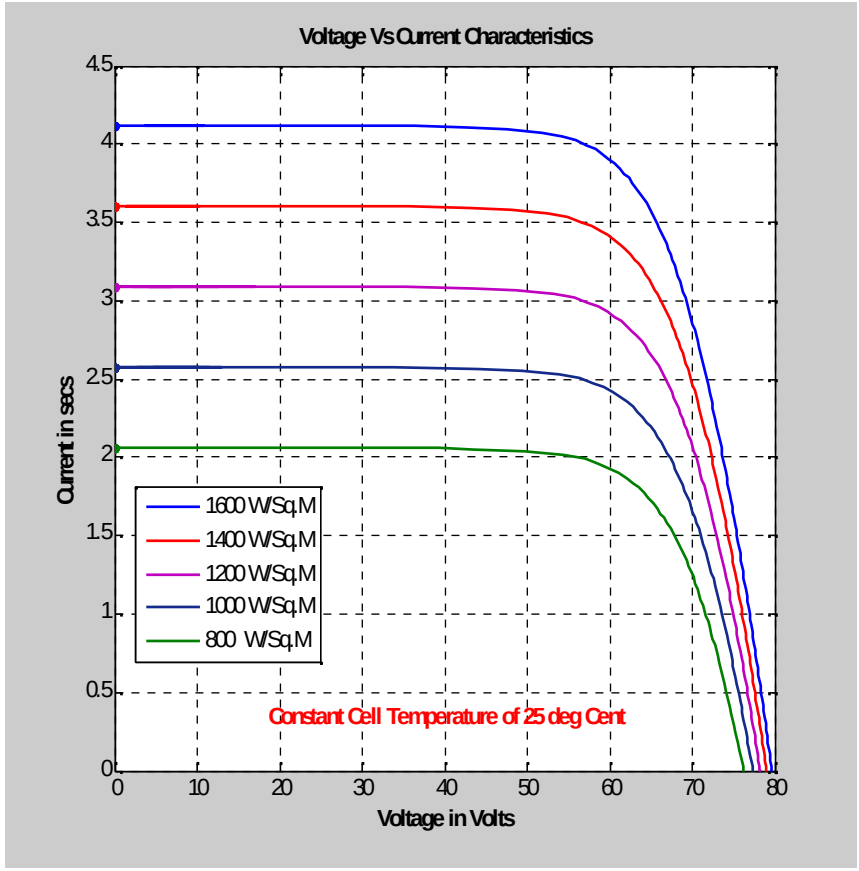


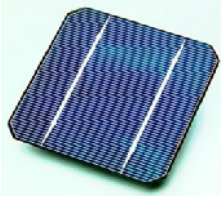


Presented By: M.Kaliamoorthy,AP,PSNACET,EEE

CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE

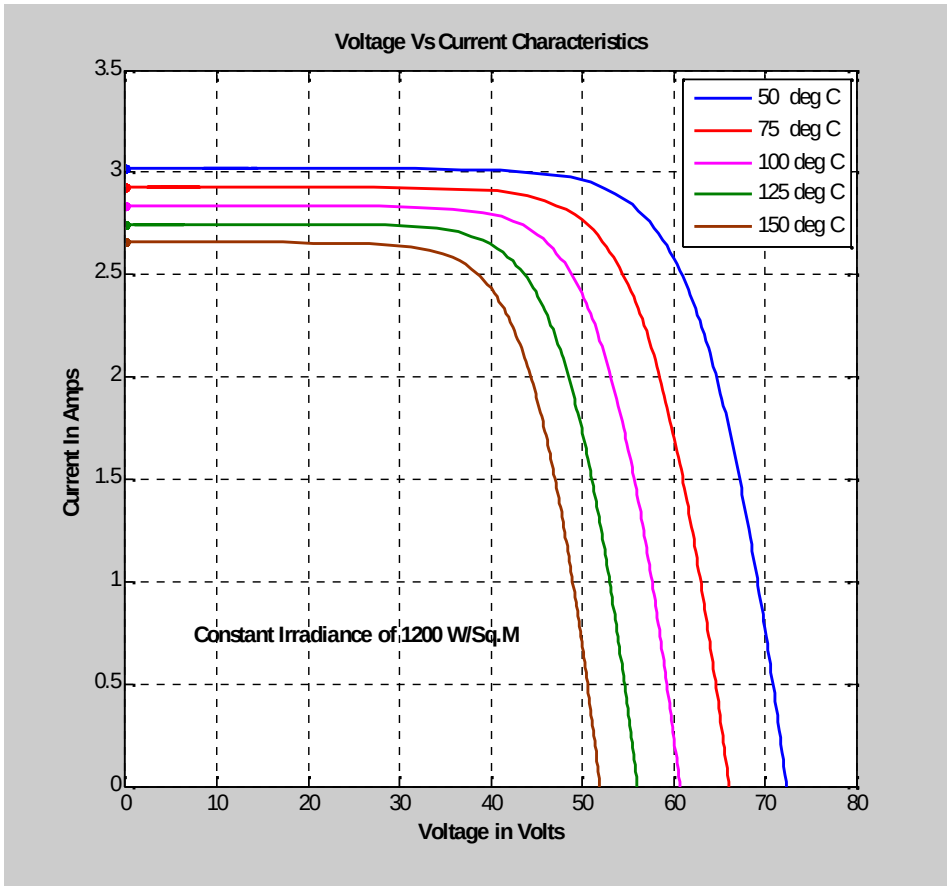


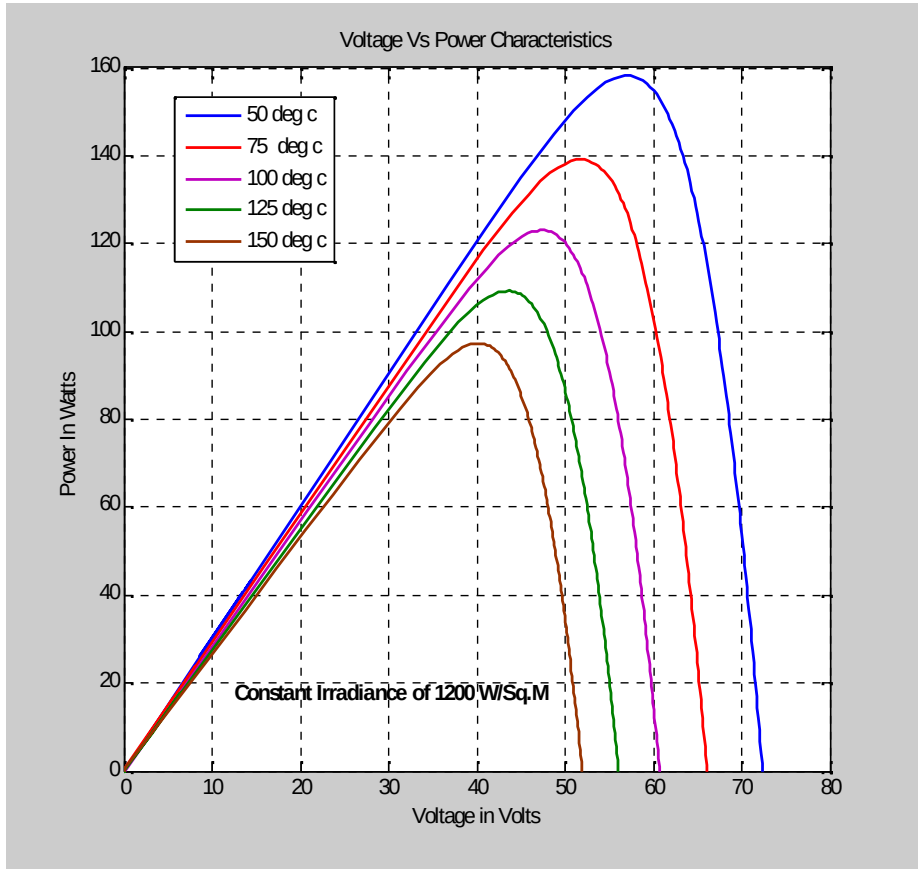




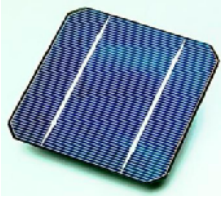
Presented By: M.Kaliamoorthy,AP,PSNACET,EEE

CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE





Everything comes to him who waits -Ammeter – Edward Weston -1886



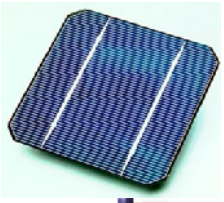
Maximum Power Point Tracking of PV cell Using Evolutionary Programming

The fitness function used here in the program is to minimize the value of I_{max} and it is the function of irradiance and cell temperature.

$$I_{\max} = \frac{\partial P}{\partial I}\left[f\left(\phi, T_C, P, V, I\right)\right]$$

The main objective of the EP is to minimize the above fitness function.

Population Size	**: 40**
Number of Iterations	**: 200**
Number of Functional Evaluation	**: 8000**
Mutation Scale	**:0.5**
Control Variable Limits	**: [0 ,3.7]**



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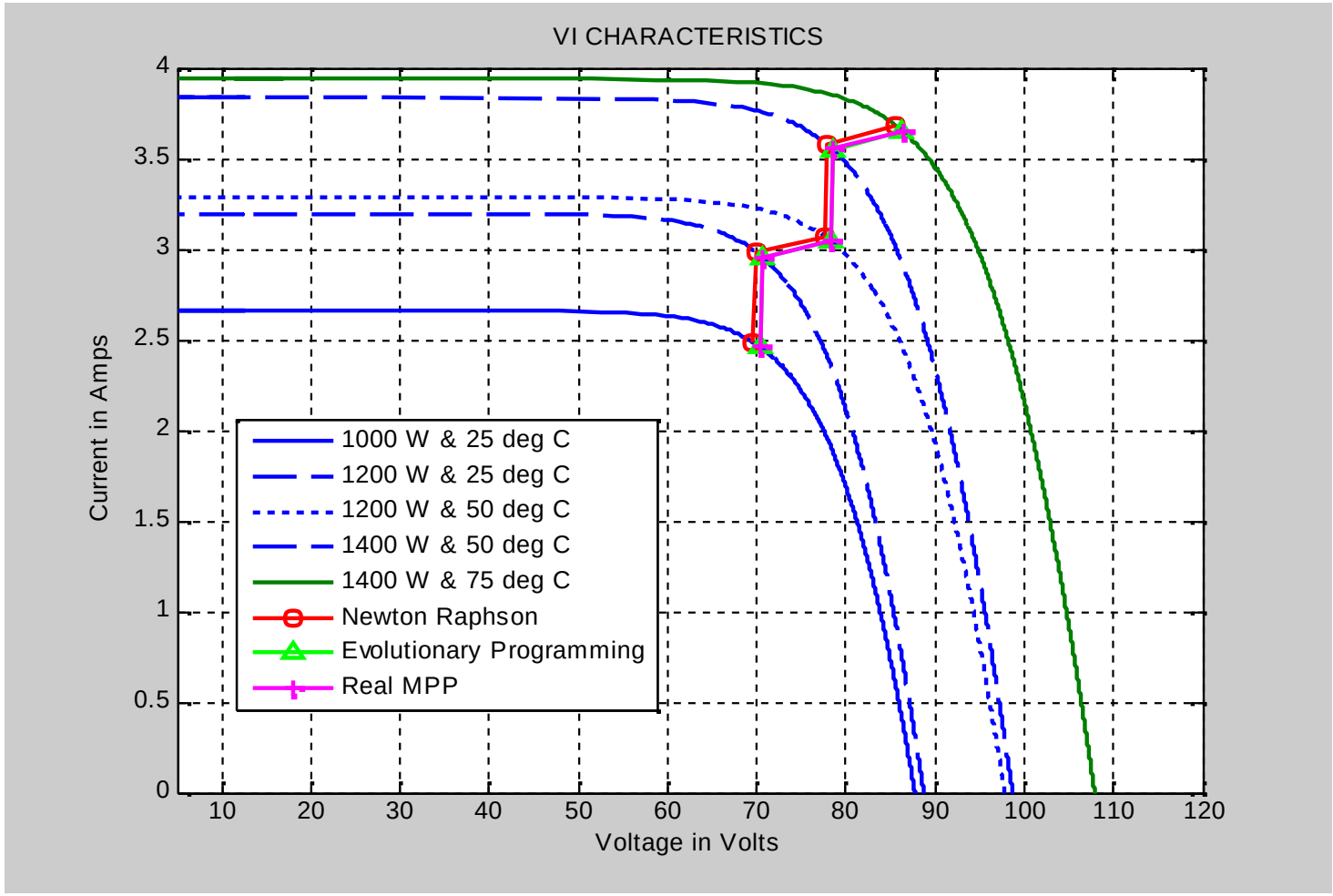
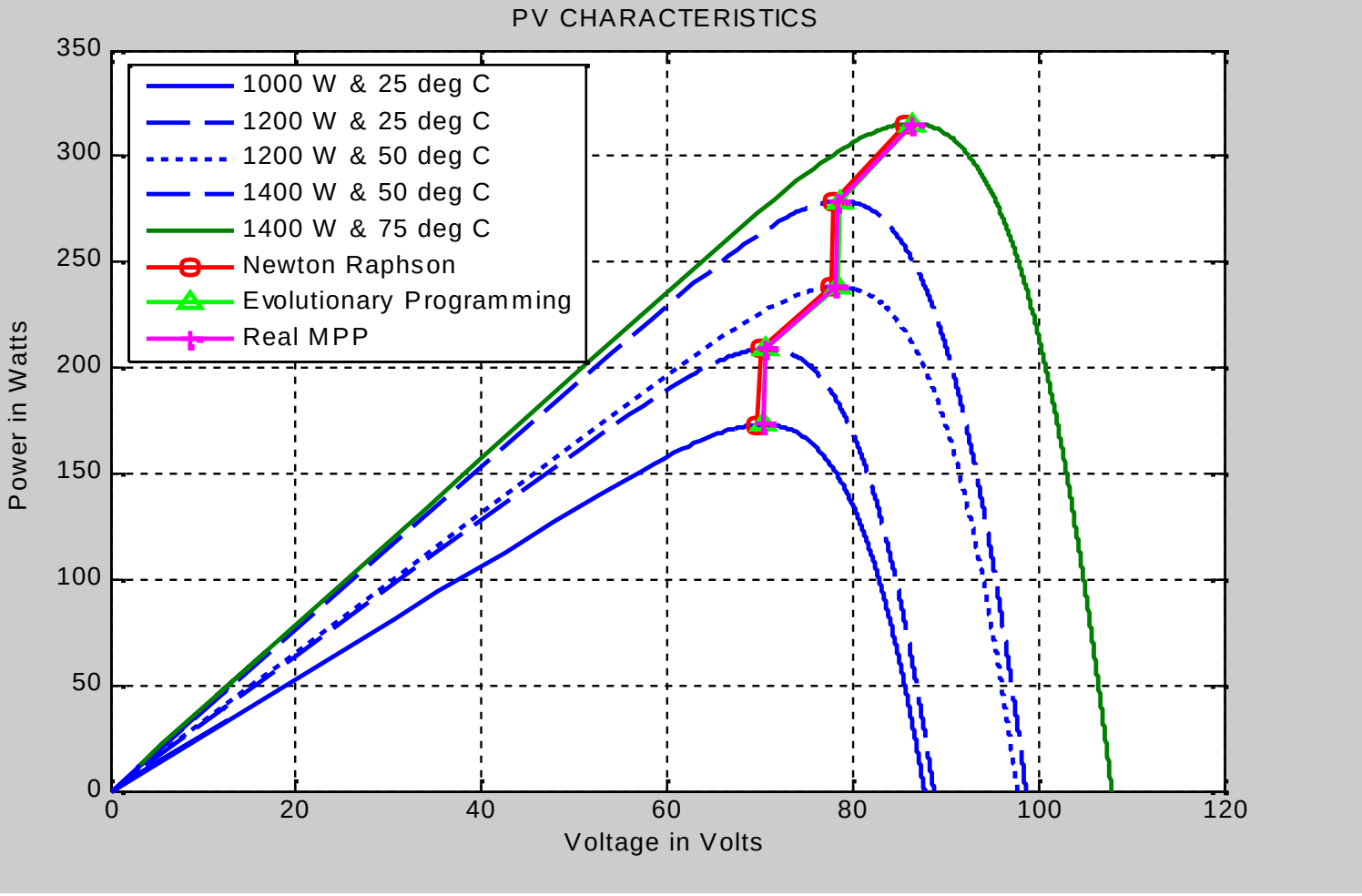
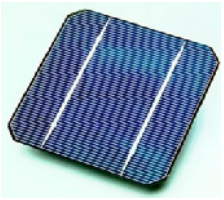
Maximum Power Point Tracking of PV cell Using Evolutionary Programming



Maximum Power Point Tracking of PV cell Using Evolutionary Programming





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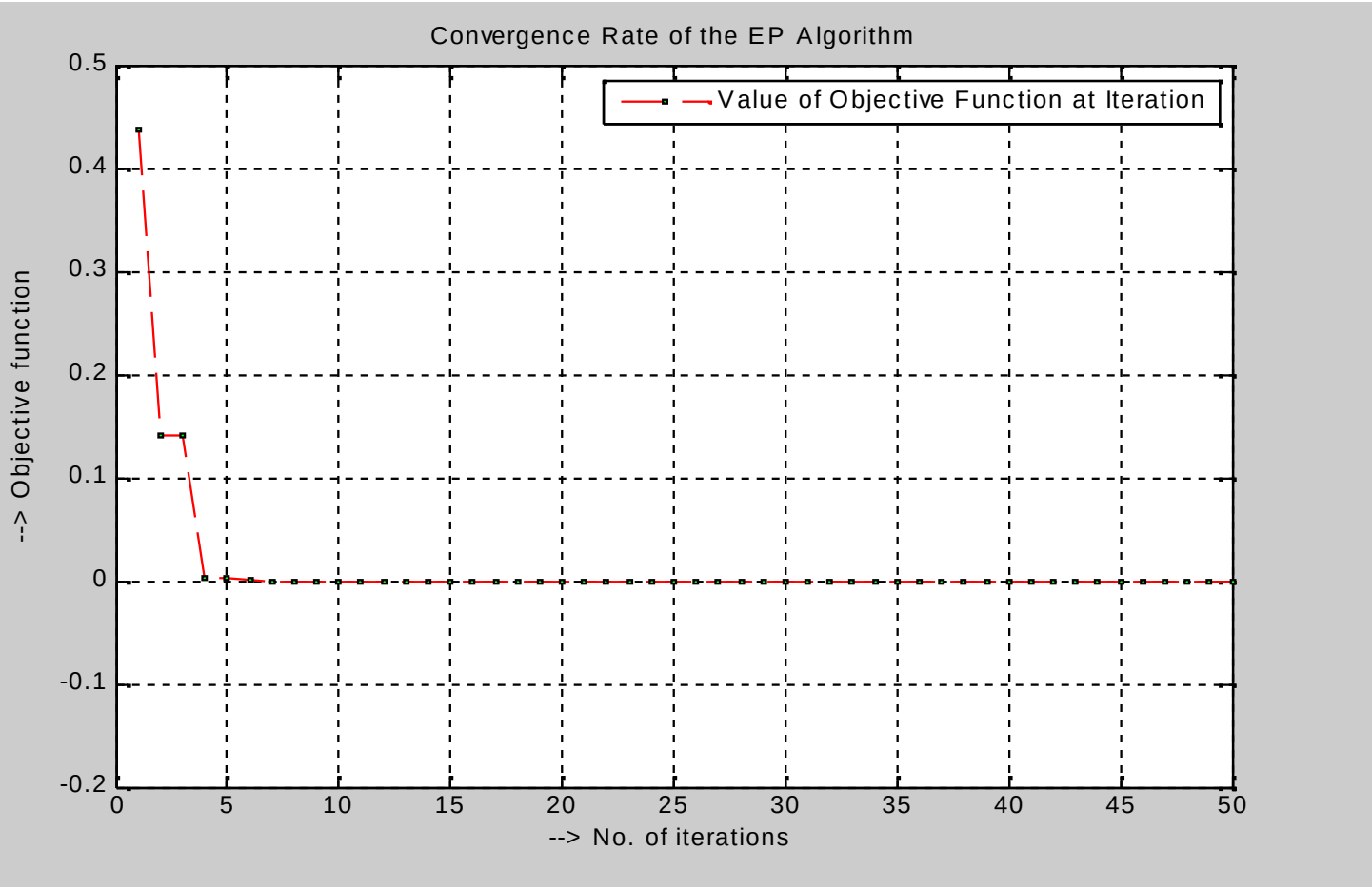
Maximum Power Point Tracking of PV cell Using Evolutionary Programming

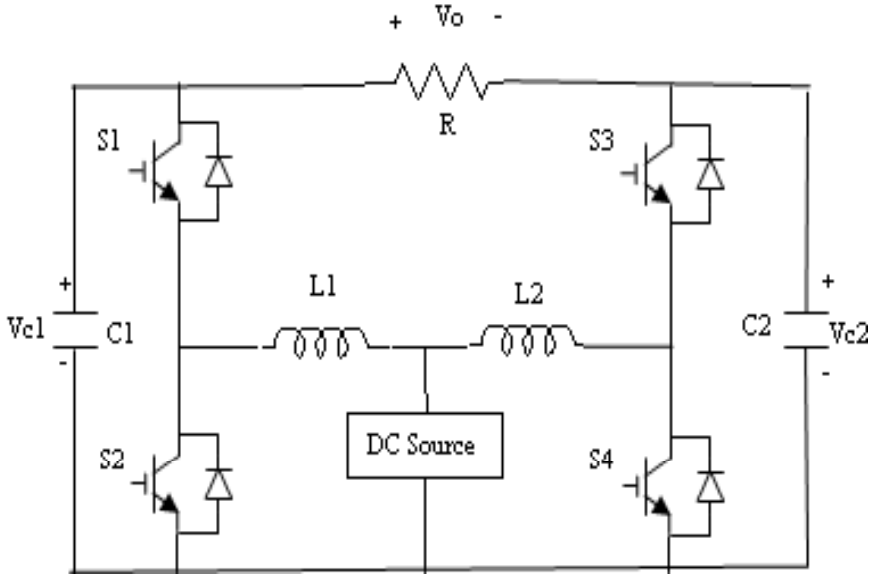


Maximum Power Point Tracking of PV cell Using Evolutionary Programming

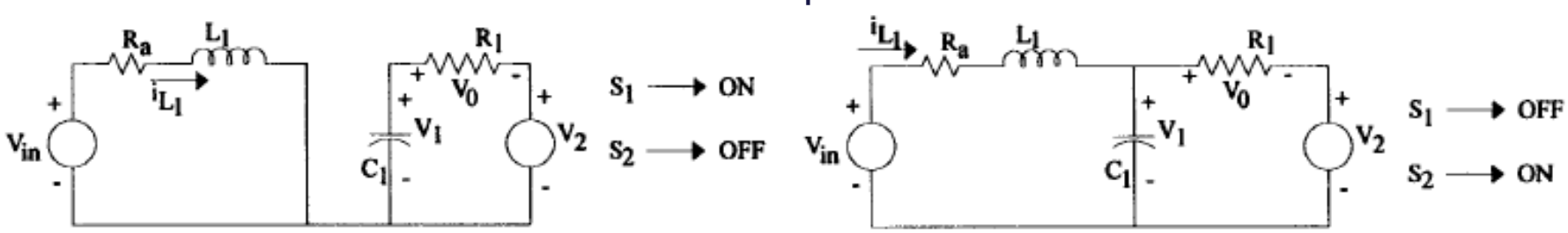
Summary of Simulation results of different algorithms

Weather Conditions		Rapson (NR)			Evolutionary Programming (EP)			Real Maximum Power Point			% Error of P_{mp}	
Irradiance in W/Sq.m	Temp in deg C	V_{mp} (Volts)	I_{mp} (Amps)	P_{mp} (Watts)	V_{mp} (Volts)	I_{mp} (Amps)	P_{mp} (Watts)	V_{mp} (Volts)	I_{mp} (Amps)	P_{mp} (Watts)	EP	NR
1000	25	69.60	2.48	173.07	70.31	2.46	173.19	70.41	2.45	173.19	0	6.62e-4
1200	25	70.02	2.98	208.73	70.68	2.95	208.85	70.61	2.95	208.85	0	5.65e-4
1200	50	77.58	3.06	238.14	78.28	3.04	238.26	78.20	3.04	238.26	0	5.25e-4
1400	50	77.90	3.57	278.71	78.55	3.54	278.84	78.49	3.55	278.84	0	4.54e-4
1400	70	85.64	3.68	315.22	86.32	3.65	315.35	86.35	3.65	315.35	0	4.27e-4

Single Stage Boost Inverter

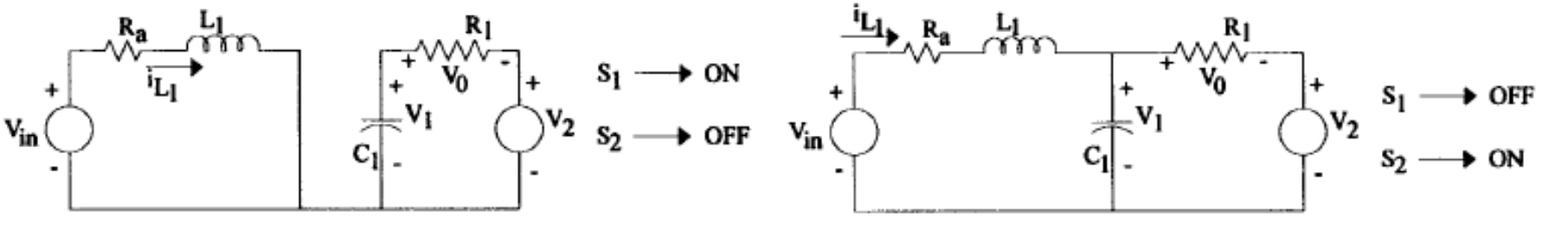


Circuit implementation



Modes of operation

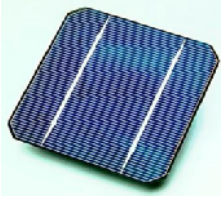
Modeling of Single Stage Boost Inverter



$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_1}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_1} & -\frac{1}{L_1} \\ \frac{1}{C_1} & -\frac{1}{C_1 R_1} \end{bmatrix} \begin{bmatrix} i_{L1} \\ V_1 \end{bmatrix} + \begin{bmatrix} \frac{V_1}{L_1} \\ -\frac{i_{L1}}{C_1} \end{bmatrix} \gamma + \begin{bmatrix} \frac{V_{in}}{L_1} \\ \frac{V_2}{C_1 R_1} \end{bmatrix}$$

The above equation is of the form

$$\dot{V} = AV + B\gamma + C$$

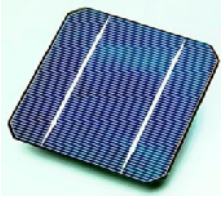


Modeling of Single Stage Boost Inverter

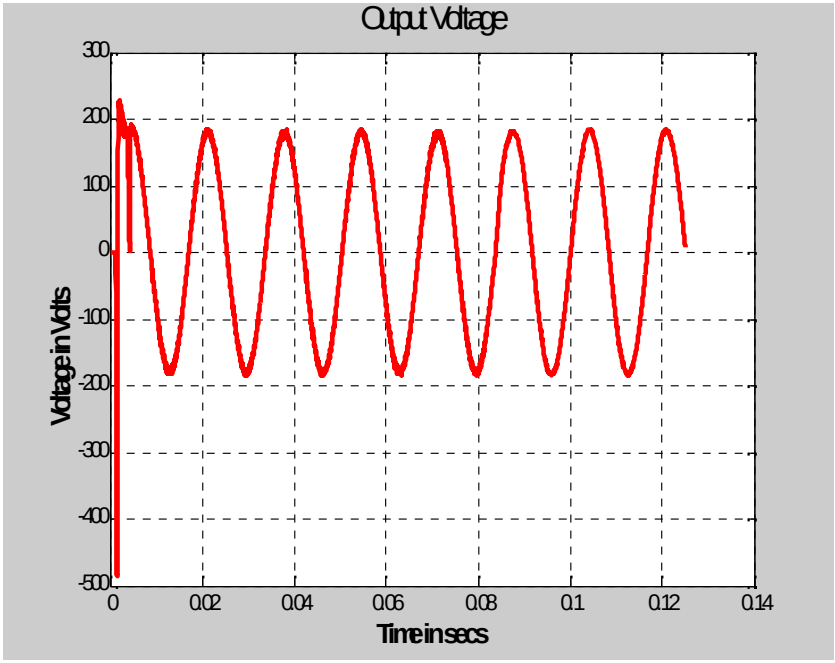
Similarly we can write the state space equations when switches S_3 and S_4 are switched and the total state space equation is given by

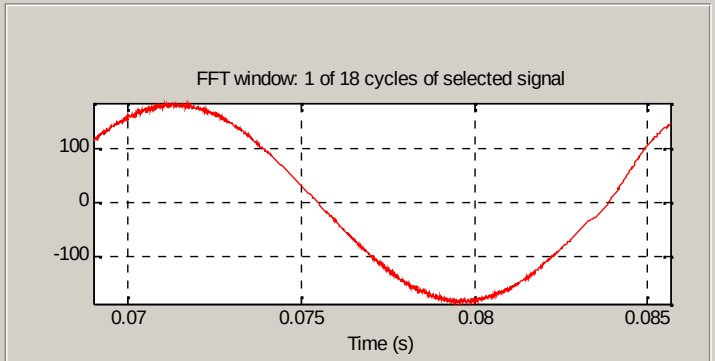
$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_1}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_2}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_1} & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & -\frac{1}{C_1 R_1} & 0 & 0 \\ 0 & 0 & -\frac{R_a}{L_2} & -\frac{1}{L_2} \\ 0 & 0 & \frac{1}{C_2} & -\frac{1}{C_2 R_1} \end{bmatrix} \begin{bmatrix} i_{L1} \\ V_1 \\ i_{L2} \\ V_2 \end{bmatrix} + \begin{bmatrix} \frac{V_1}{L_1} \\ -\frac{i_{L1}}{C_1} \\ \frac{V_2}{L_2} \\ -\frac{i_{L2}}{C_2} \end{bmatrix} \gamma + \begin{bmatrix} \frac{V_{in}}{L_1} \\ \frac{V_2}{C_1 R_1} \\ \frac{V_{in}}{L_2} \\ \frac{V_1}{C_2 R_1} \end{bmatrix}$$

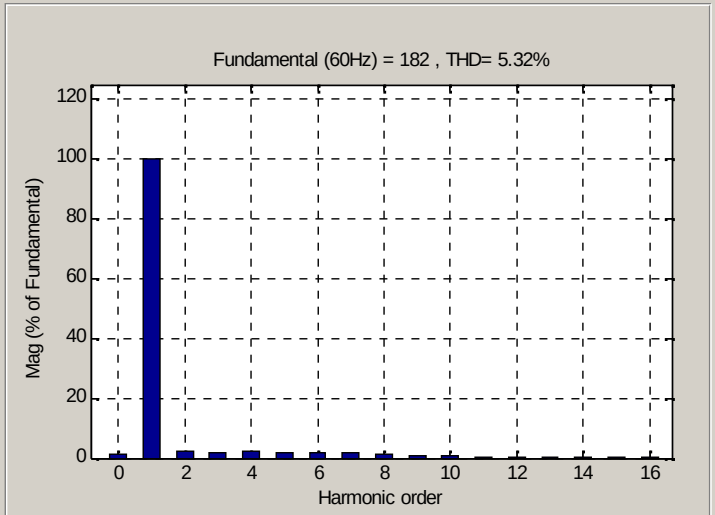
Where γ is the status of switches

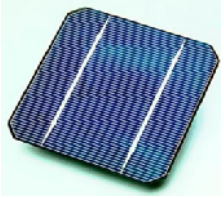


Simulation Results
With Constant Irradiance and Temperature

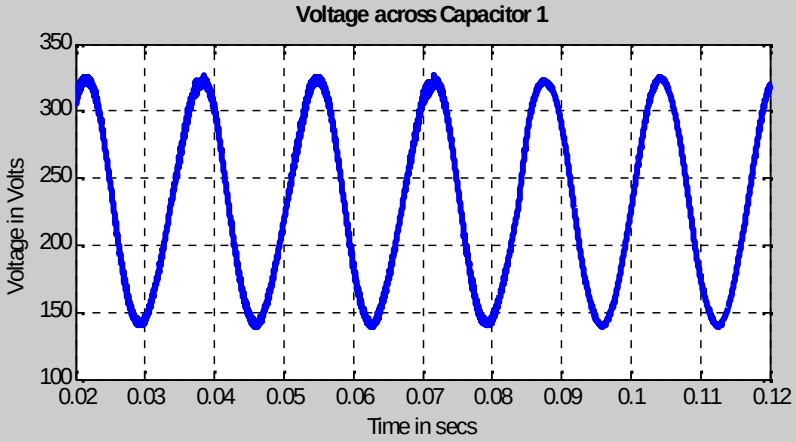


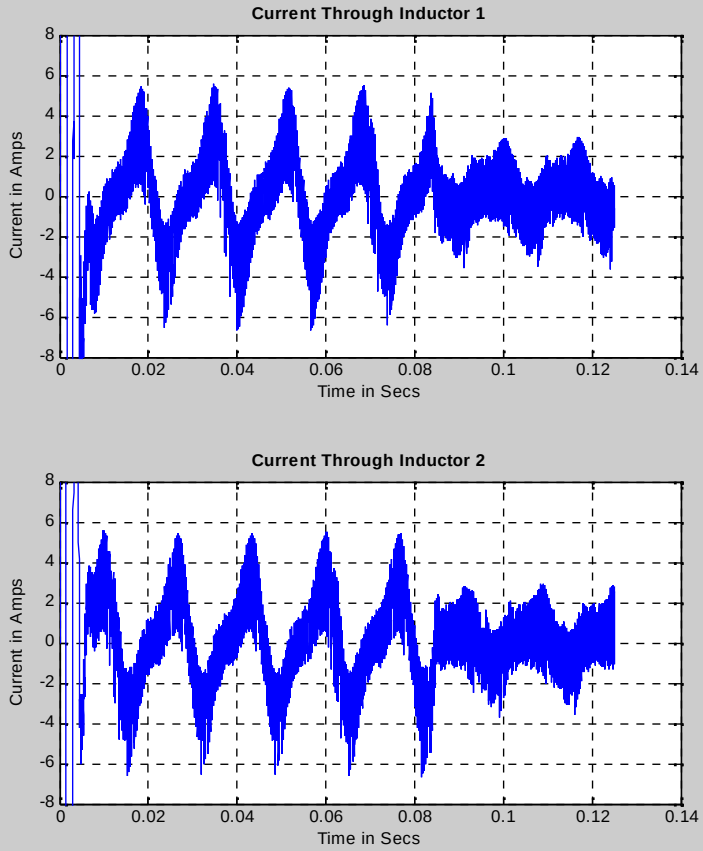


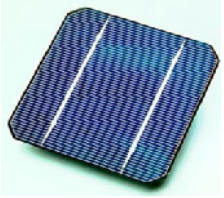




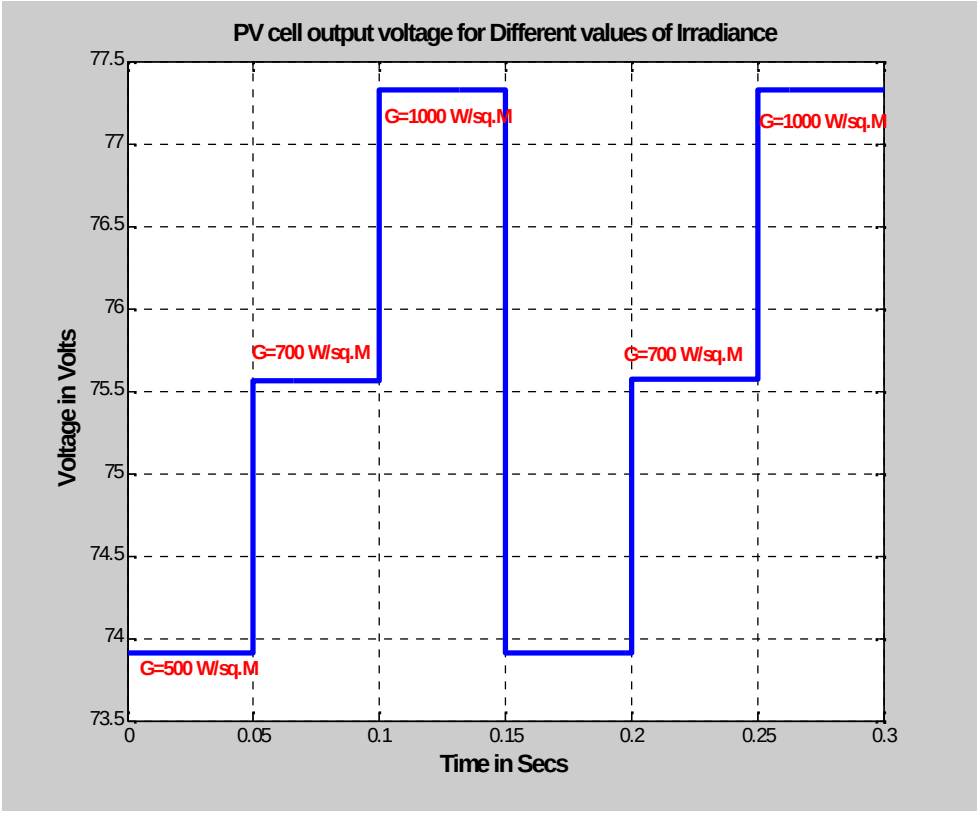
Simulation Results
With Constant Irradiance and Temperature Continues….



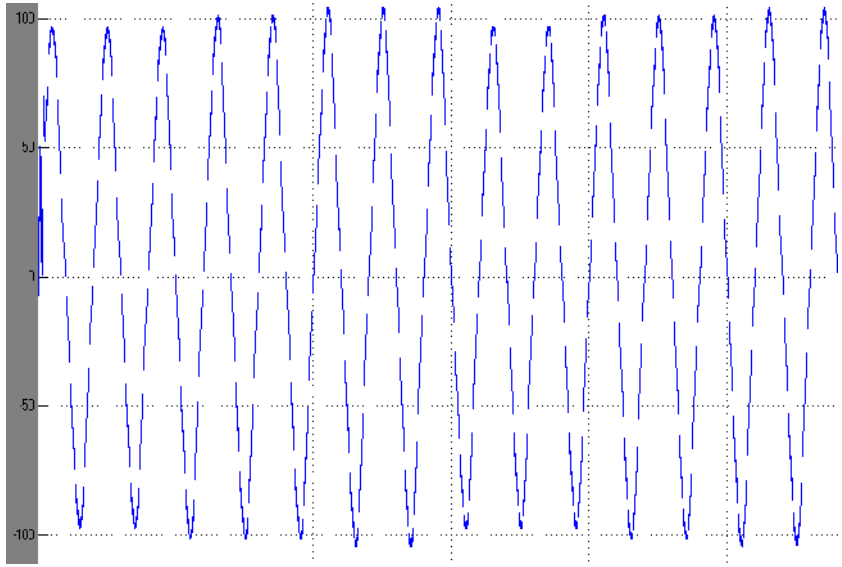




Simulation Results
With Variable Irradiance and Constant Temperature



PV panel voltage

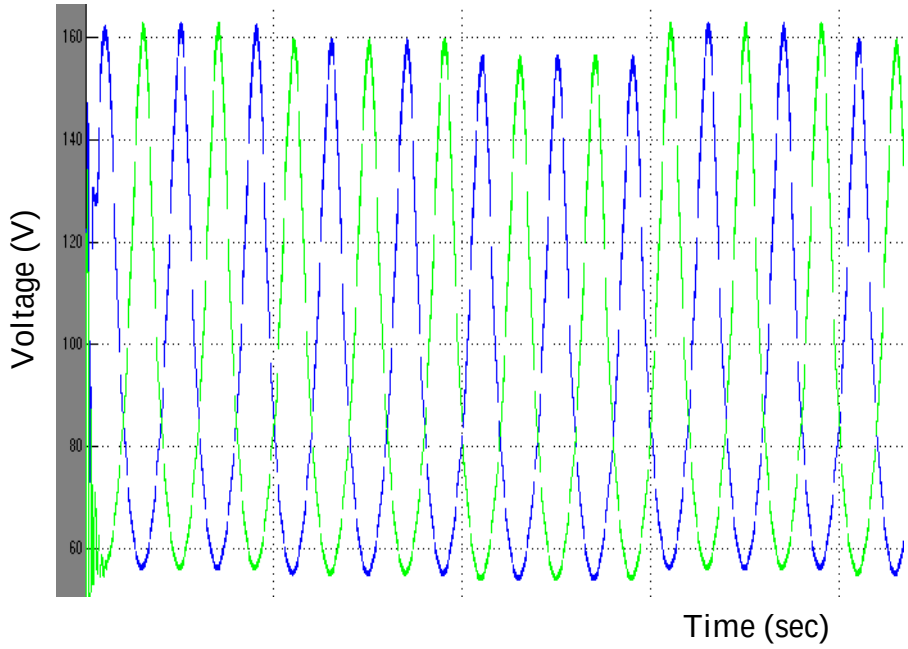


Time (sec)

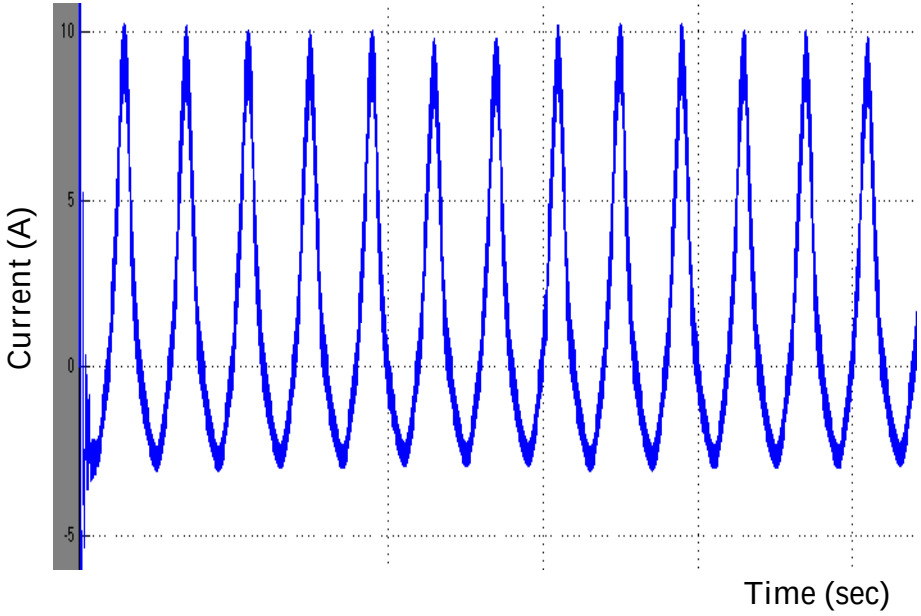
Output voltage

Believing in yourself is the first step to success- Neon Lamp –Georges Claude-1910

Simulation Results
With Variable Irradiance and Constant Temperature Continues…



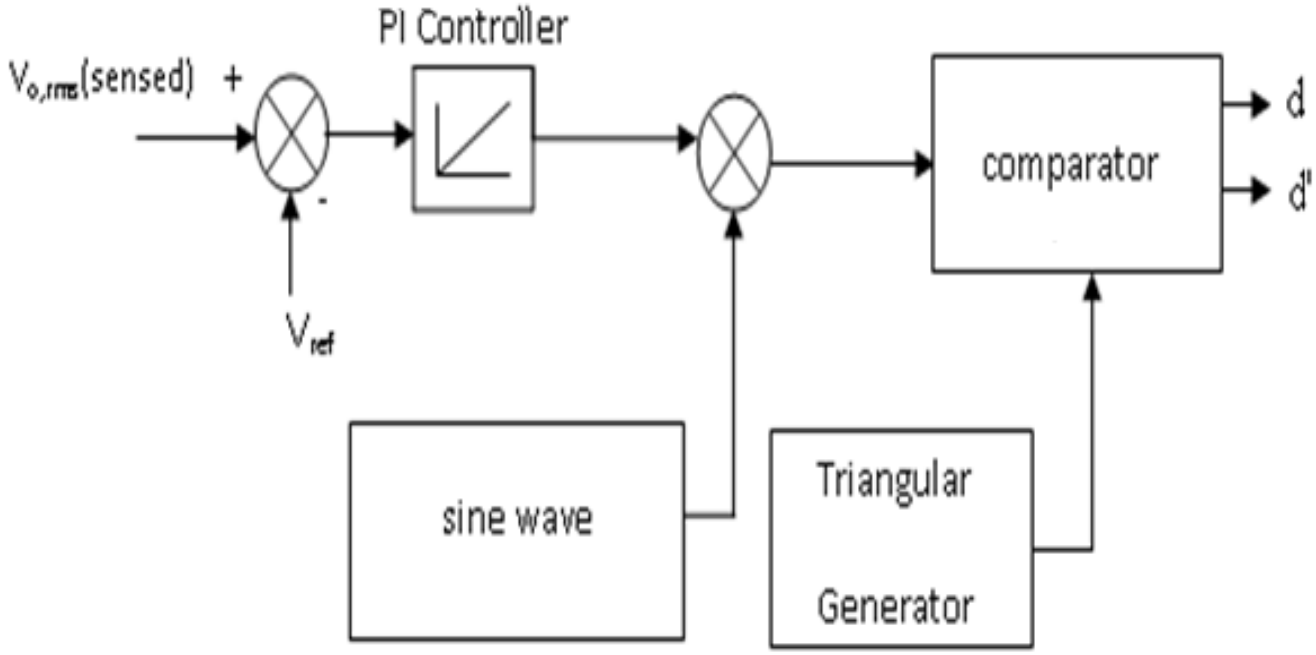
Capacitor voltage

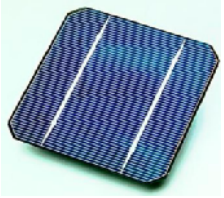


Inductor current

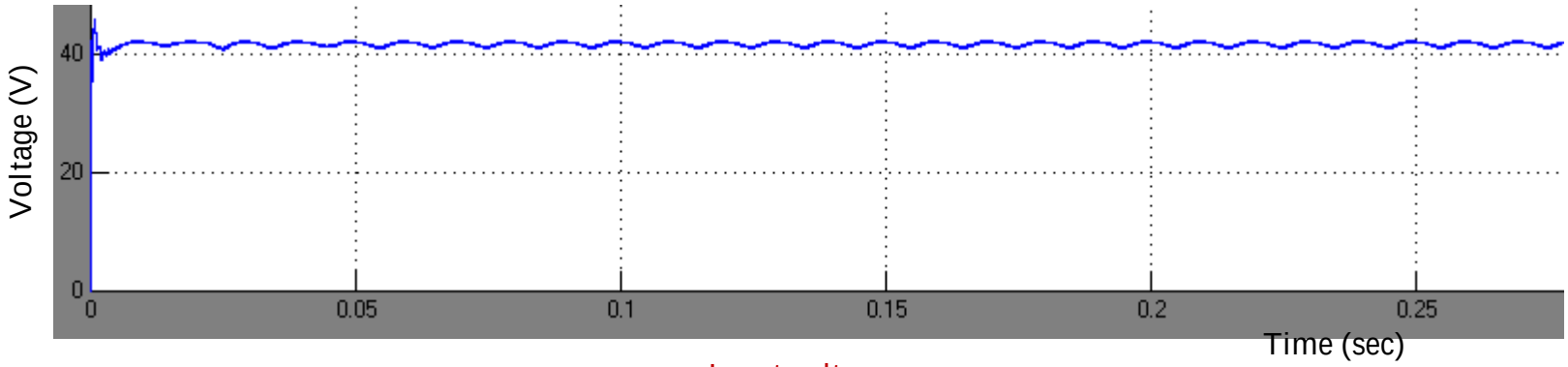
A hungry man is an angry man -Pager-Al Gross-1949

PI Controller Fed Single Stage Boost Inverter

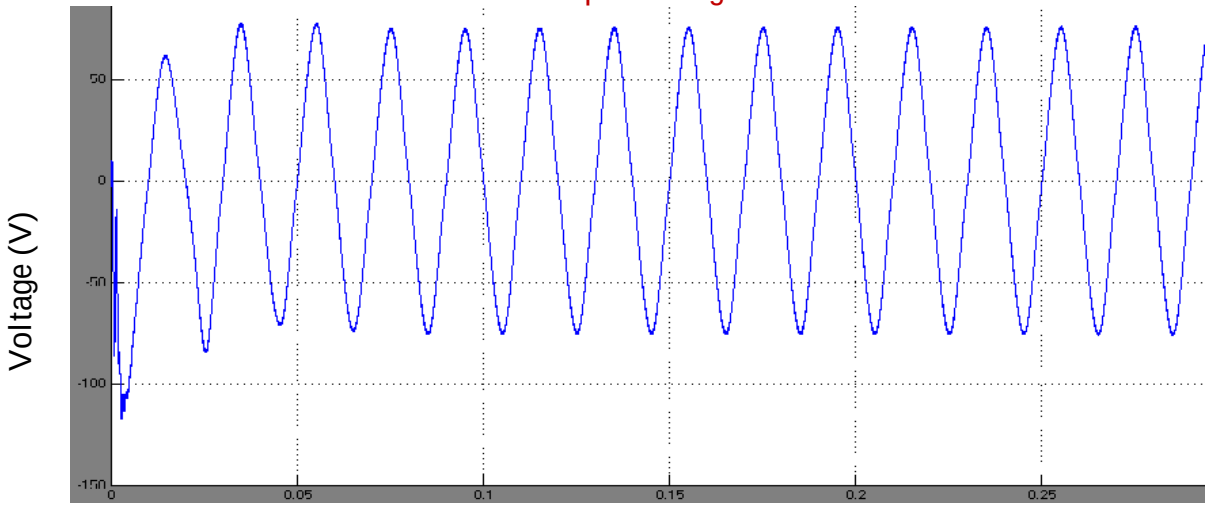




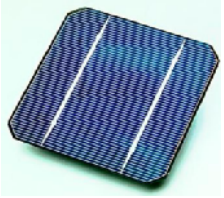
Simulation of PI Controller With Constant Irradiance and Temperature



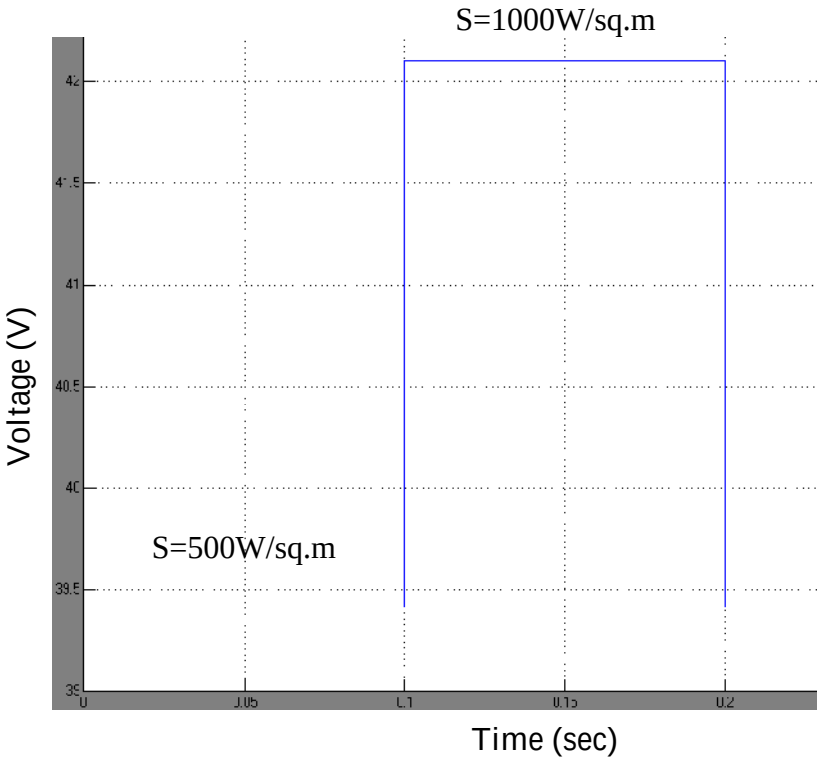
Input voltage



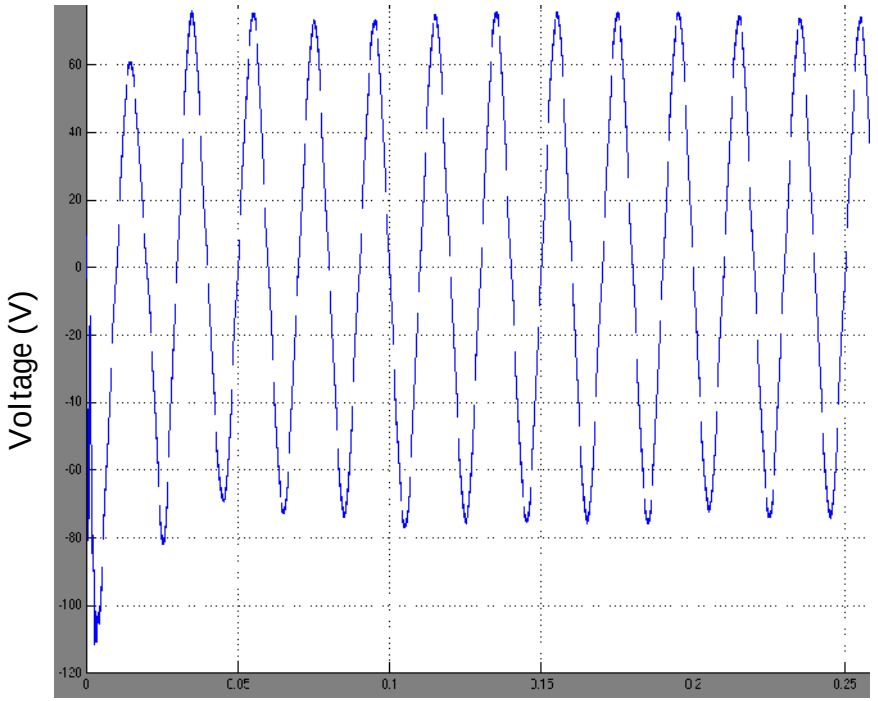
Output voltage



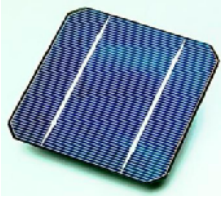
Simulation Results
With Variable Irradiance and Constant Temperature



PV panel voltage



Output voltage



Sliding Mode Controller

When good transient response of the output voltage is needed, a sliding surface equation in the state space, expressed by a linear combination of state-variable errors ε_I (defined by difference to the references variables), can be given by

$$S(i_{L1}, V_1) = K_1\varepsilon_1 + K_2\varepsilon_2 = 0$$

where coefficients K_1 and K_2 are proper gains, ε_1 is the feedback current error, ε_2 and is the feedback voltage error, or

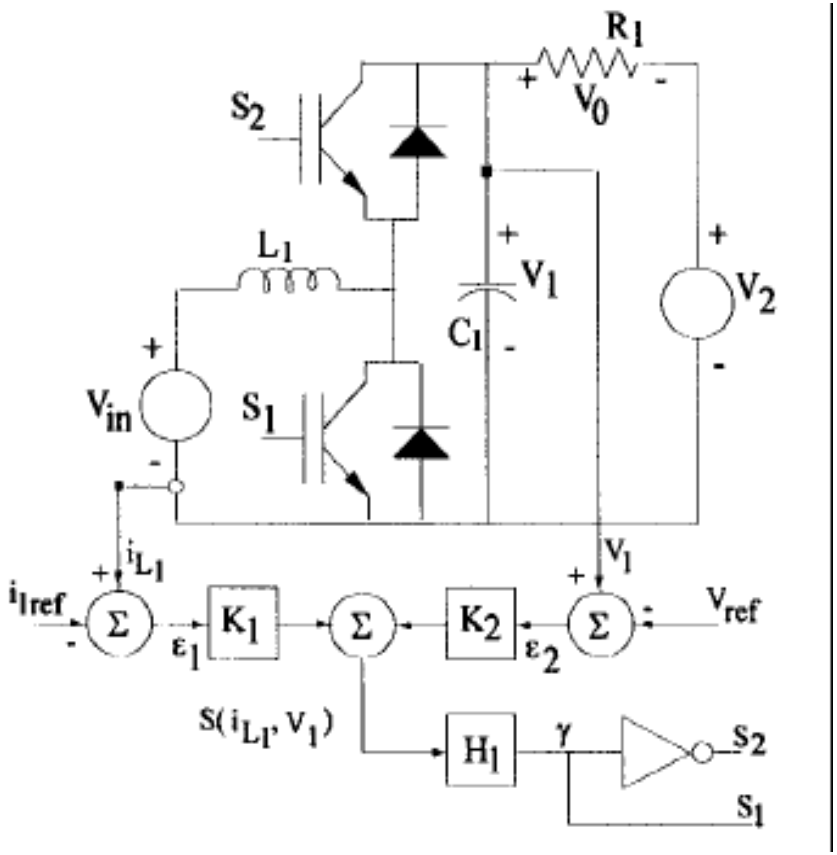
$$\varepsilon_1 = i_{L1} - i_{Lref}$$

$$\varepsilon_2 = V_1 - V_{ref}$$

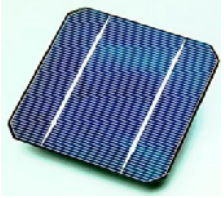
$$S(i_{L1}, V_1) = K_1(i_{L1} - i_{Lref}) + K_2(V_1 - V_{ref}) = 0$$

The system response is determined by the circuit parameters and coefficients K_1 and K_2 . With a proper selection of these coefficients in any operating condition, high control robustness, stability, and fast response can be achi

Sliding Mode Controller Continued….

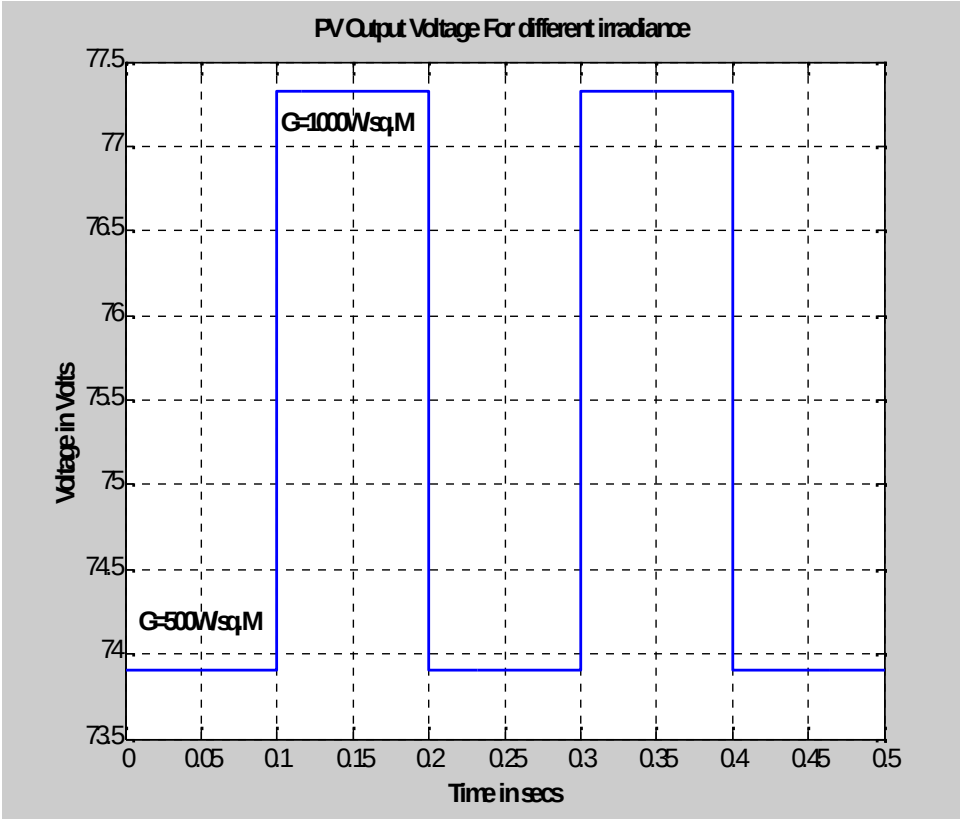


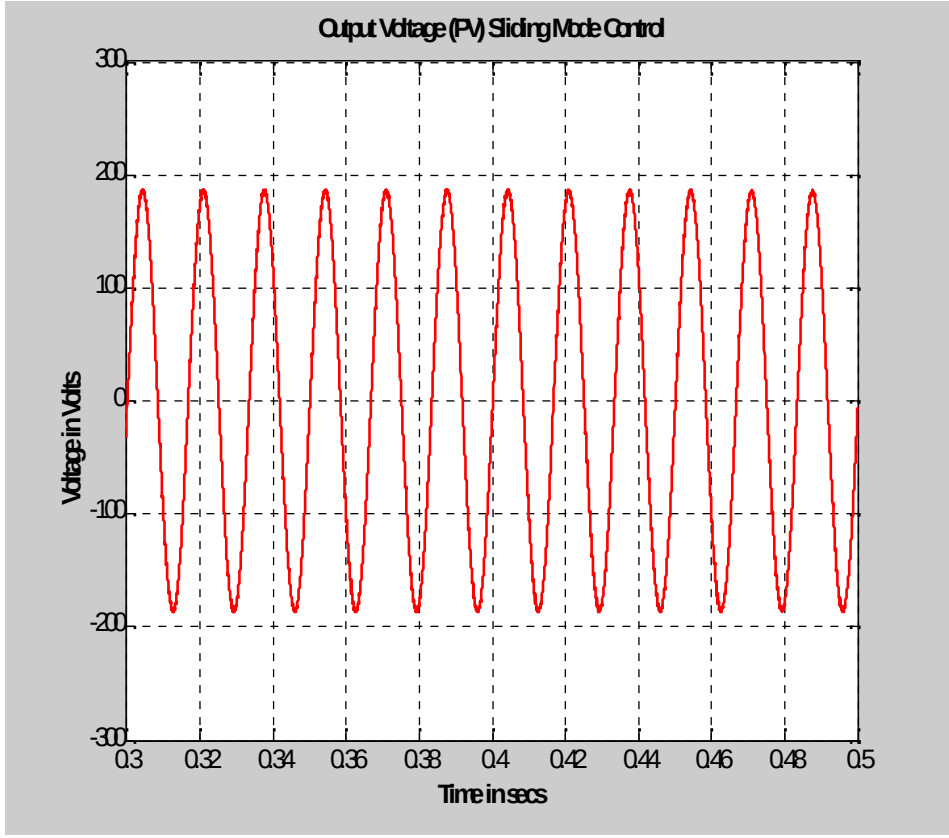
Sliding mode controller scheme



Presented By: M.Kaliamoorthy,AP,PSNACET,EEE

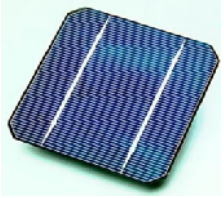
Simulation Results for Sliding Mode Controller With Variable Irradiance



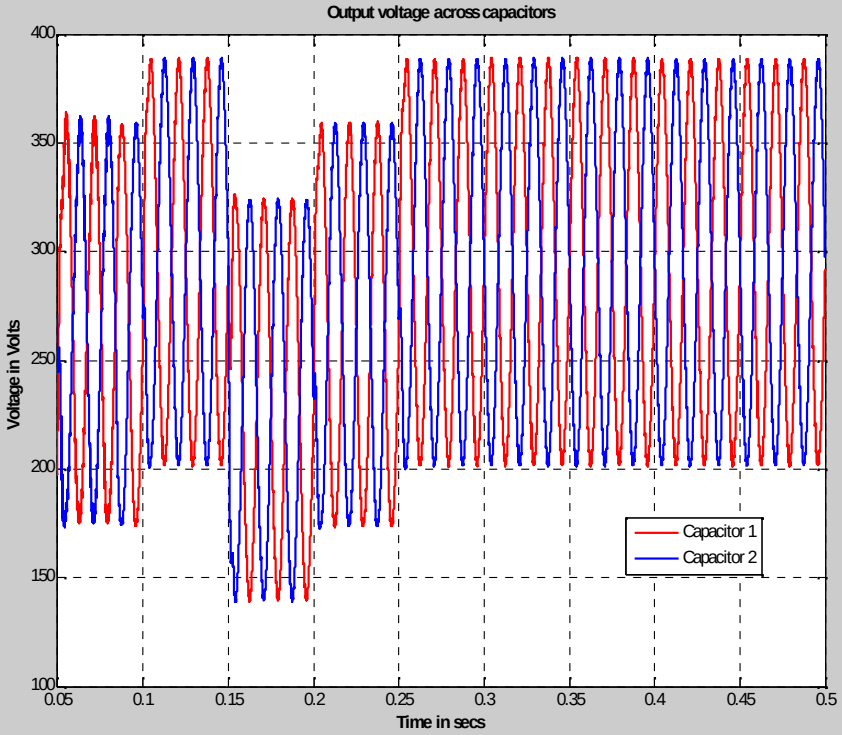


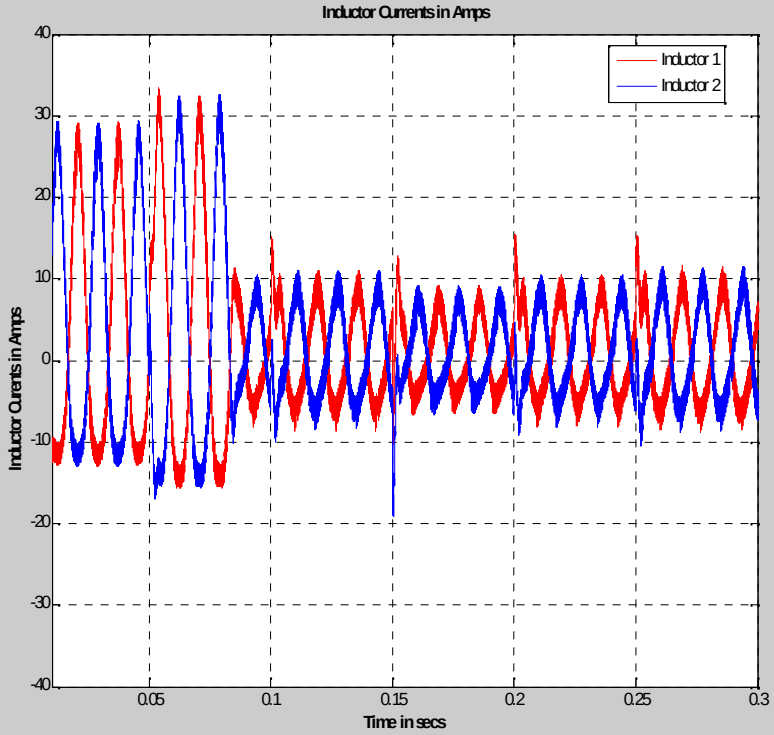
PV panel voltage

No one can make you feel inferior without your consent –Regenerative Circuit-Edwin Armstrong-1914

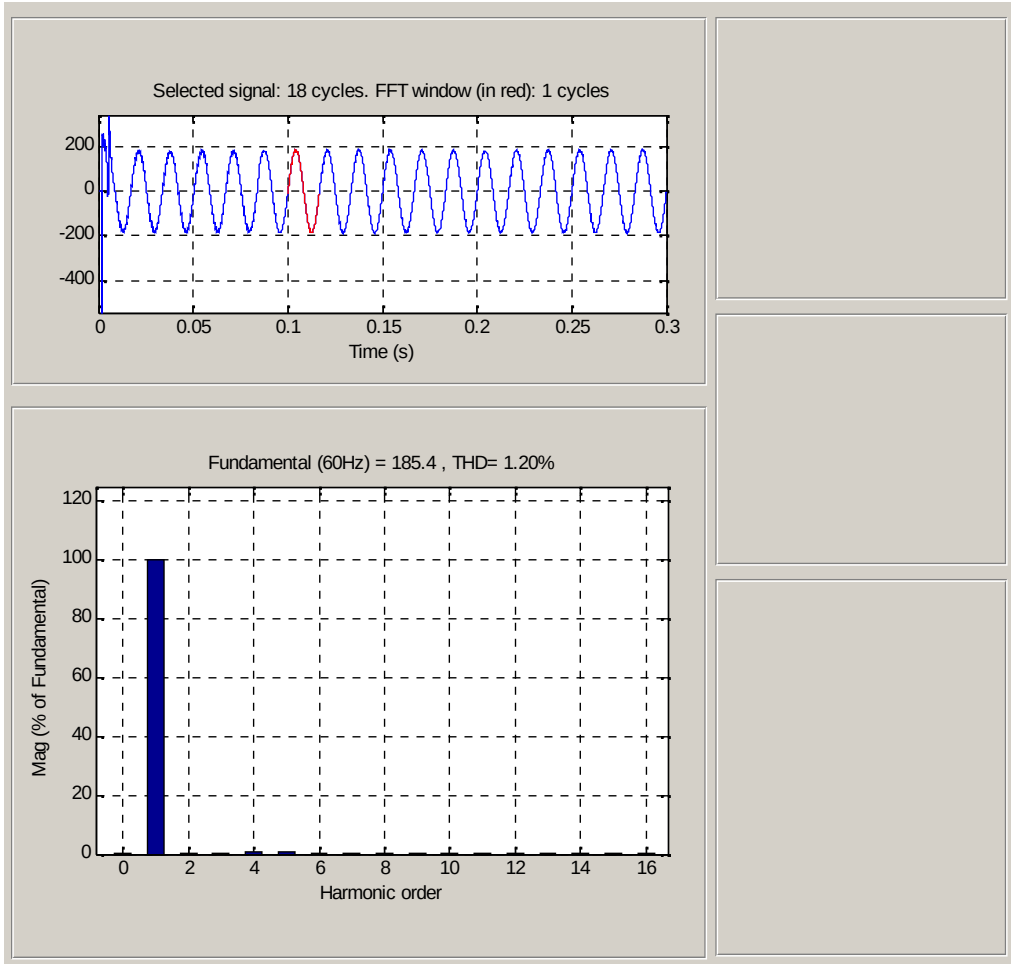


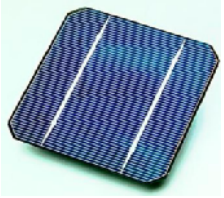
Simulation Results for Sliding Mode Controller With Variable Irradiance continues….



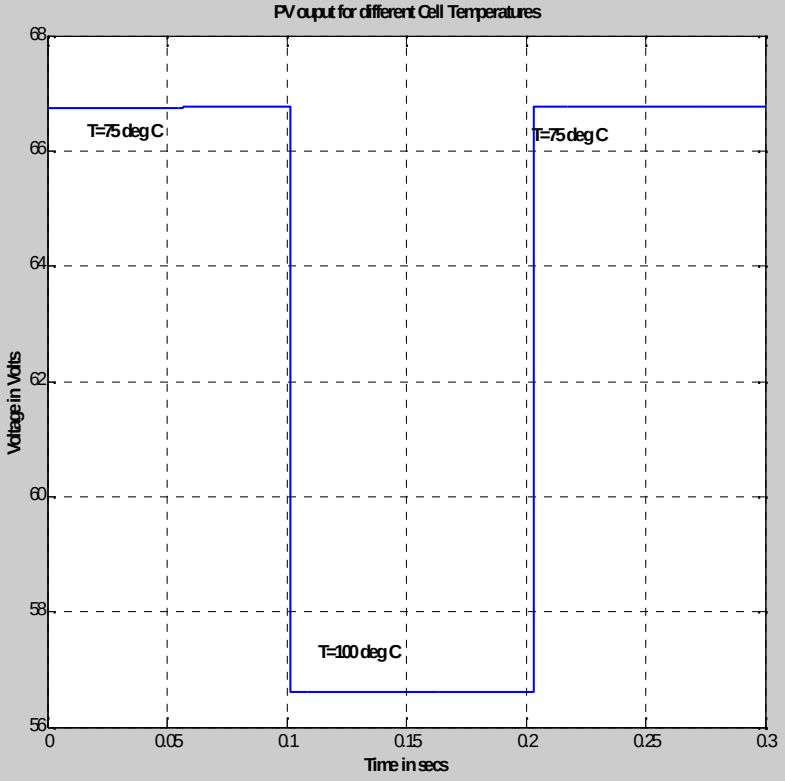


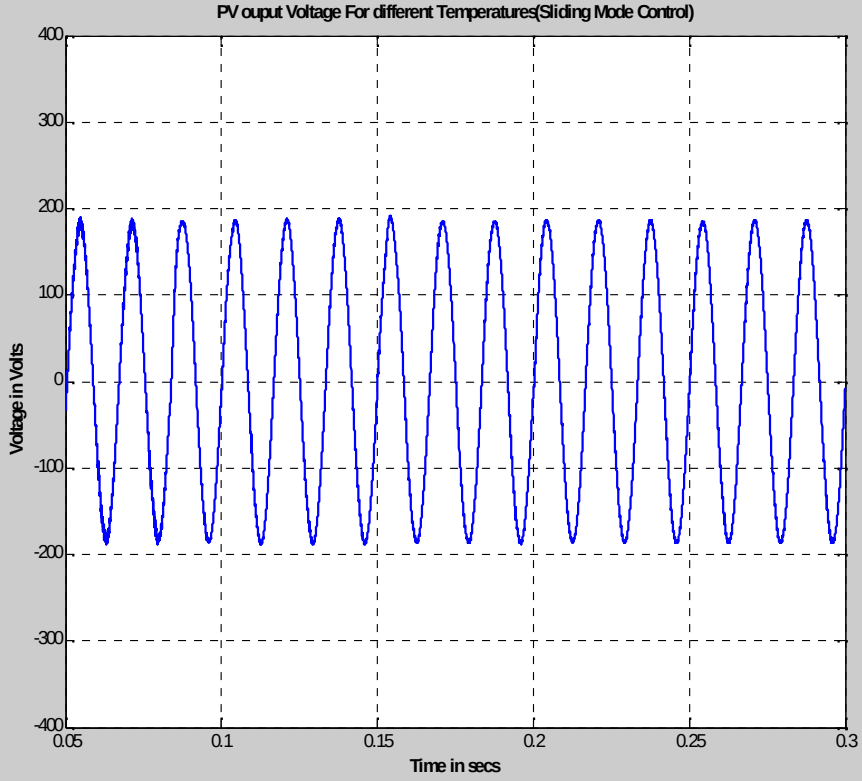
Simulation Results for Sliding Mode Controller With Variable Irradiance continues….

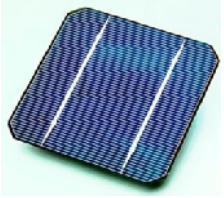




Simulation Results for Sliding Mode Controller With Variable Temperature continues….

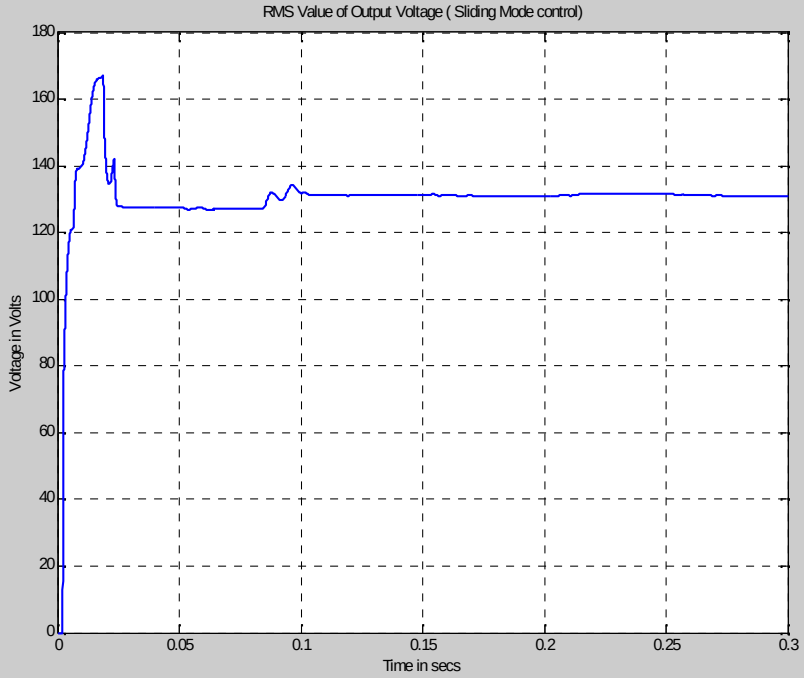


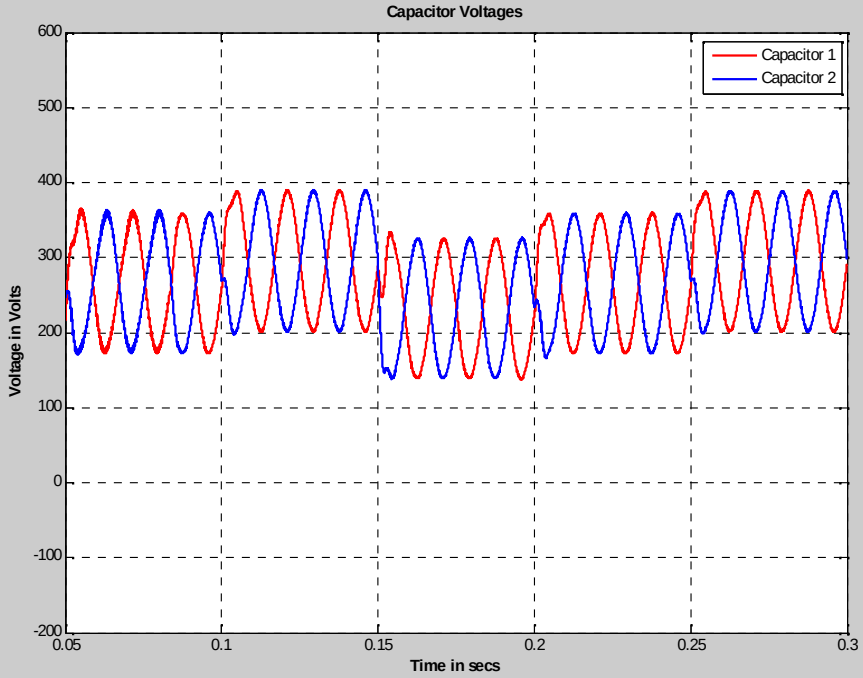




Presented By: M.Kaliamoorthy,AP,PSNACET,EEE

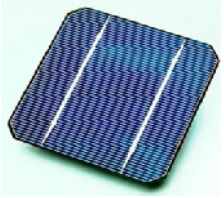
Simulation Results for Sliding Mode Controller With Variable Temperature continues….





Comparisons

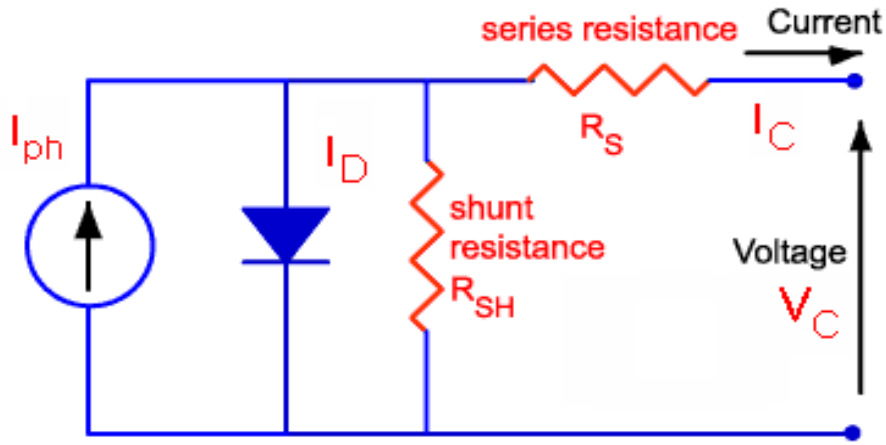
Controller	Output	THD	Settling time	Input condition	Atmospheric condition
Open loop	AC with constant RMS	≈ 5	≈0.01 s	Constant V_{ph} and I_{ph}	Constant irradiation (G) and temperature (T)
Open loop	AC with changing RMS	≈9	≈0.01 s	Varying V_{ph} and I_{ph}	Varying G / T
PI	AC with almost constant RMS	≈2	≈0.005s	Varying V_{ph} and I_{ph}	Varying G / T
SMC	AC with constant RMS	≈1.5	≈0.002s	Varying V_{ph} and I_{ph}	Varying G / T



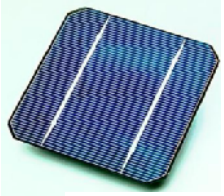
Conclusions

- Simple and reliable operation
- The cost of this inverter is relatively low as minimum number of power devices are used
- Closed loop controlling improves the reliability and dynamic stability
- Closed loop controlling using MPPT is simple and more reliable compared to all other controllers

PHOTOVOLTAIC CELL MODELING



$$V_c = \frac{AkT_c}{e} \ln\left[\frac{I_{ph} + I_0 - I_c}{I_0}\right] - R_s I_c$$



Temperature and Irradiance Dependence

$$V_{ocT} = V_{oc} + k_v(T_x - T_c)$$

$$I_{SCT} = I_{sc} + k_i(T_X - T_C)$$

$$I_x = I_{scT} S_x$$

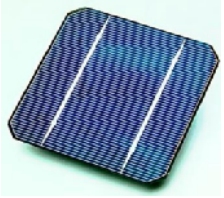
$$V_x = \frac{-I_x R_s + \ln\left[-I_x e^{\frac{Voc}{Vt}} - I_x e^{\frac{I_{scT} R_s}{V_t}} - I_{sc} e^{\frac{Voc}{Vt}}\right]}{I_{sc}}$$

Where:

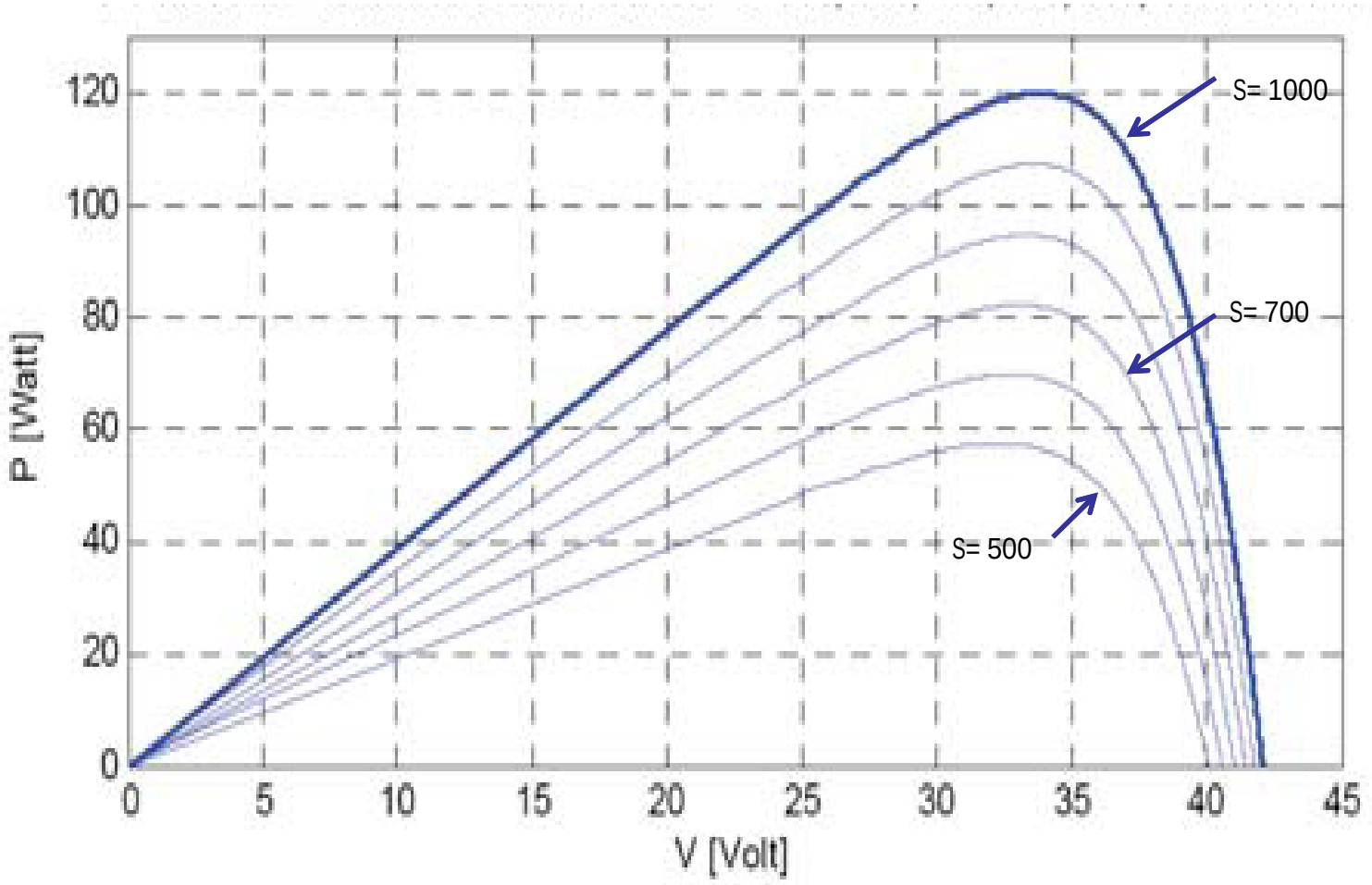
$$V_t = \frac{A_D k T_x n_c}{e}$$

Datasheet values

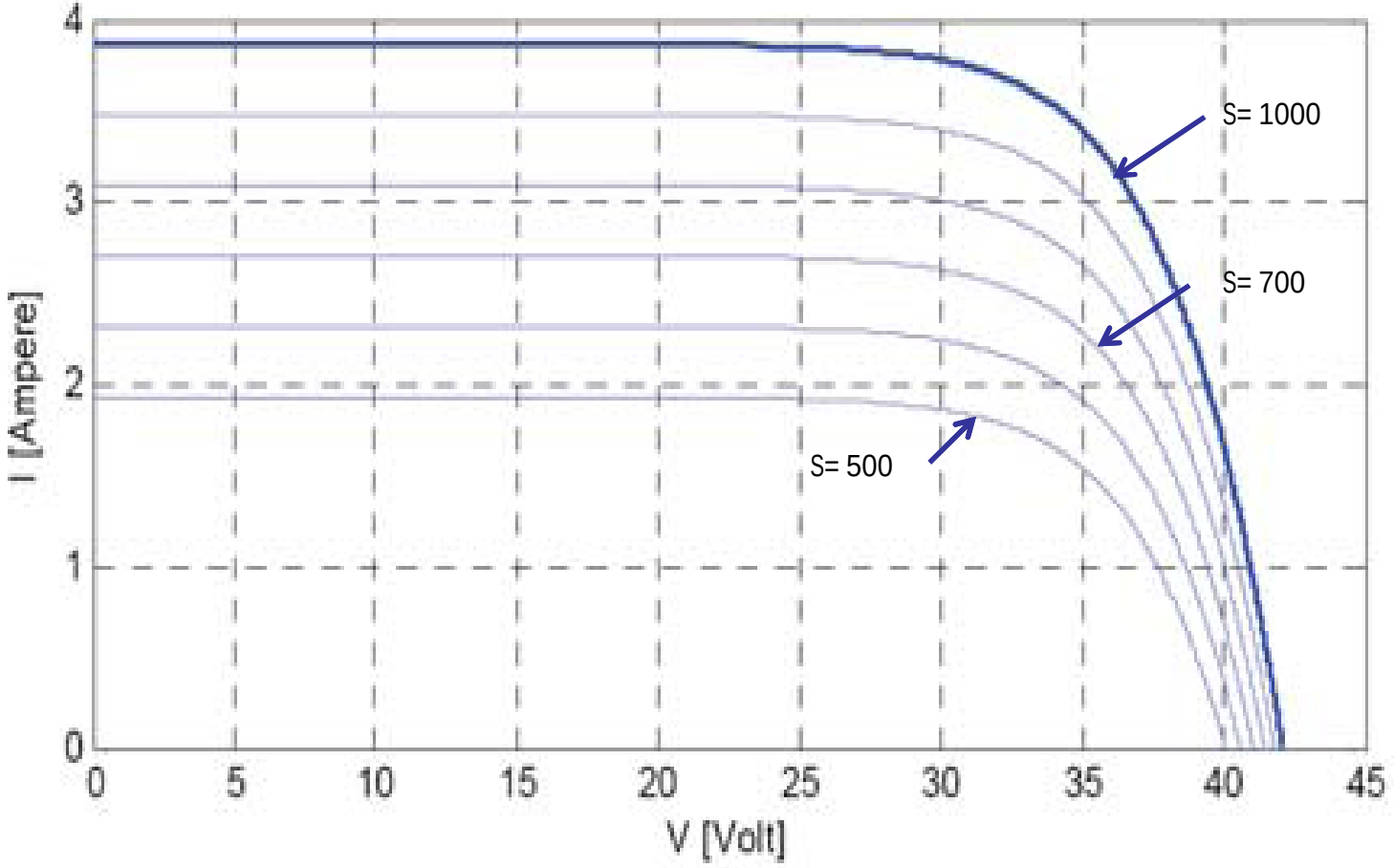
V_{mpp}=33.7V
I_{mpp}=3.56
V_{oc}=42.1
I_{sc}=3.87
n_c=72
k_i=0.065 x 10^{-2} %/^{0}C
k_v=-160 x 10^{-3} %/^{0}C
k_p=-0.5 x 10^{-2} %/^{0}C

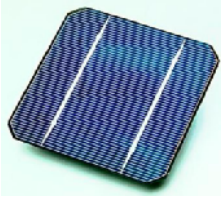


CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE

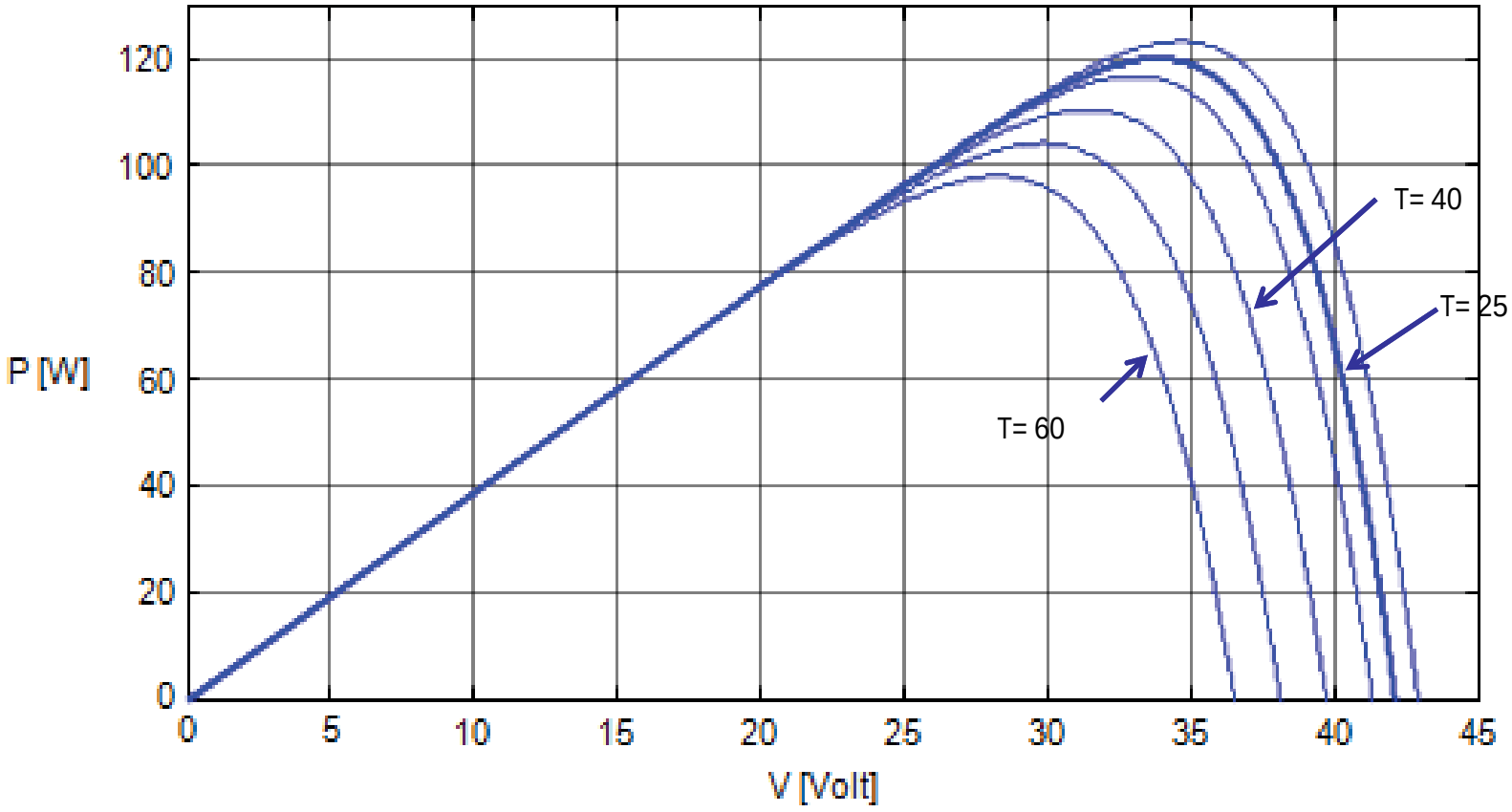


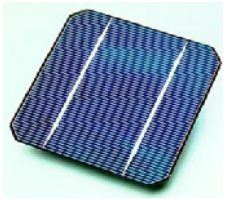
CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE



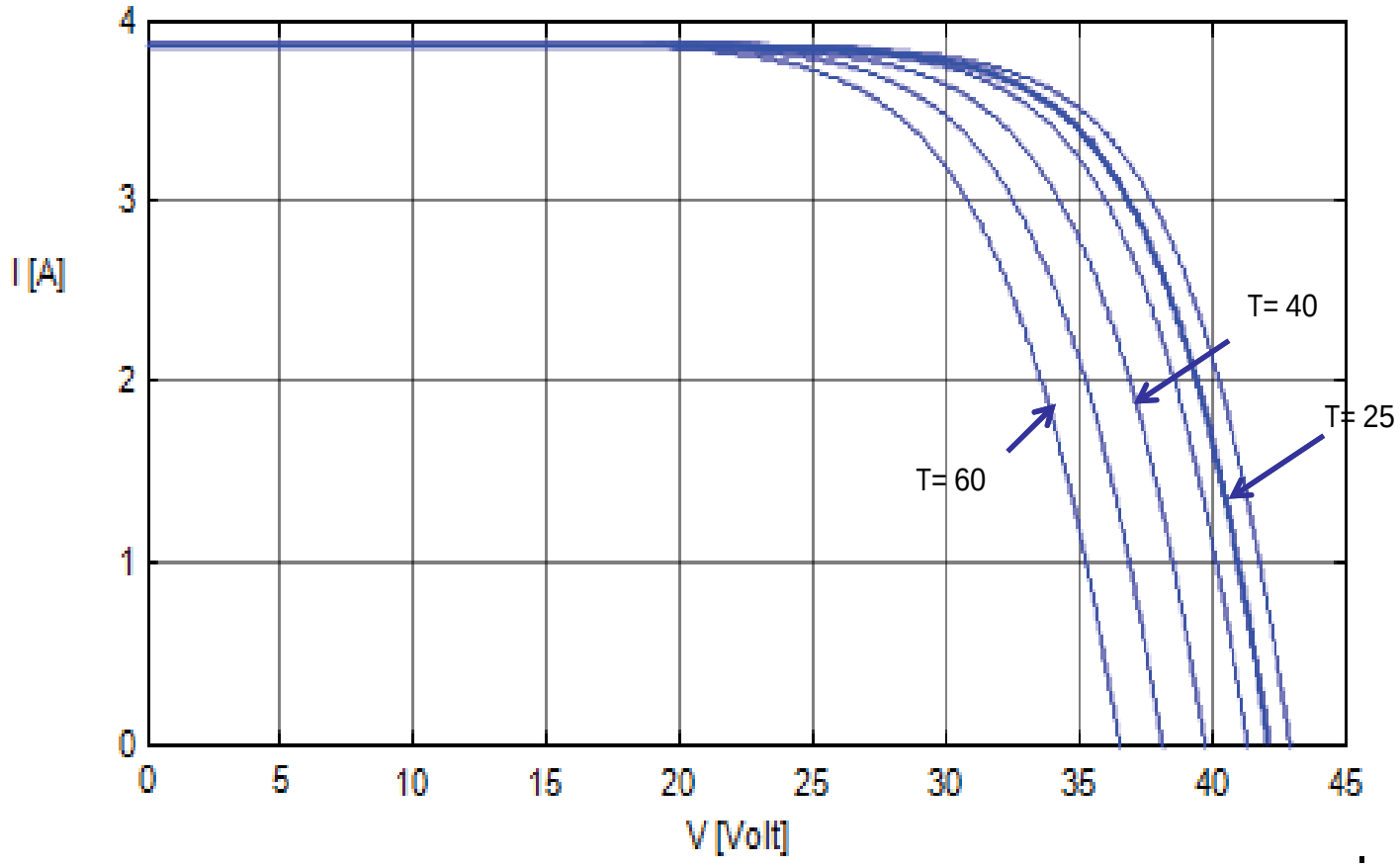


CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE

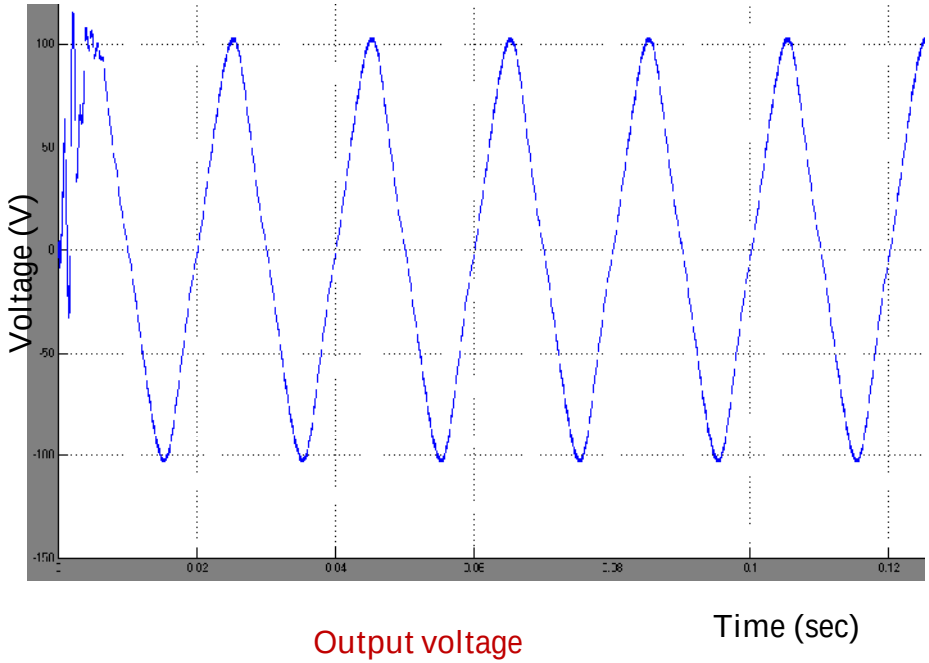




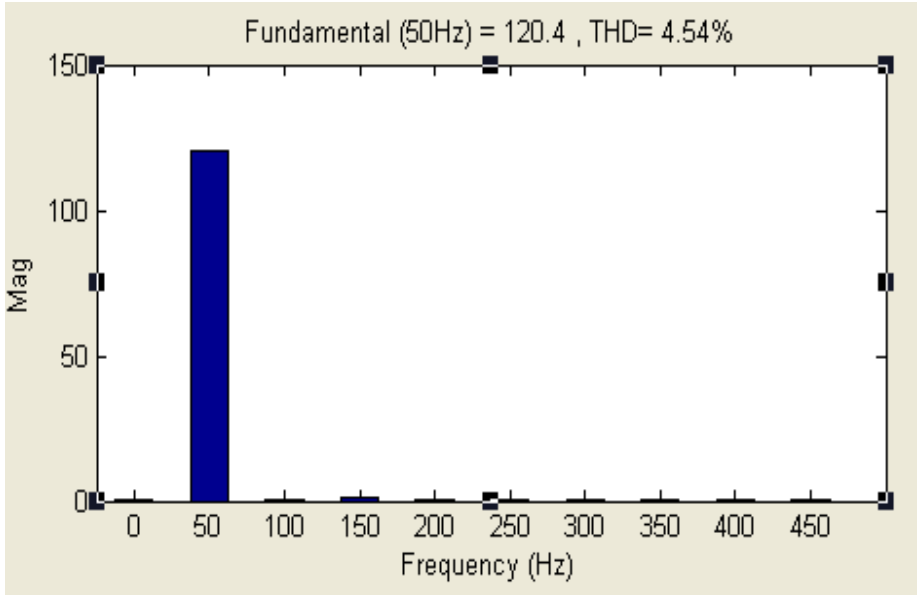
CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE



Simulation Results
With Constant Irradiance and Temperature

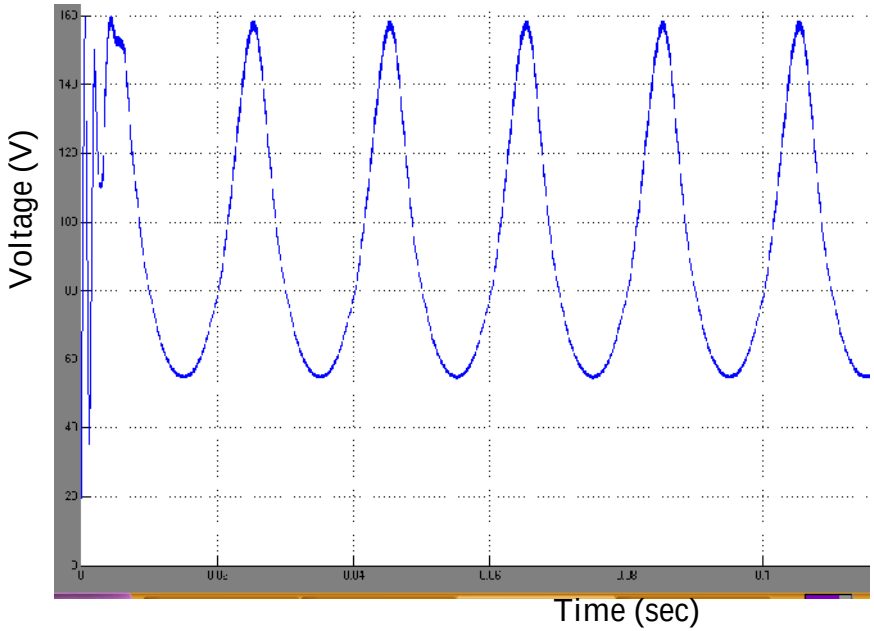


Output voltage

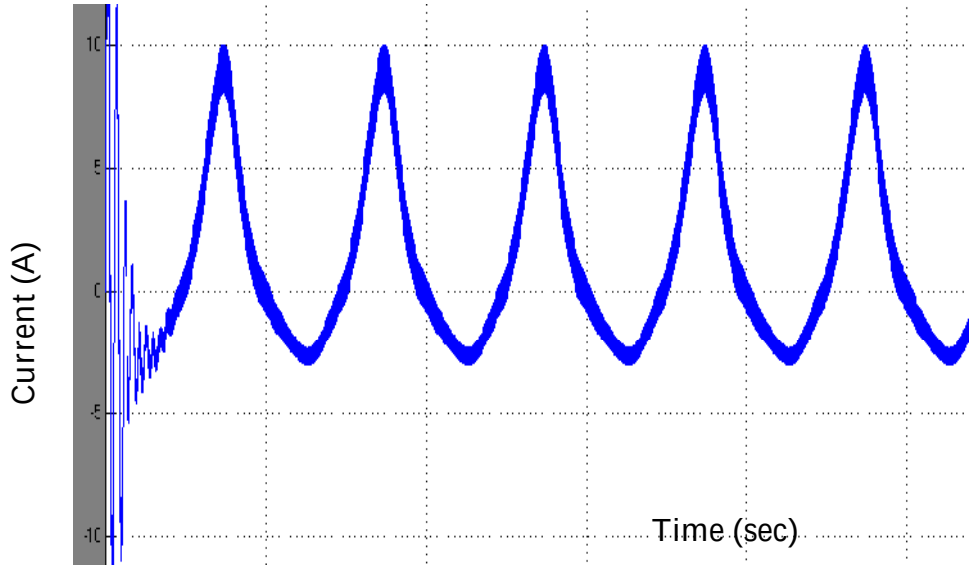


THD of output voltage

Simulation Results
With Constant Irradiance and Temperature Continues….



Capacitor voltage



Inductor current

Be willing to accept temporary inconvenience for permanent improvement