



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



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Presentation By

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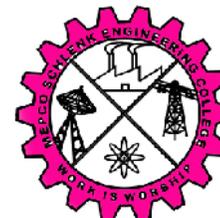
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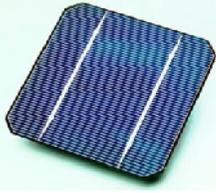
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Paper Number : 111



The Journey of Thousand Miles Begins with a single step





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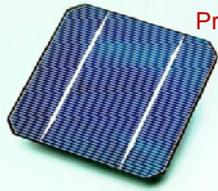
Objectives of This Paper

- 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



Low aim is a crime- Diode-John Ambrose Fleming-1904





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Contents of Presentation

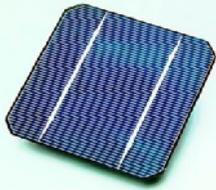


- Simulation of accurate PV panel
- Simulation of improved maximum power point tracking algorithm using Evolutionary Programming
- Analysis and simulation of open loop single stage PV fed boost dc-ac converter
- Developing sliding mode control and PI control for PV fed boost inverter
- Comparison of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



Model a Drop, To know the power of the OCEAN- Zener Diode –Clarence Melvin Zener-1915

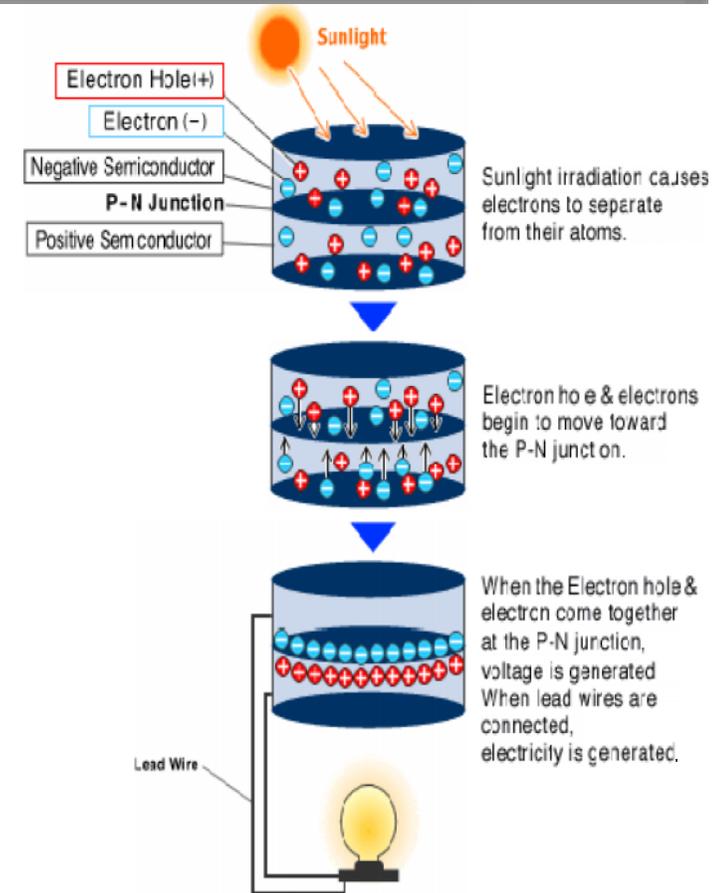
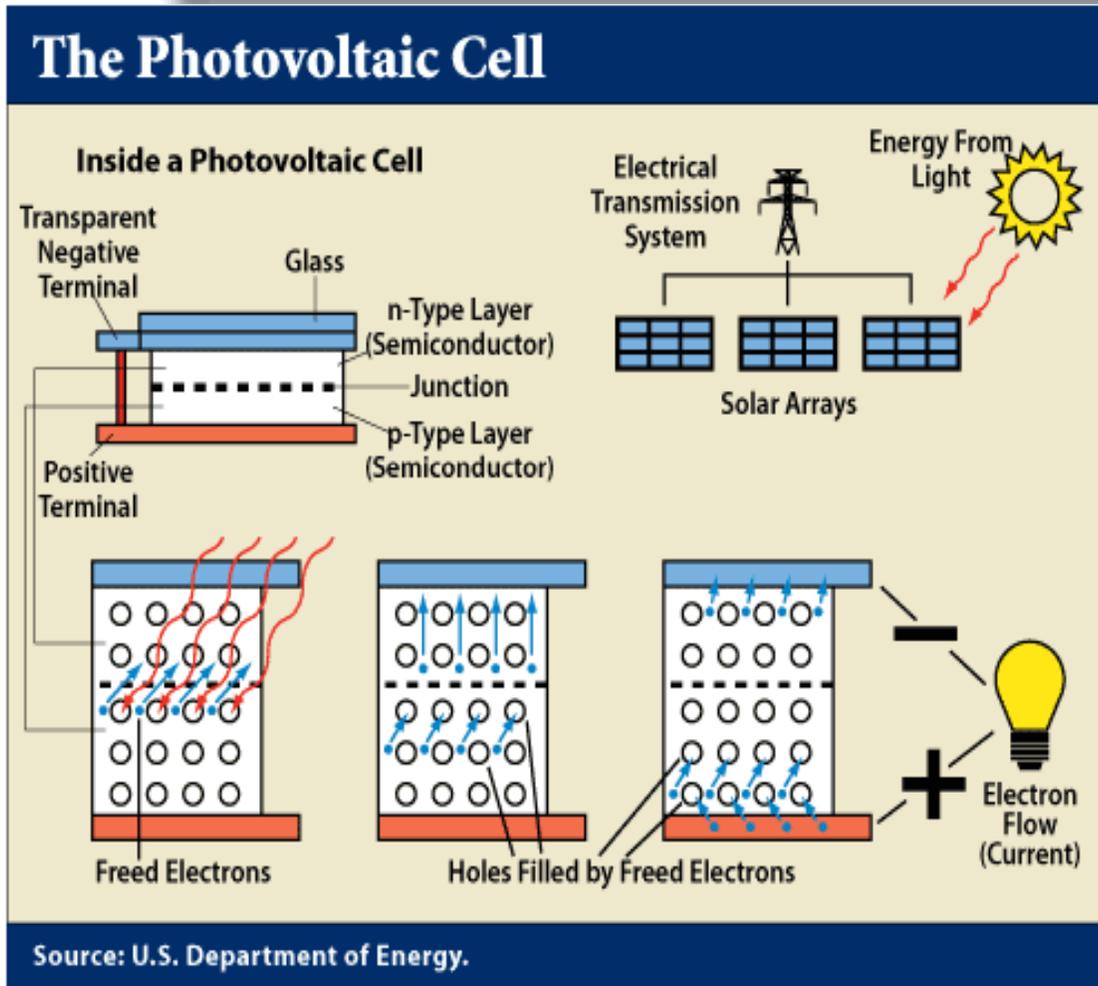




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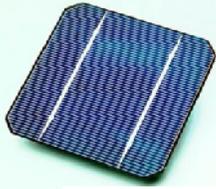


PHOTOVOLTAIC CELL WORKING PRINCIPLE



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

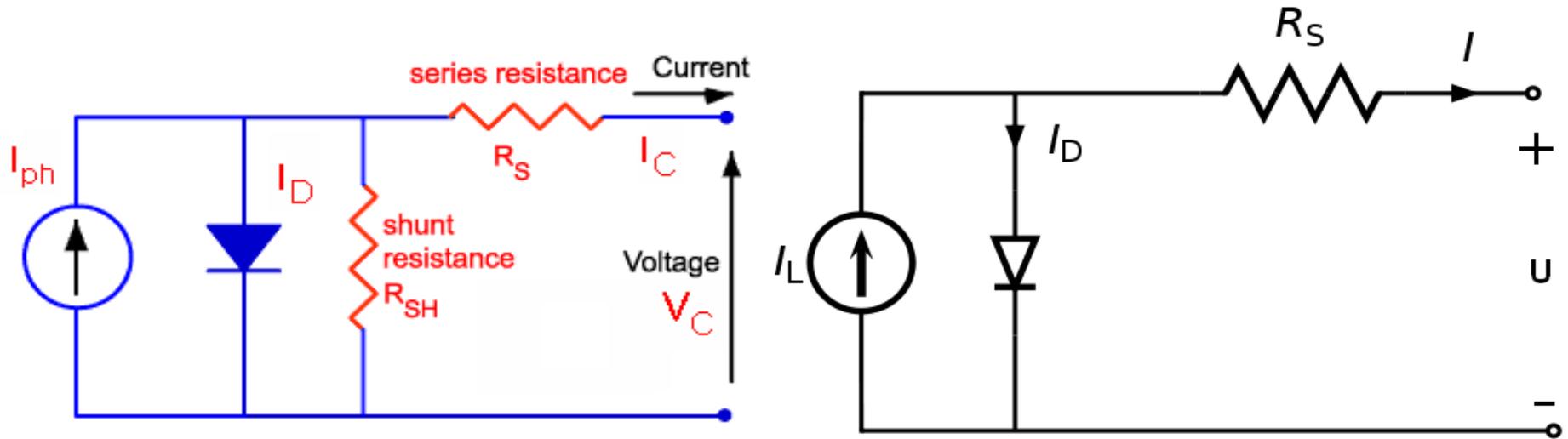




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PHOTOVOLTAIC CELL MODELING



From the figure

$$I = I_L - I_D \text{ --- --- --- (1)}$$

Where I=Output Current In Amps

I_L =light Current Or Photo Generated Current In Amps

I_D = Diode Current in amps



Reading is an adventure that never ends- Photo Voltaic Cell- Russell Ohl-1903





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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°C $nkT/q = 0.0259$ volts =

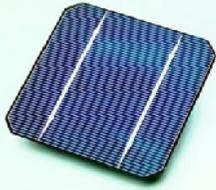
$$I_D = I_o \left[\exp \left(\frac{U + IR_s}{\alpha} \right) - 1 \right]$$



Believing in yourself is the first step to success- Lead Acid Battery- Raymond Gaston Plante-1859

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PHOTOVOLTAIC CELL MODELING Cont...

Substituting above equation in equation (1) we get

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

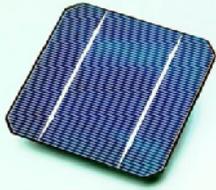
Where $\alpha = nkT/q$ is known as Thermal Voltage

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



Look at your strengths and not your weaknesses- SCR-General Electric (GE)-1958





PHOTOVOLTAIC CELL MODELING Cont...

LIGHT CURRENT I_L determination

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

Where ϕ = irradiance(W/m^2)

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

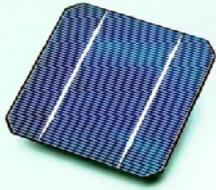
$I_{L,ref}$ = Light current at reference condition ($1000 \text{ W}/\text{m}^2$ and 25°C)

T_c = PV cell temperature

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

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

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)

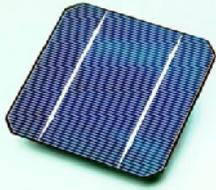
α_{ref} = The value of α at the reference condition

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

$U_{oc,ref}$ = The open circuit voltage of the PV module

at the reference condition(V) (Will be provided by manufacturers)





PHOTOVOLTAIC CELL MODELING Cont...

Calculation of

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

Where

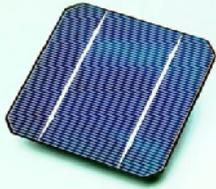
$U_{mp,ref}$ = Maximum power point voltage at the reference condition (V)

$I_{mp,ref}$ = 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

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

C_{pv} = The overall heat capacity per unit area of the PV cell/Module [J/($^{\circ}C.m^2$)]

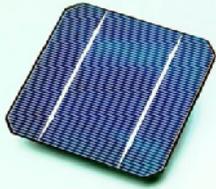
$K_{in,pv}$ = Transmittance absorption product of PV cells

k_{loss} = Overall heat loss coefficient [W/($^{\circ}C.m^2$)]

T_a = Ambient temperature ($^{\circ}C$)

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





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PHOTOVOLTAIC CELL MODEL PARAMETERS

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

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



Be willing to accept temporary inconvenience for permanent improvement –Dynamo-Michael Faraday-1832

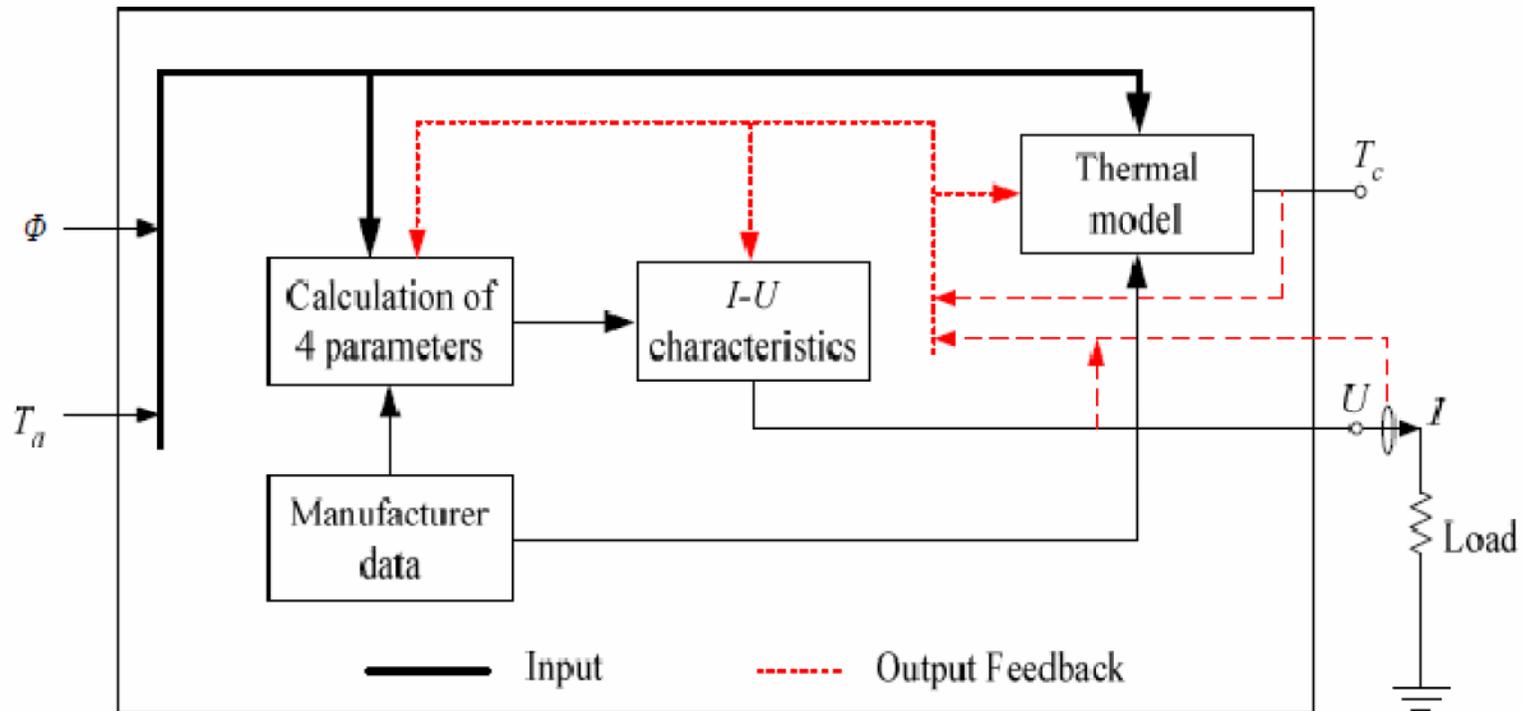




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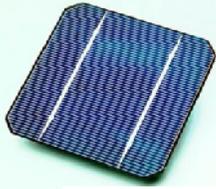


PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK



Better safe than sorry –Analog Storage Oscilloscope- Hughes-1957

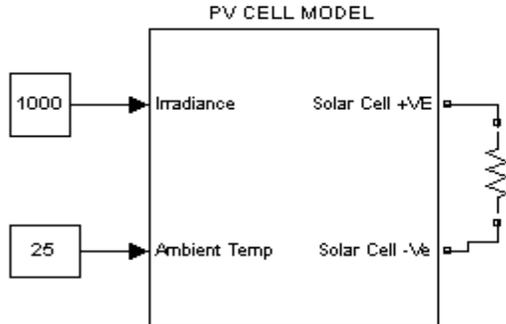




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PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK



Block Parameters: PV CELL MODEL

Photovoltaic cell (mask)
Complete model of Photovoltaic cell
Developed by Kaliamoorthy and Team

Parameters

Reference Temperature in degree centigrades
25

Reference Irradiance
1000

Overall Heat Loss Coefficient(W/Cm2)
30

Number of cells in series
153

Timing factor at reference Condition(Alpha_ref)
5.472

Transmittance Absorption
0.9

Effective Area of the PV cell/Module(m2)
1.5

Over all heat capacity / unit area/Module
50000

Series Resistance
1.324

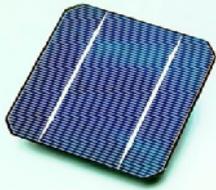
OK Cancel Help Apply



Distance lends enchantment to the view –CRO- Karl Ferdinand Braun- 1897

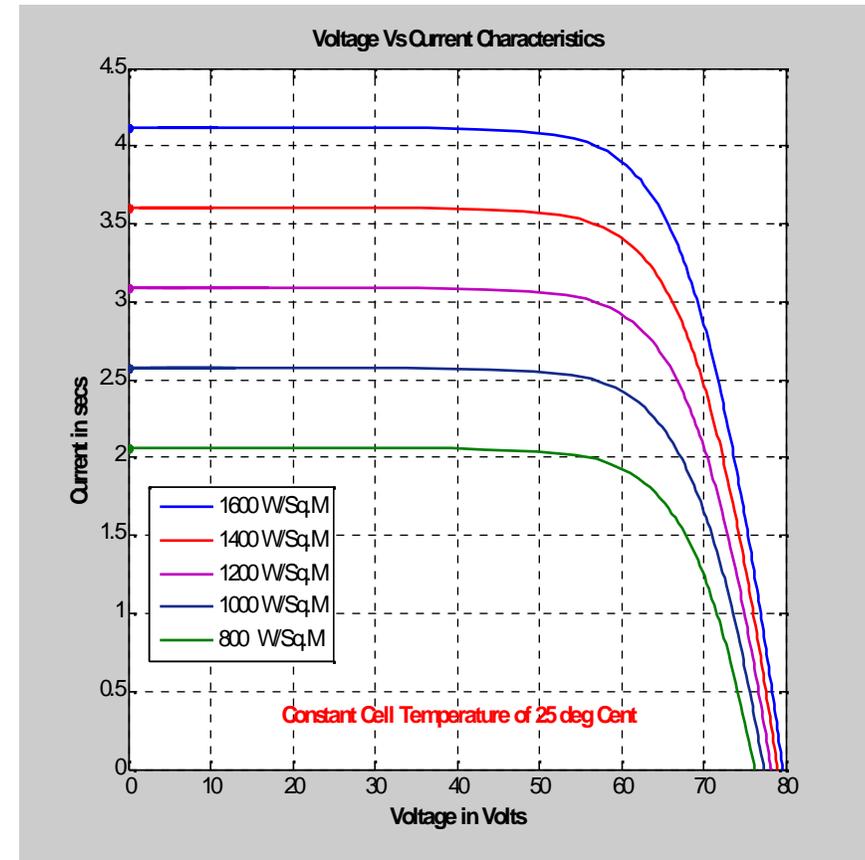
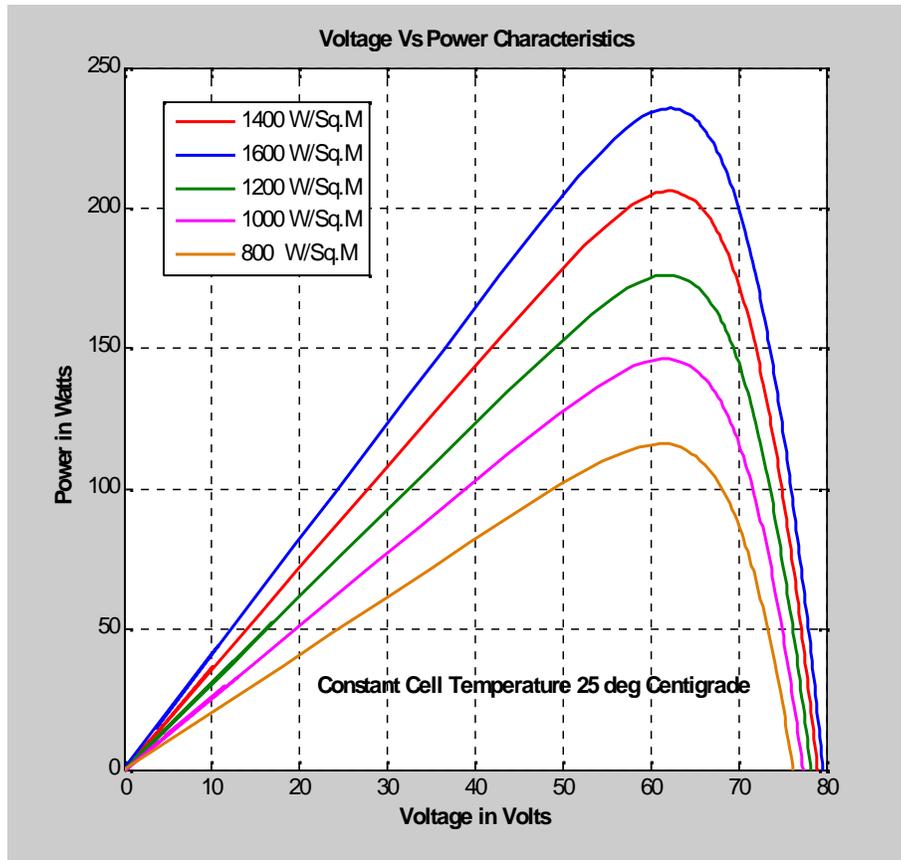
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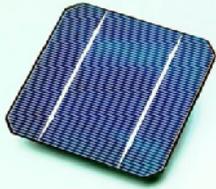
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CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE



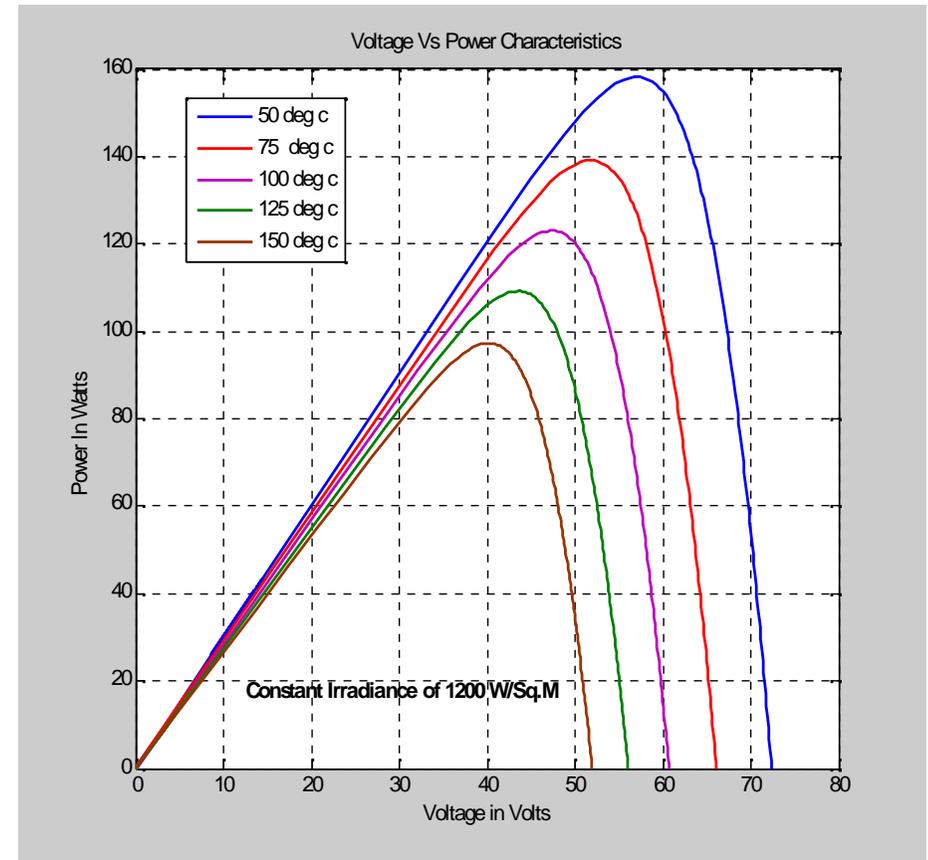
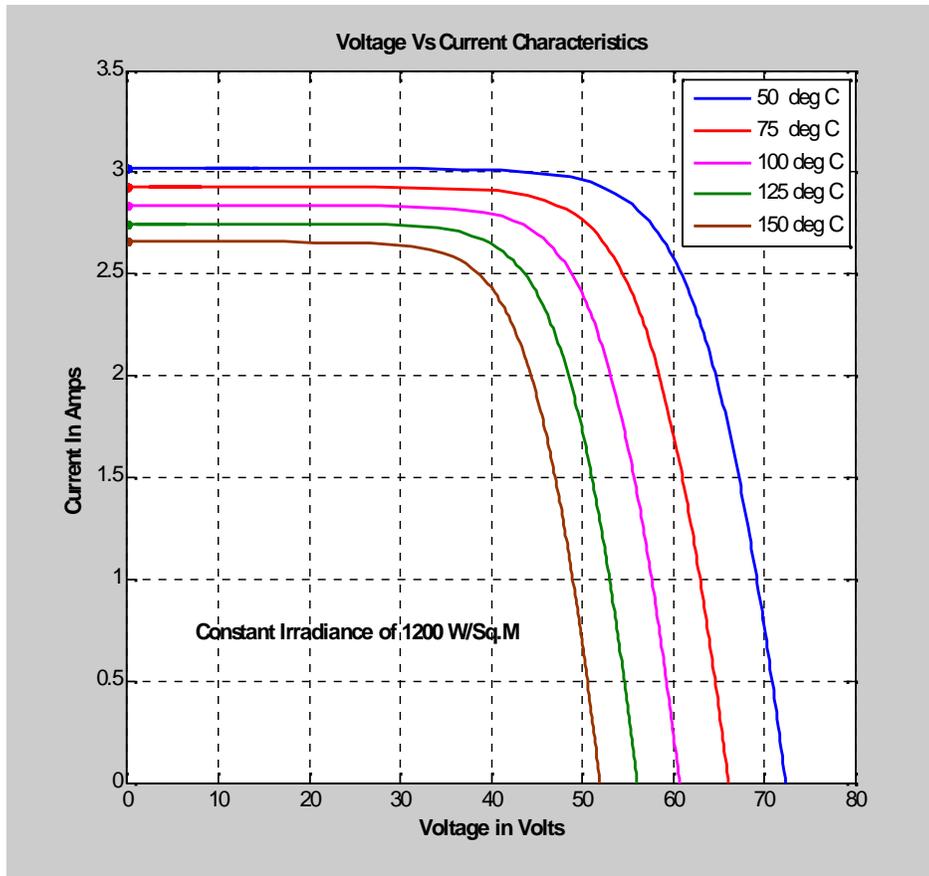
Everyone wants to go to heaven but nobody wants to die - Megger – Evershed - 1905





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CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE



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

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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.

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

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

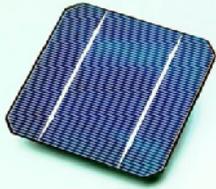
Population Size	: 40
Number of Iterations	: 200
Number of Functional Evaluation	: 8000
Mutation Scale	: 0.5
Control Variable Limits	: [0 ,3.7]



Fish and guests smell after three days - Digital Multimeter –Fluke Electronics- 1969

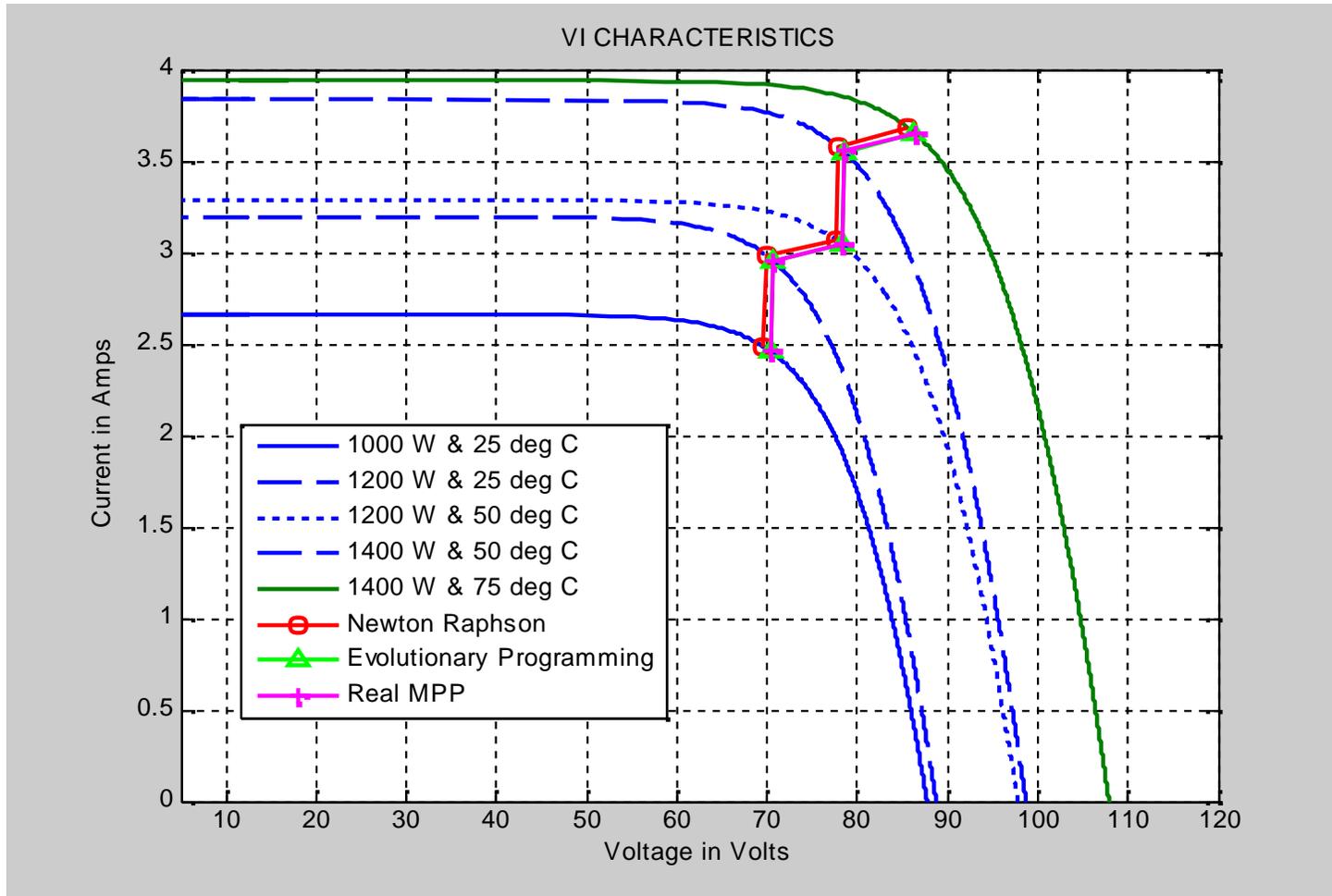
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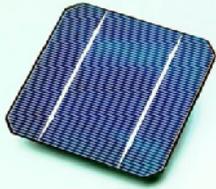
Maximum Power Point Tracking of PV cell Using Evolutionary Programming



History repeats itself - Electrolytic capacitor- Julius Edgar-1928

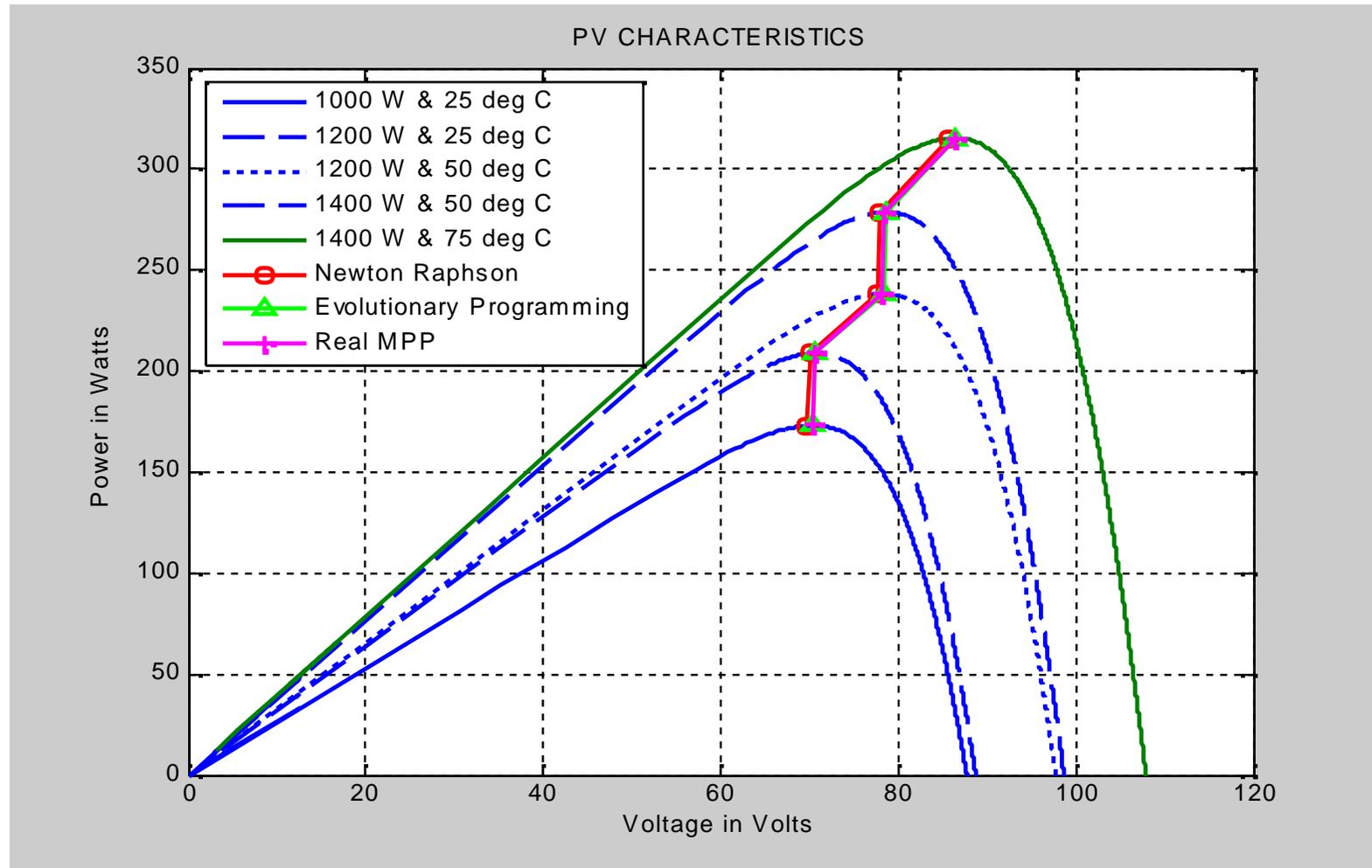
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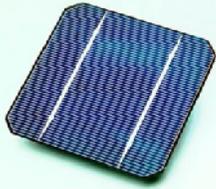
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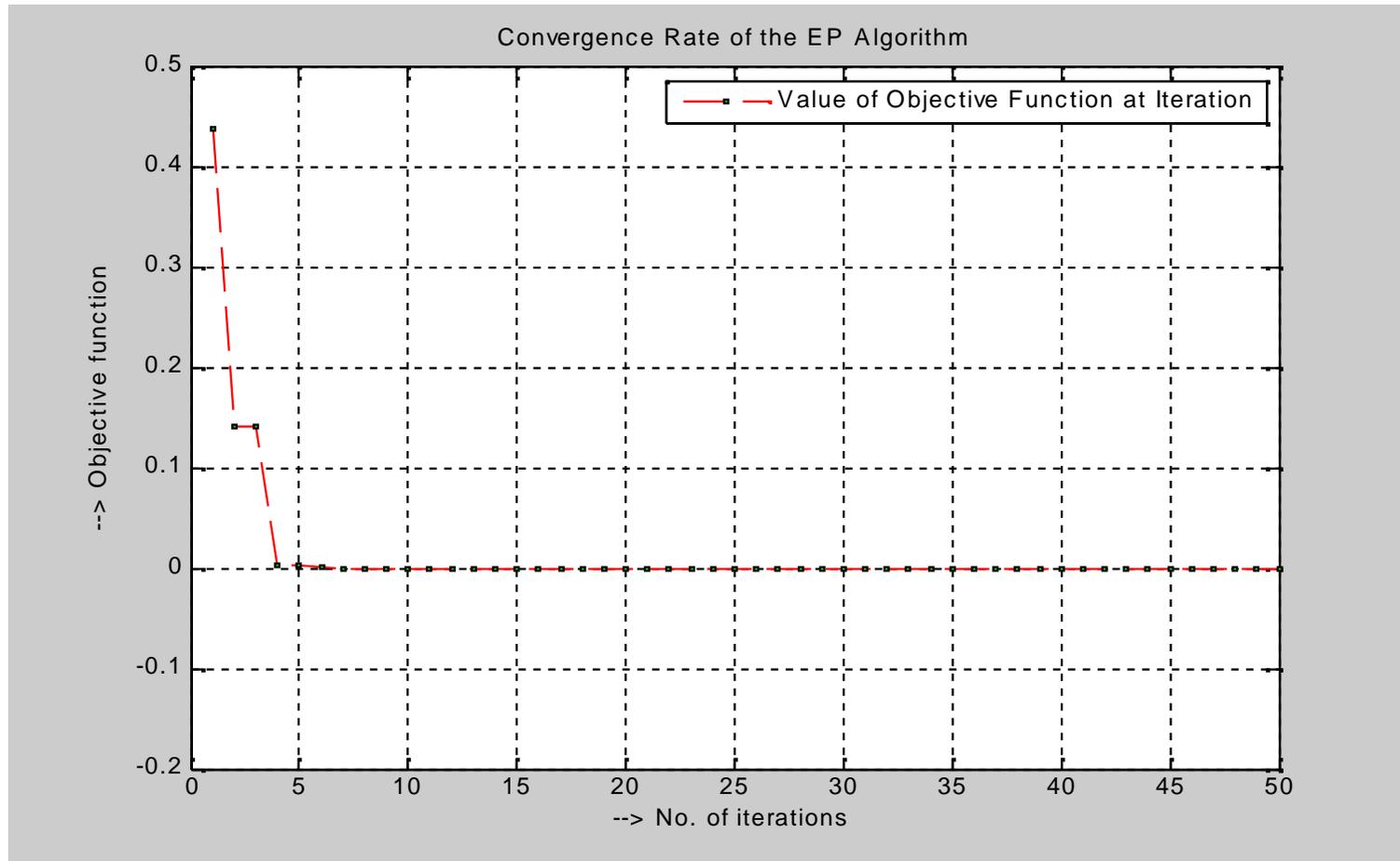
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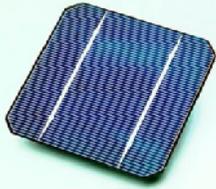
Maximum Power Point Tracking of PV cell Using Evolutionary Programming



One can never consent to creep when one feels an impulse to soar – Electromagnetism –Maxwell-1865

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Maximum Power Point Tracking of PV cell Using Evolutionary Programming



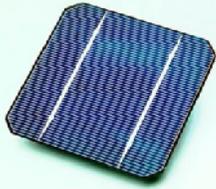
Summary of Simulation results of different algorithms

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



History repeats itself - Electrolytic capacitor- Julius Edgar-1928

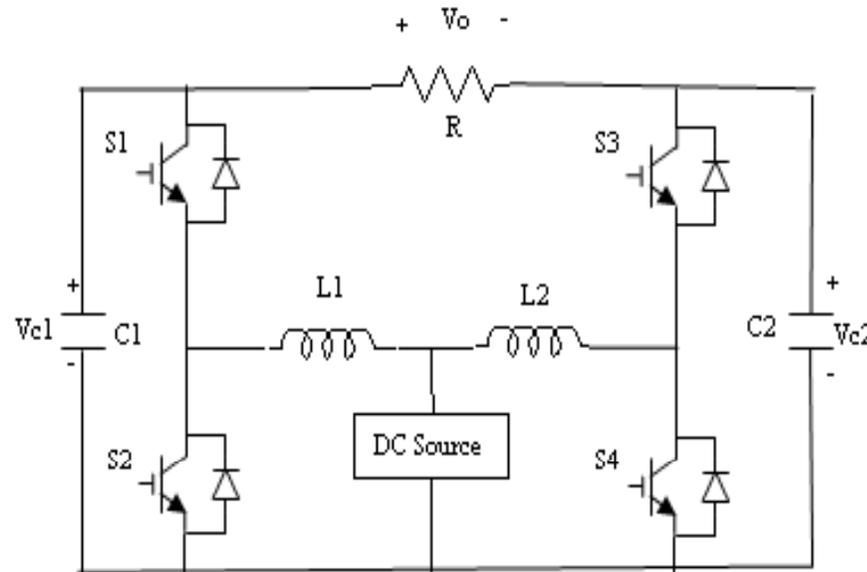




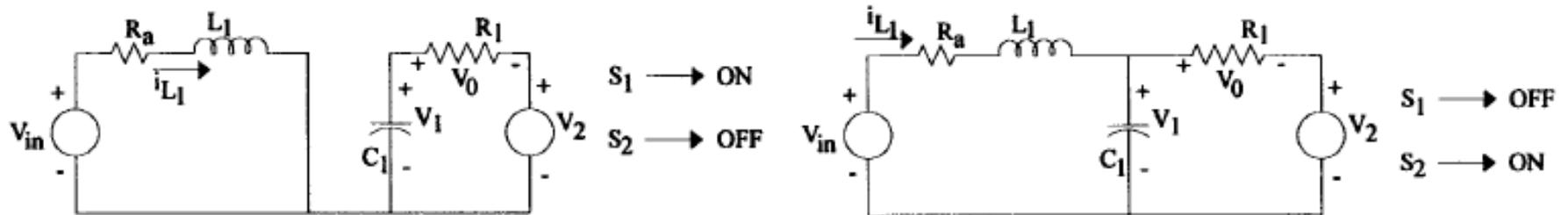
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Single Stage Boost Inverter



Circuit implementation

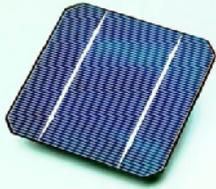


Modes of operation

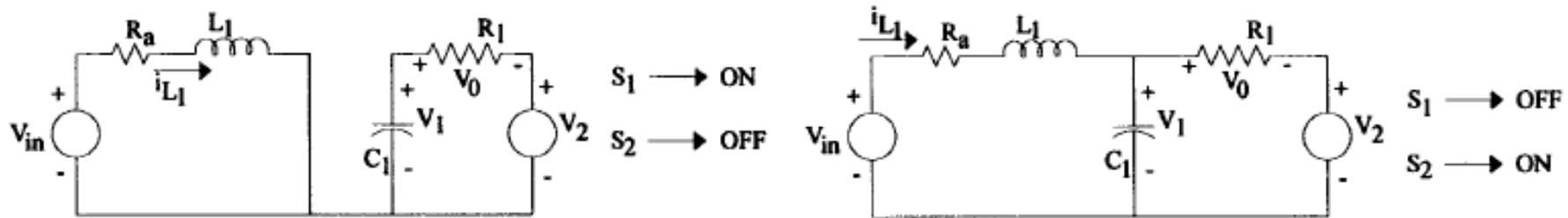


Don't sit like a rock work like a clock- Fluorescent Lamp –Edmund Germer - 1926





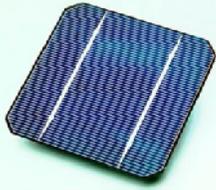
Modeling of Single Stage Boost Inverter



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

The above equation is of the form

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

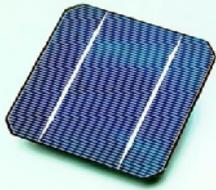


Modeling of Single Stage Boost Inverter

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

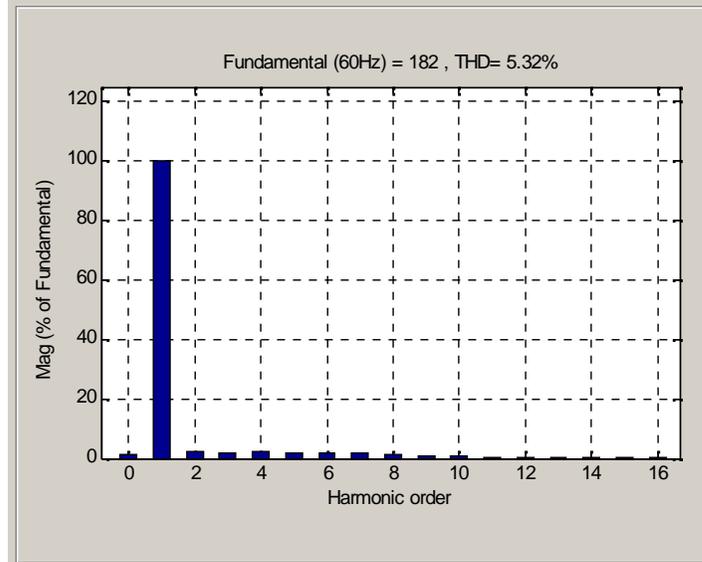
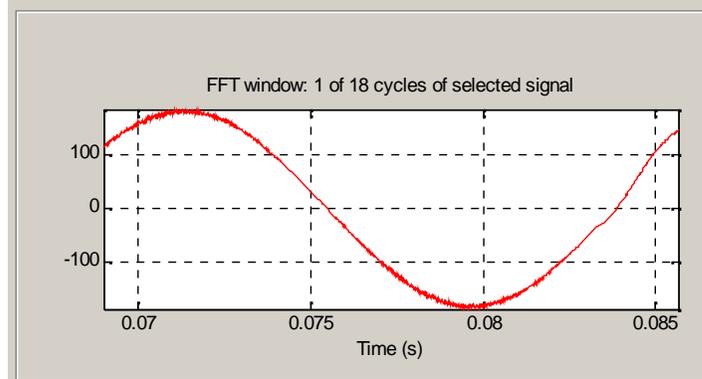
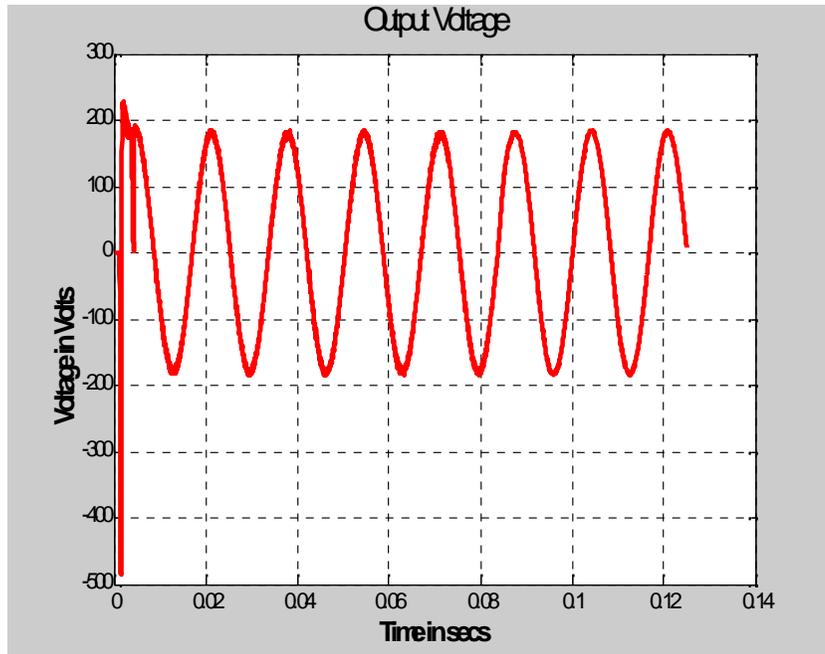
$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_1}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_2}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_1} & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & -\frac{1}{C_1 R_1} & 0 & 0 \\ 0 & 0 & -\frac{R_a}{L_2} & -\frac{1}{L_2} \\ 0 & 0 & \frac{1}{C_2} & -\frac{1}{C_2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

Where γ is the status of switches



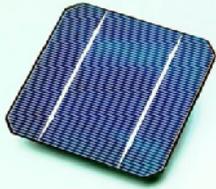
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Simulation Results With Constant Irradiance and Temperature



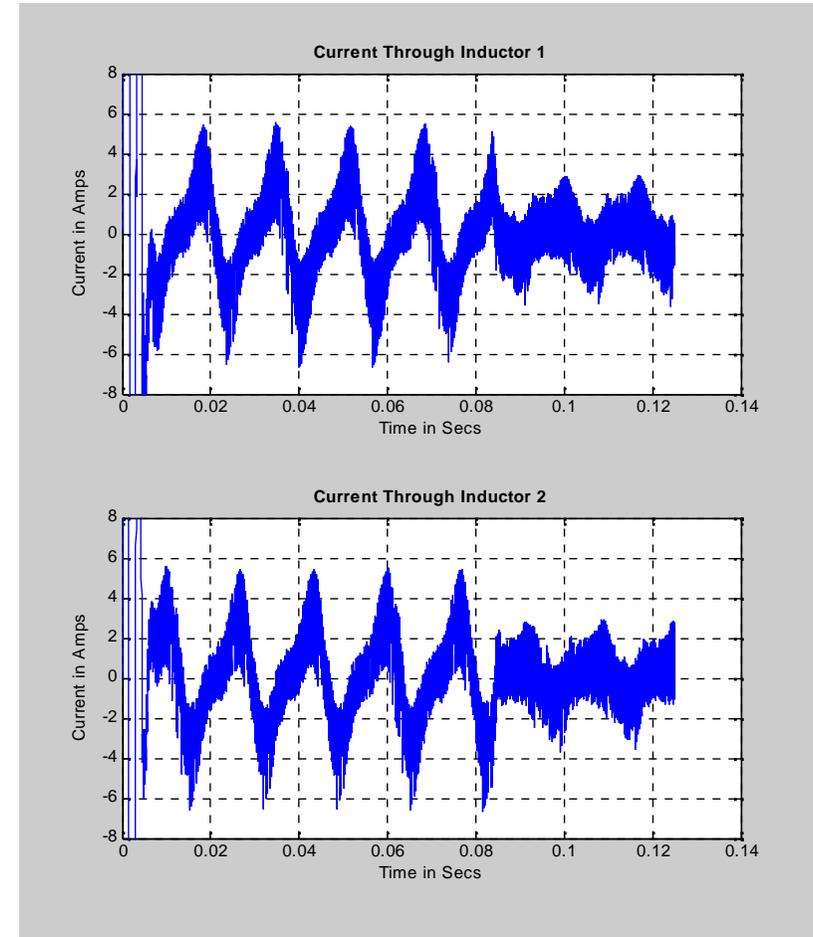
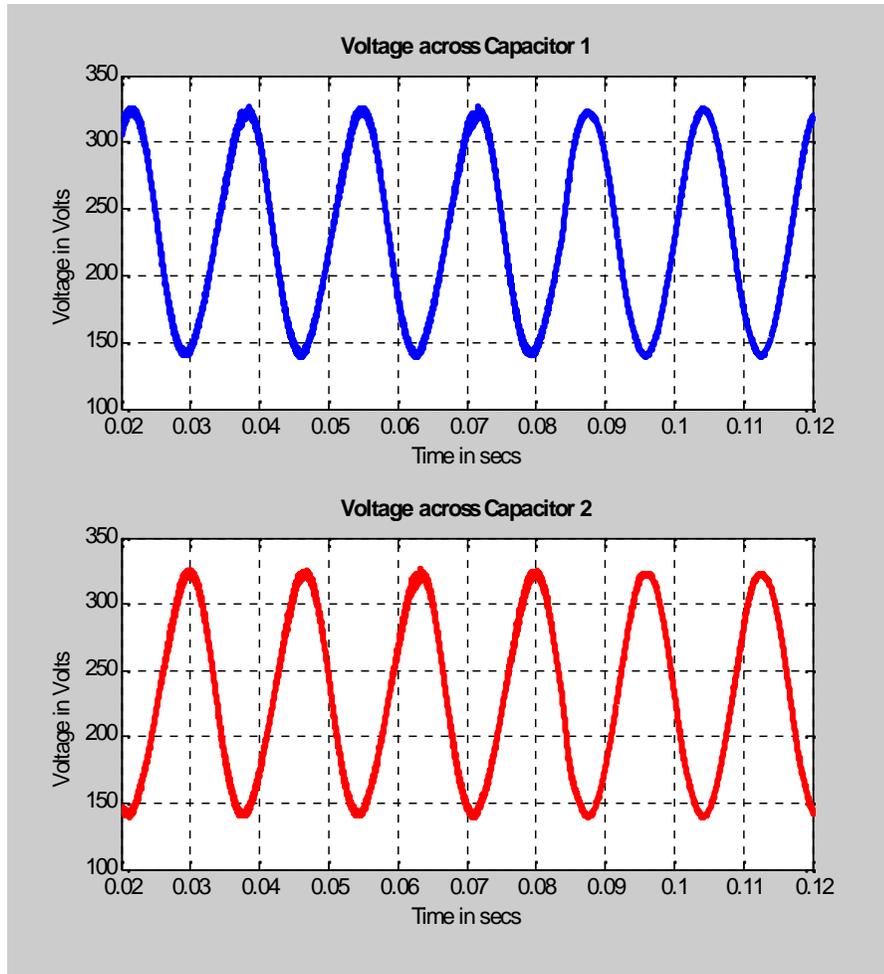
A man is as old as he feels - Hybrid Vehicle –Ferdinand Porsche-1899





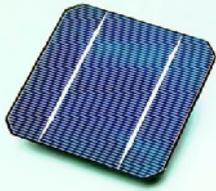
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Simulation Results With Constant Irradiance and Temperature Continues....



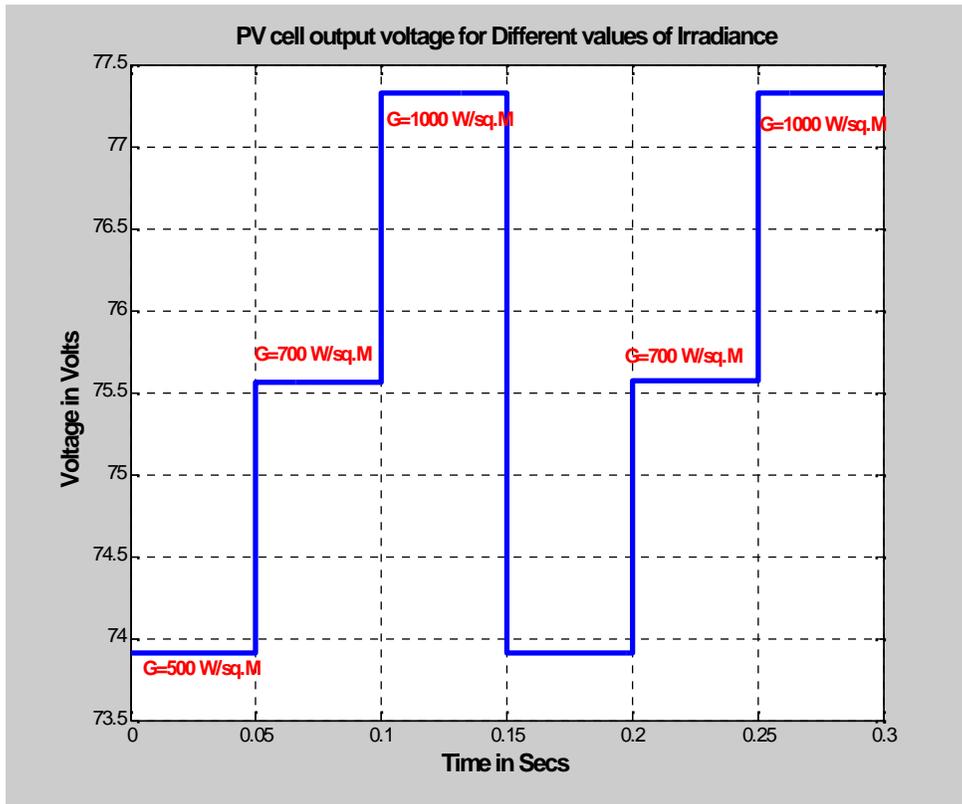
Be willing to accept temporary inconvenience for permanent improvement- Logic gates-Charles Babbage -1837



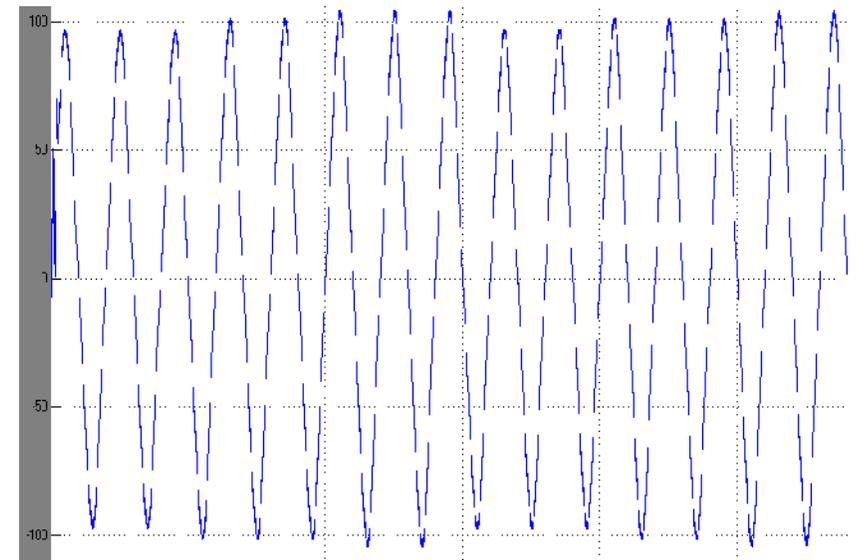


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Simulation Results With Variable Irradiance and Constant Temperature



PV panel voltage

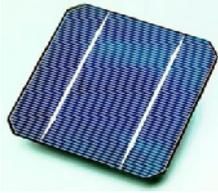


Output voltage



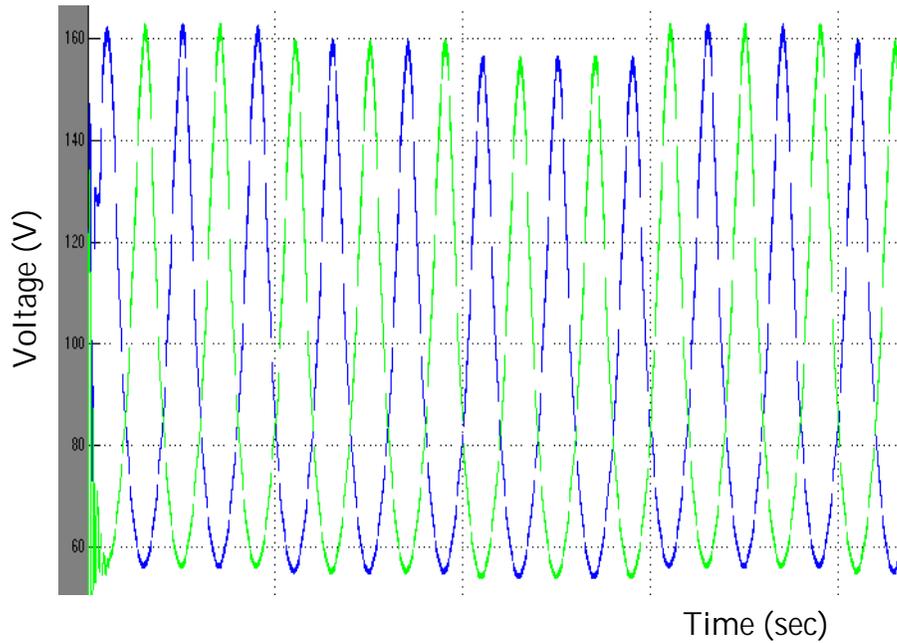
Believing in yourself is the first step to success- Neon Lamp –Georges Claude-1910



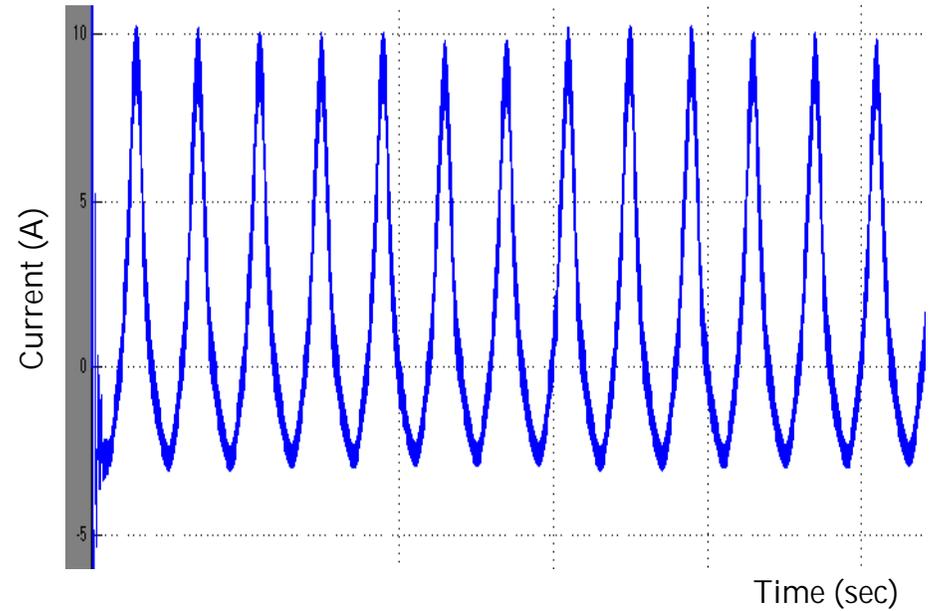


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Simulation Results With Variable Irradiance and Constant Temperature Continues...



Capacitor voltage

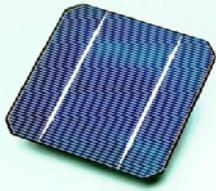


Inductor current



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

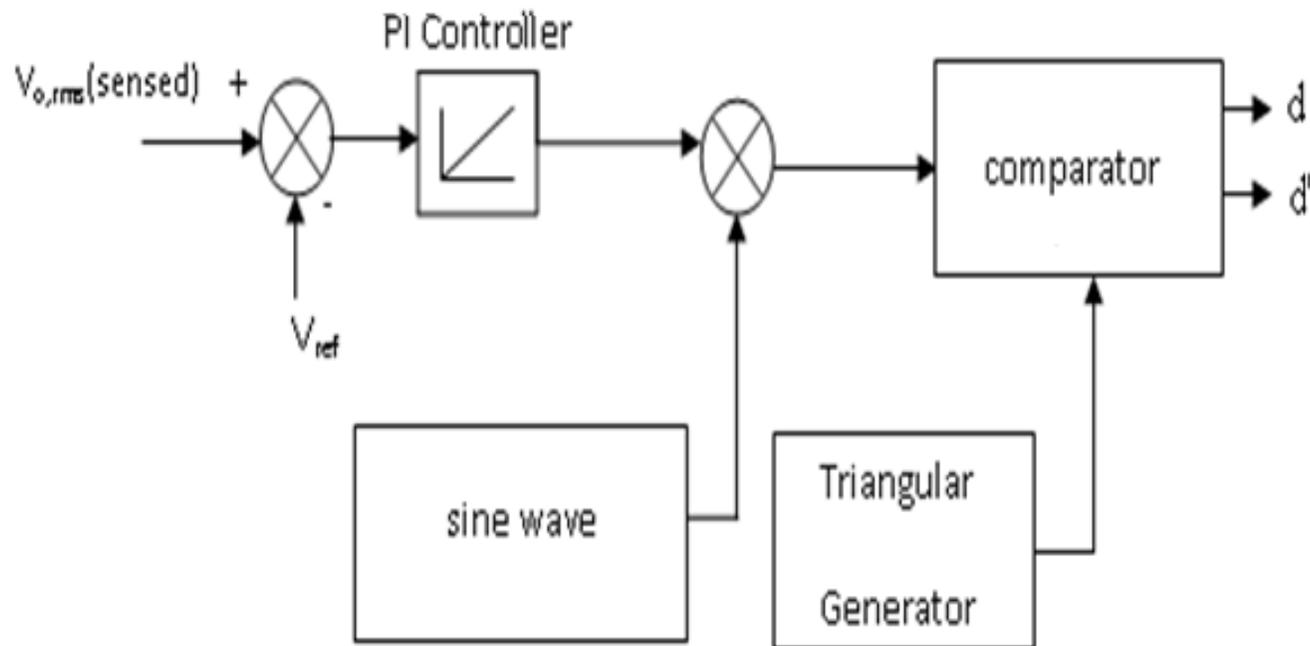




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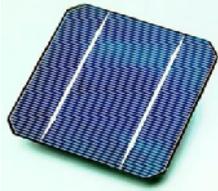
PI Controller Fed Single Stage Boost Inverter



Discretion is the better part of valor -Piezoelectricity-Pierre Curie-1880

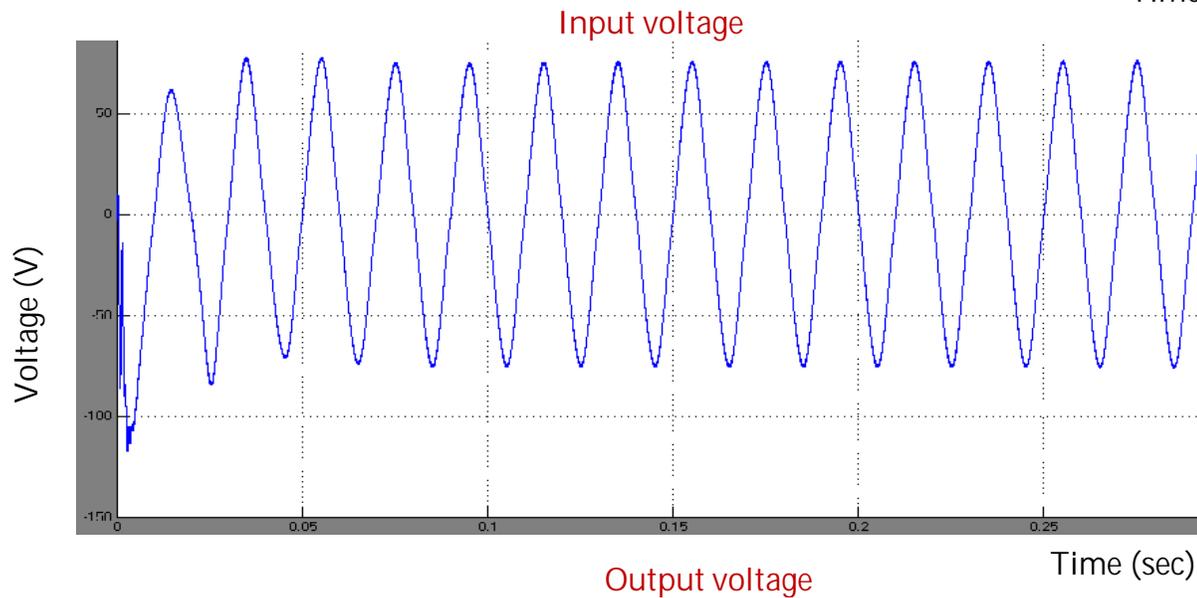
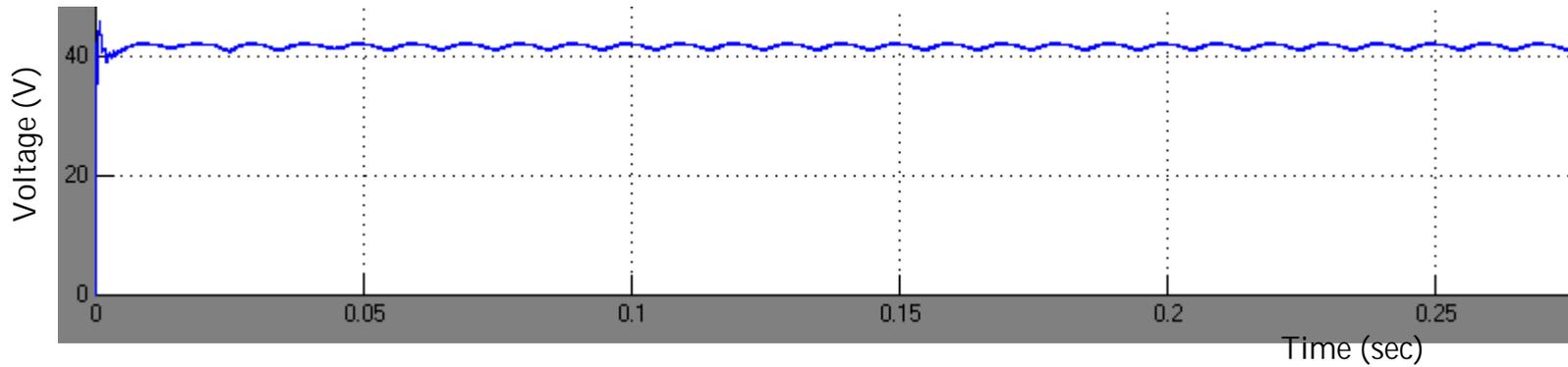
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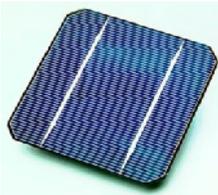
Simulation of PI Controller With Constant Irradiance and Temperature



Lightning never strikes twice in the same place -Relay-Joseph Henry-1835

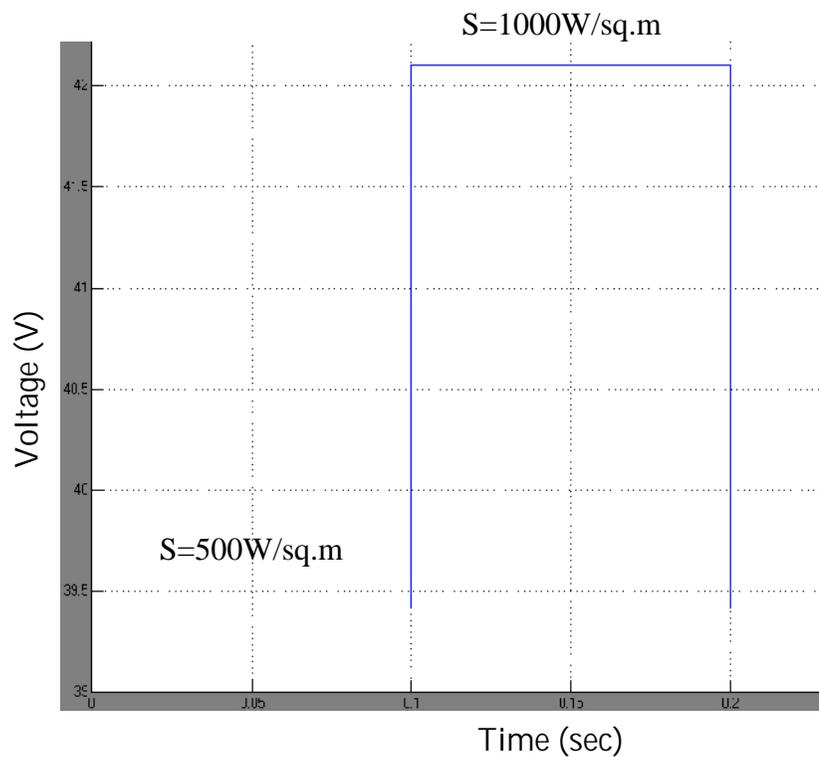
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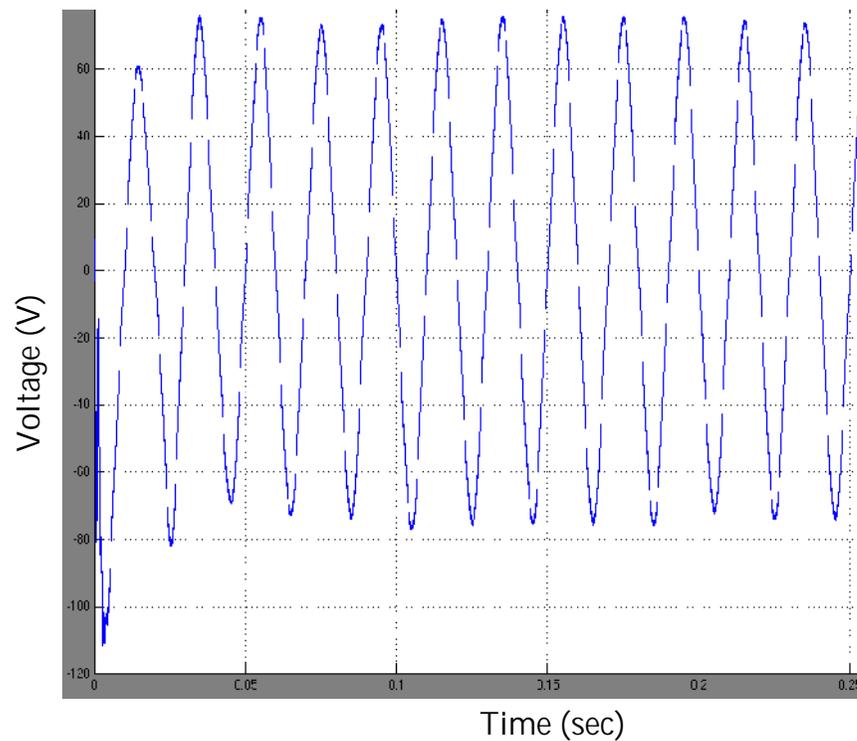


Presented By: M.Kaliamoorthy,AP,PSNACET,EEE

Simulation Results With Variable Irradiance and Constant Temperature



PV panel voltage

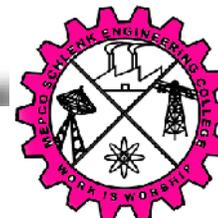


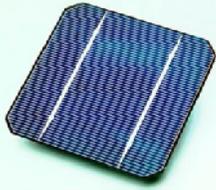
Output voltage



Money makes the world go round - Thermo Electricity –Thomson Johann Seebeck-1821

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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_1 (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

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

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

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

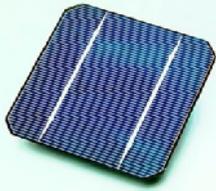
The system response is determined by the circuit parameters and coefficients K_1 and K_2 . With a proper selection of these coefficients in any operating condition, high control robustness, stability, and fast response can be achieved.



Never judge a book by its cover - Radio Guglielmo-1901

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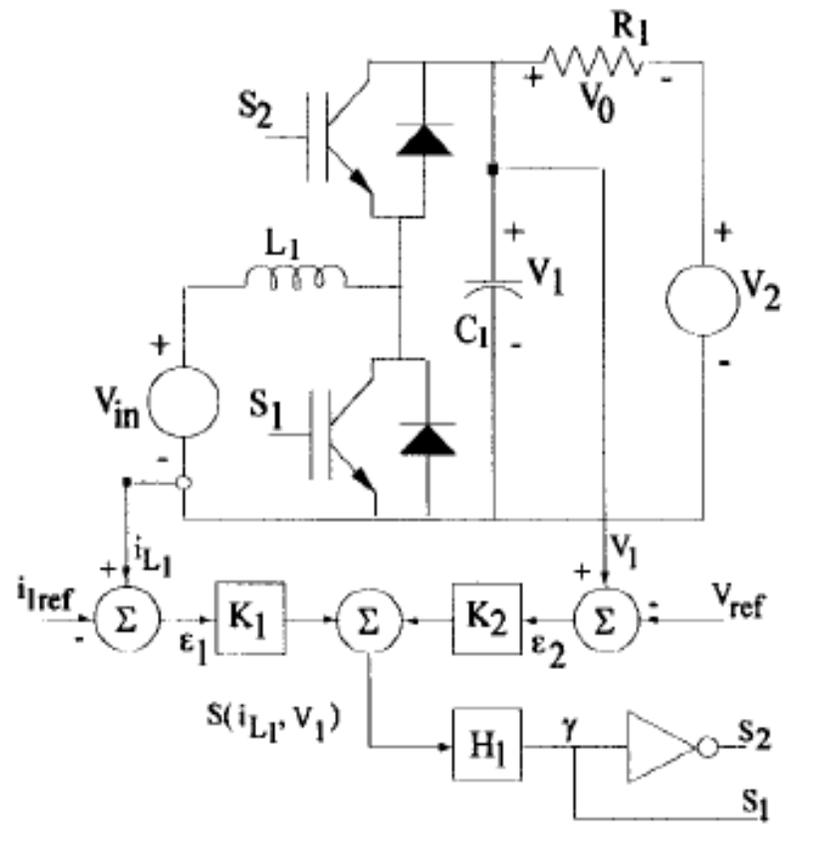




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Sliding Mode Controller Continued....

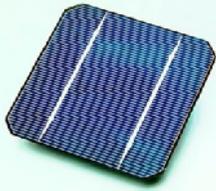


Sliding mode controller scheme



Never put off until tomorrow what you can do today - Remote Control –Nikola Tesla-1898

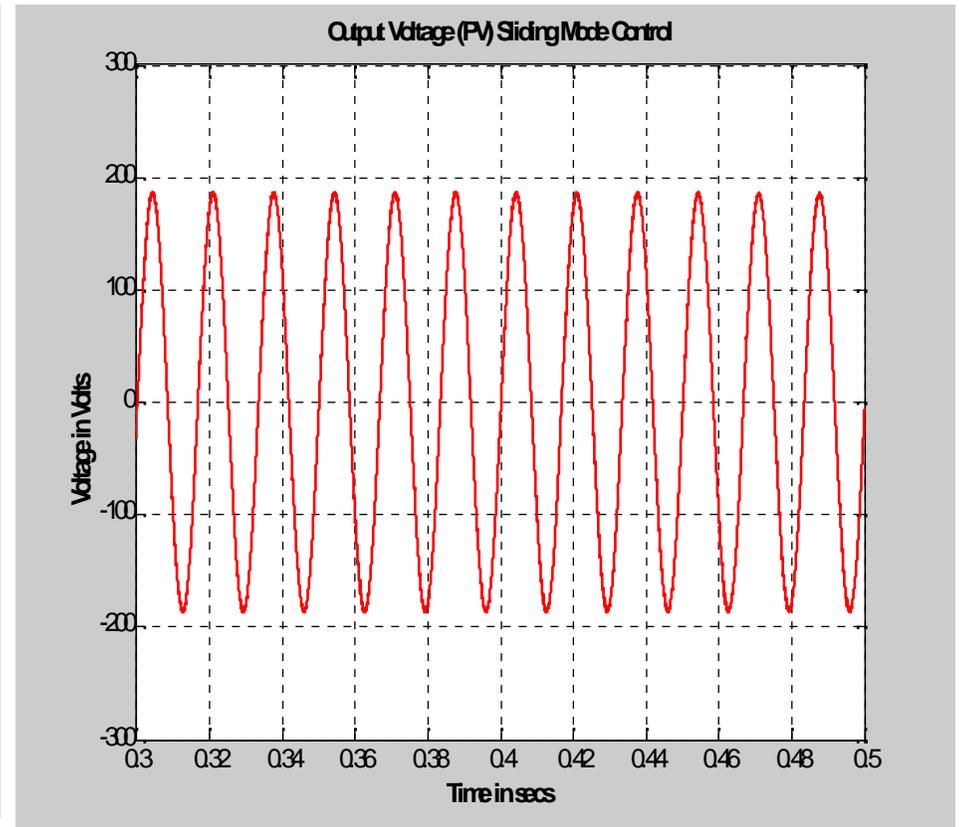
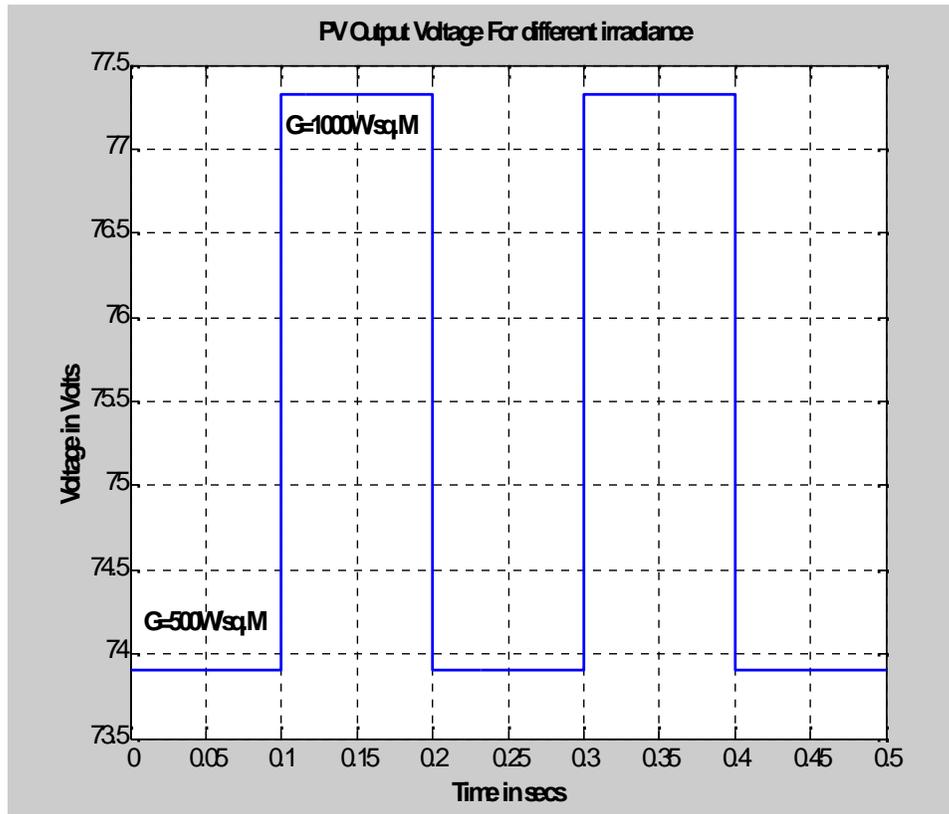




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Simulation Results for Sliding Mode Controller With Variable Irradiance



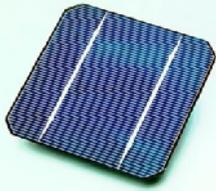
PV panel voltage



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

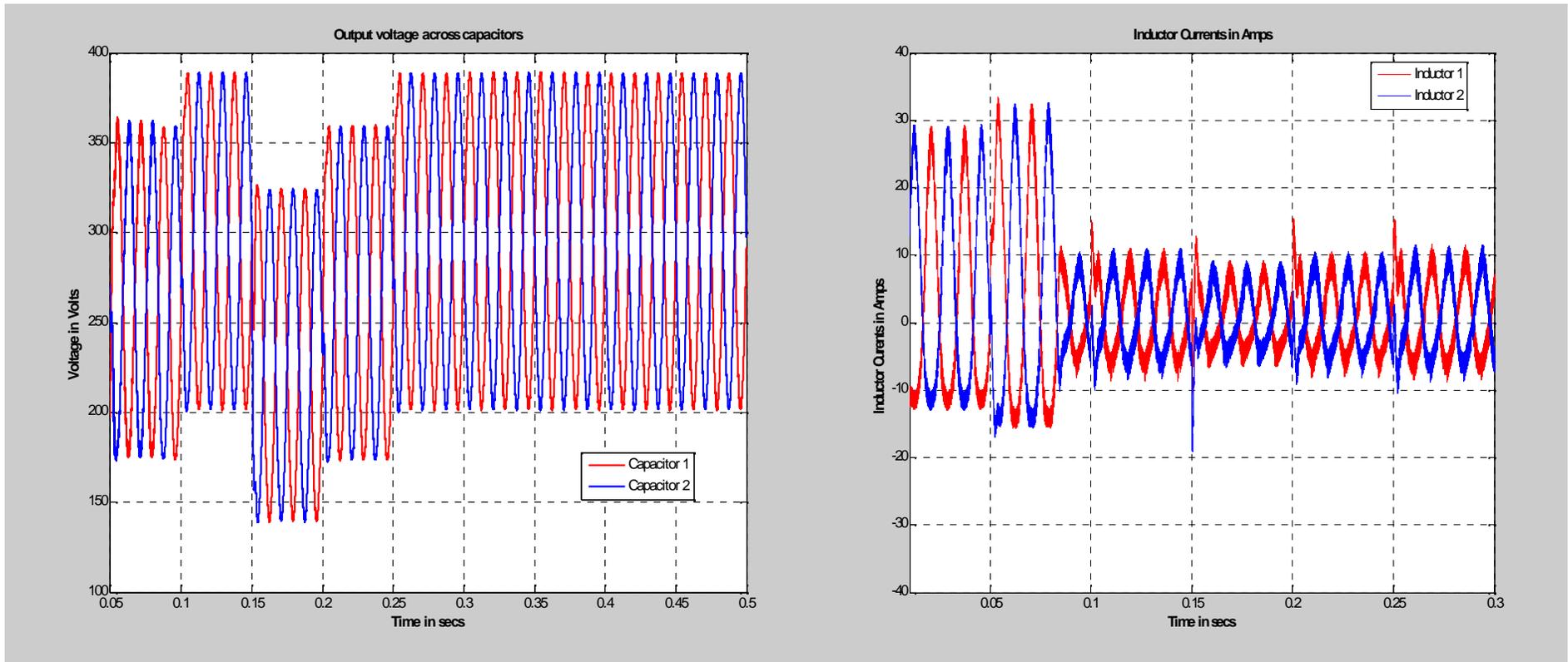
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Simulation Results for Sliding Mode Controller With Variable Irradiance continues....



Opportunity never knocks twice at any man's door - Electron -Joseph John -Thomson-1897.

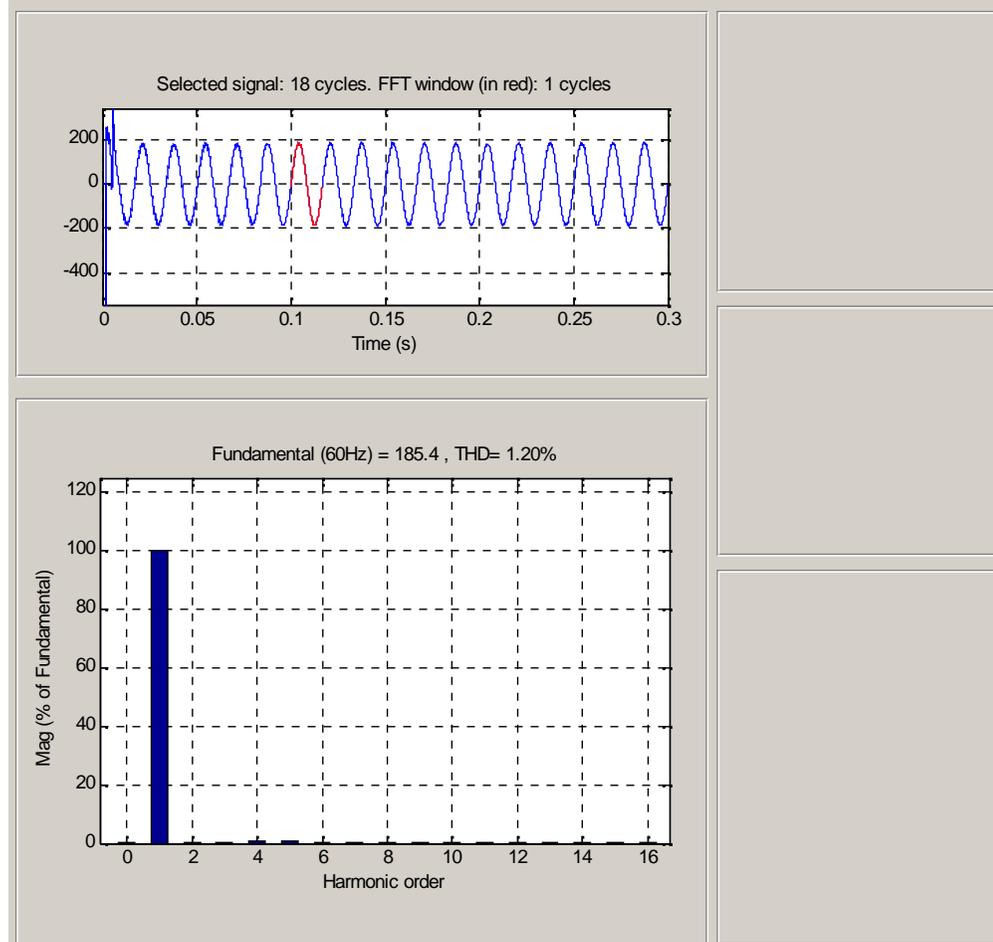
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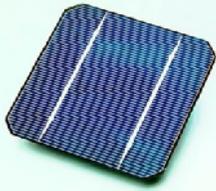
Simulation Results for Sliding Mode Controller With Variable Irradiance continues....



Practice makes perfect -Fax Machine-Alexander Bain-1842

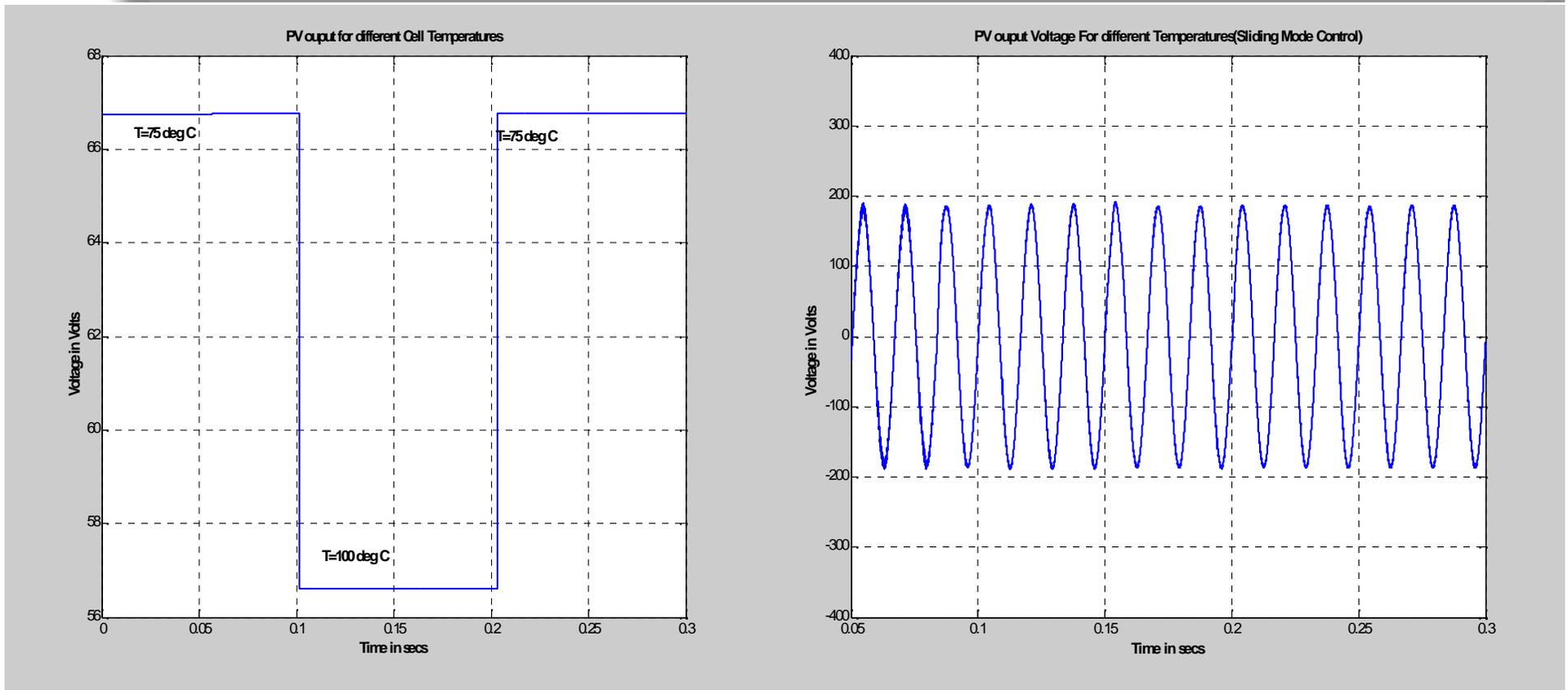
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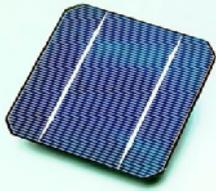
Simulation Results for Sliding Mode Controller With Variable Temperature continues....



Seeing is believing -Electro Magnet-William Sturgeon-1825

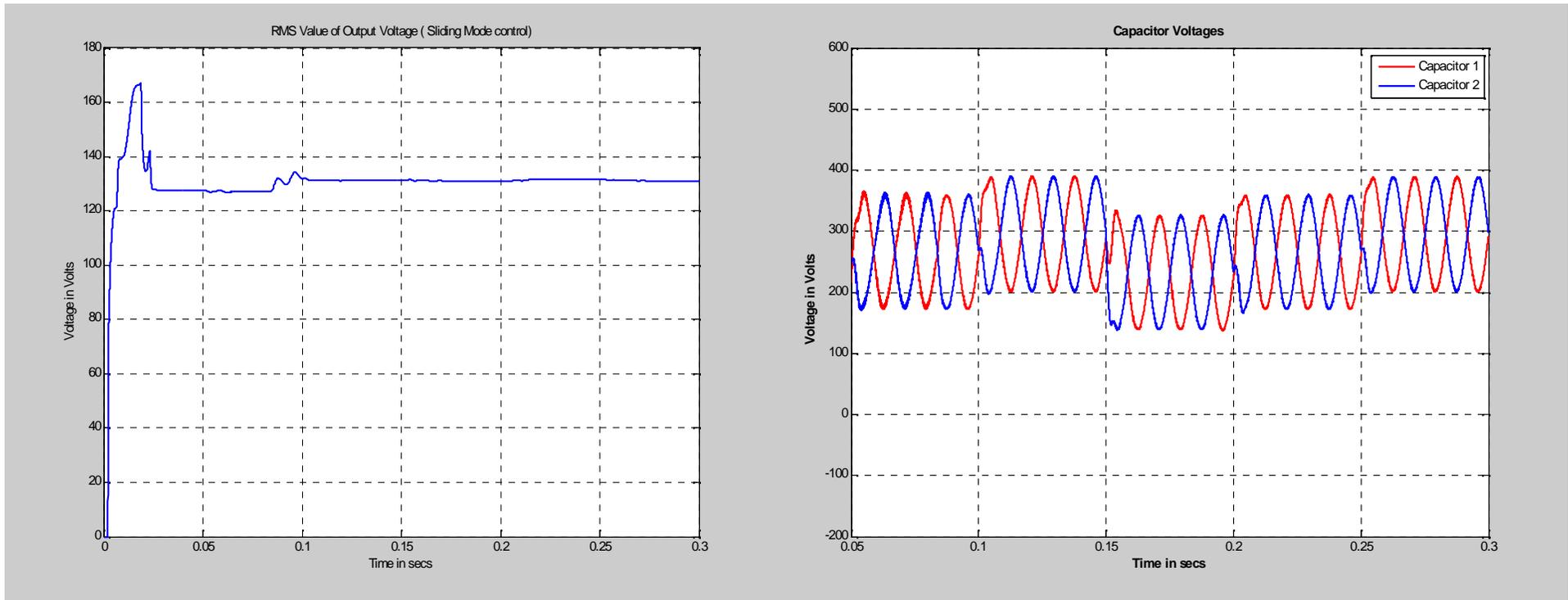
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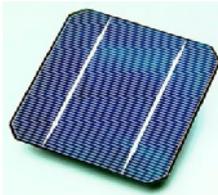
Simulation Results for Sliding Mode Controller With Variable Temperature continues....



Set a thief to catch a thief -Transistor-Brattain Walter-1947

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Comparisons

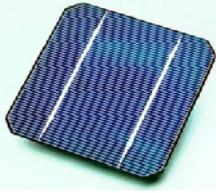
Controller	Output	THD	Settling time	Input condition	Atmospheric condition
Open loop	AC with constant RMS	5	0.01 s	Constant V_{ph} and I_{ph}	Constant irradiation (G) and temperature (T)
Open loop	AC with changing RMS	9	0.01 s	Varying V_{ph} and I_{ph}	Varying G / T
PI	AC with almost constant RMS	2	0.005s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



Attack is the best form of defence -Darlington Pair-Darlington Sidney-1953

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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



Ask no questions and hear no lies -Hysterisis- Ewing James Alferd-1890

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Success is a journey, Which has no Destination

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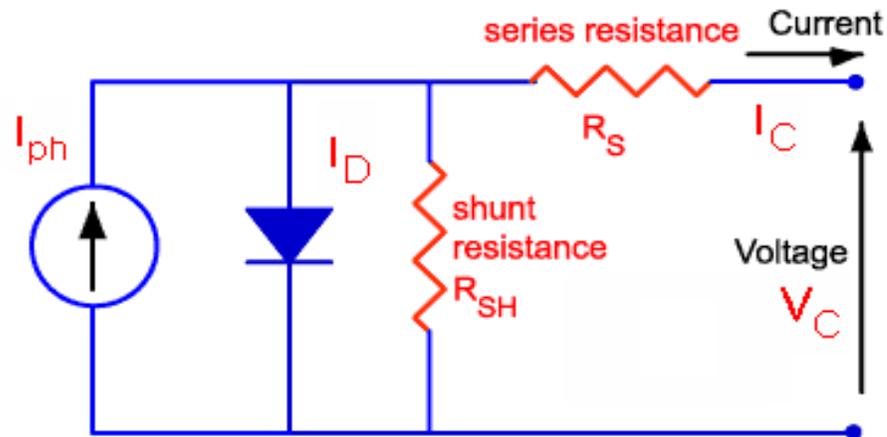




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PHOTOVOLTAIC CELL MODELING



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



Reading is an adventure that never ends





Temperature and Irradiance Dependence

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

$$I_{SCT} = I_{SC} + k_i(T_x - T_c)$$

$$I_x = I_{sc} T S_x$$

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

Where:

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

Datasheet values

$$V_{mpp} = 33.7V$$

$$I_{mpp} = 3.56$$

$$V_{oc} = 42.1$$

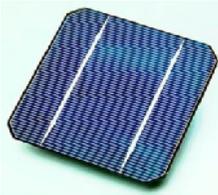
$$I_{sc} = 3.87$$

$$n_c = 72$$

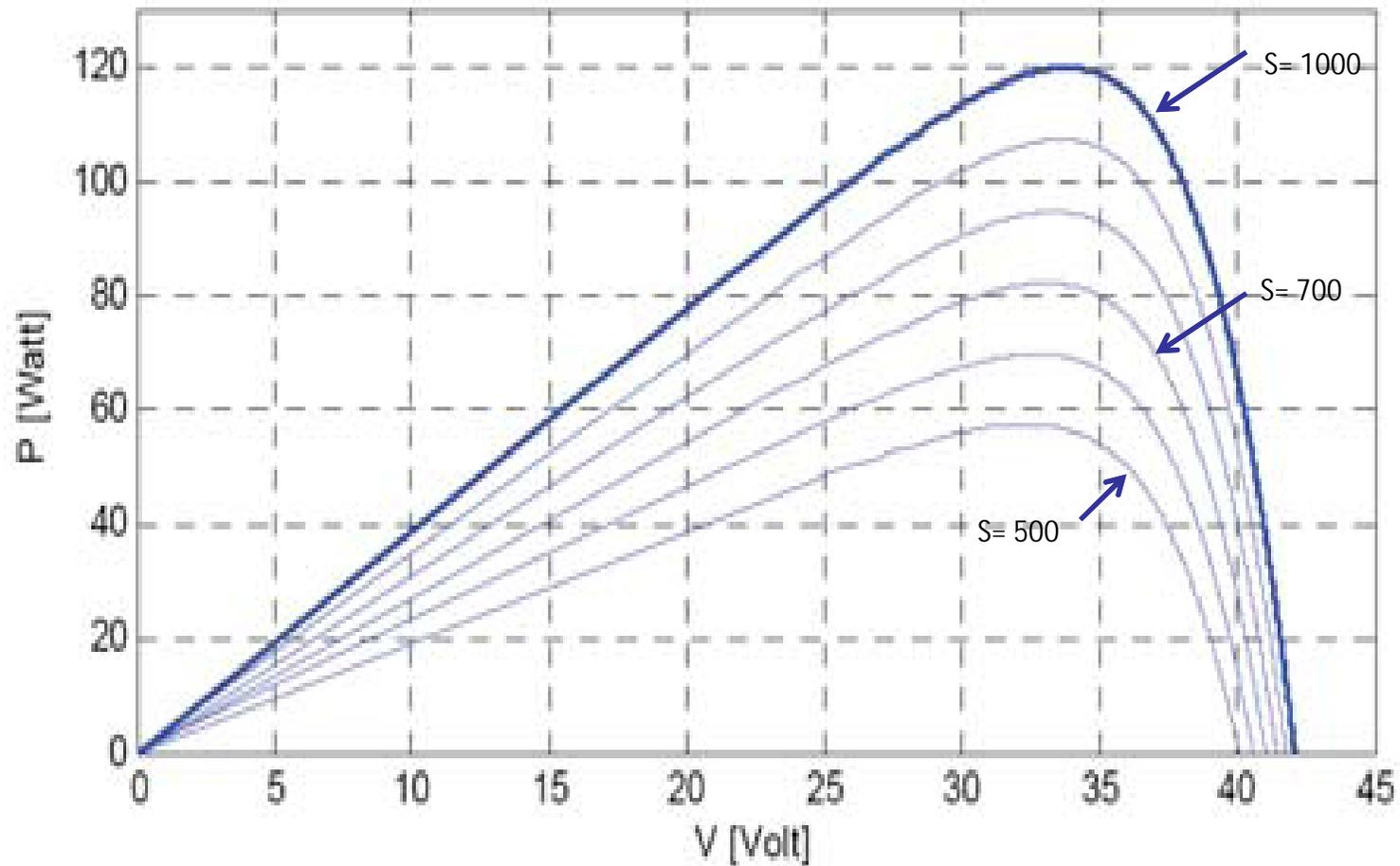
$$k_i = 0.065 \times 10^{-2} \% / ^\circ C$$

$$k_v = -160 \times 10^{-3} \% / ^\circ C$$

$$k_p = -0.5 \times 10^{-2} \% / ^\circ C$$



CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE



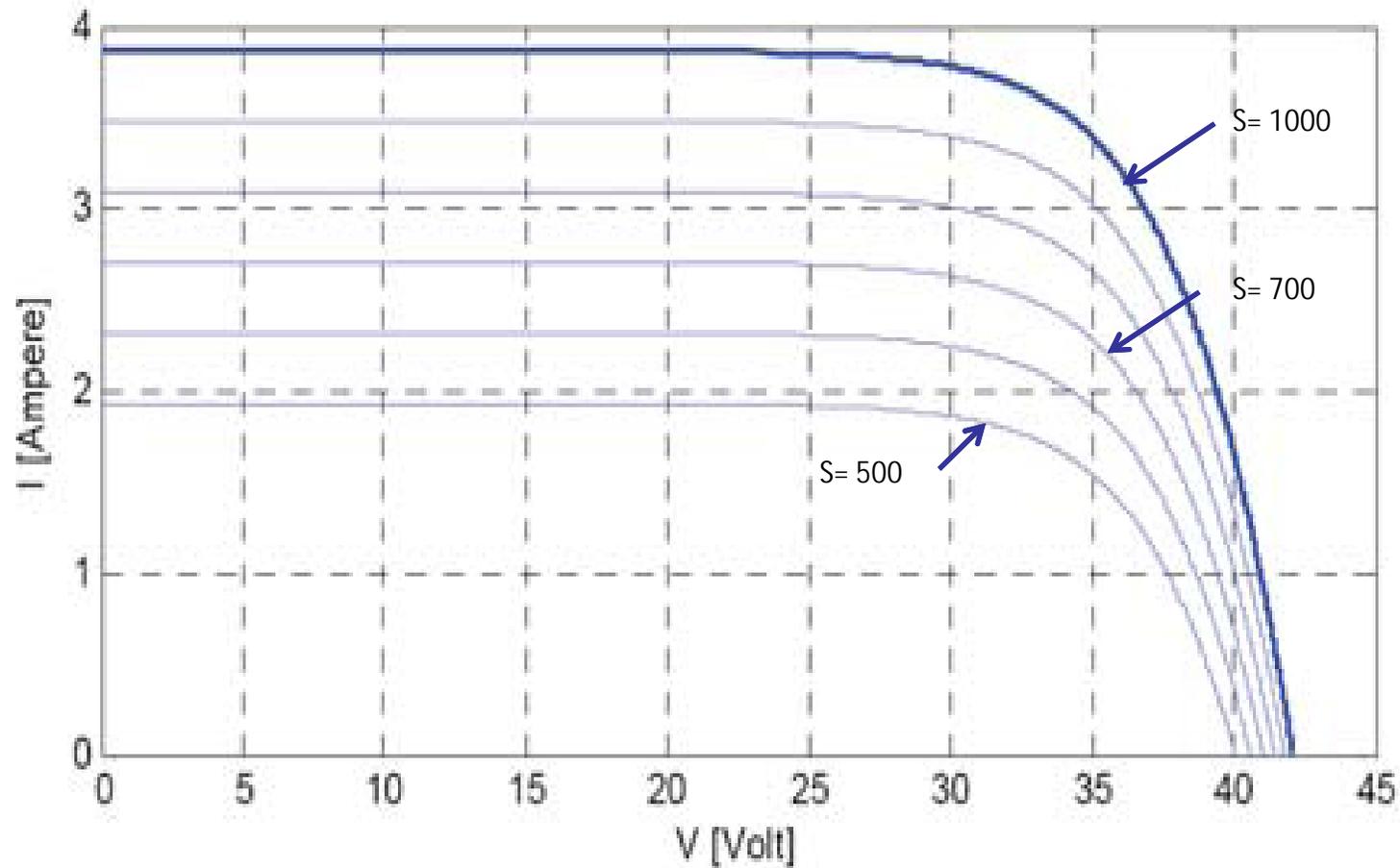
Look at your strengths and not your weaknesses

2010 IEEE International Conference on Communication Control and Computing Technologies





CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE



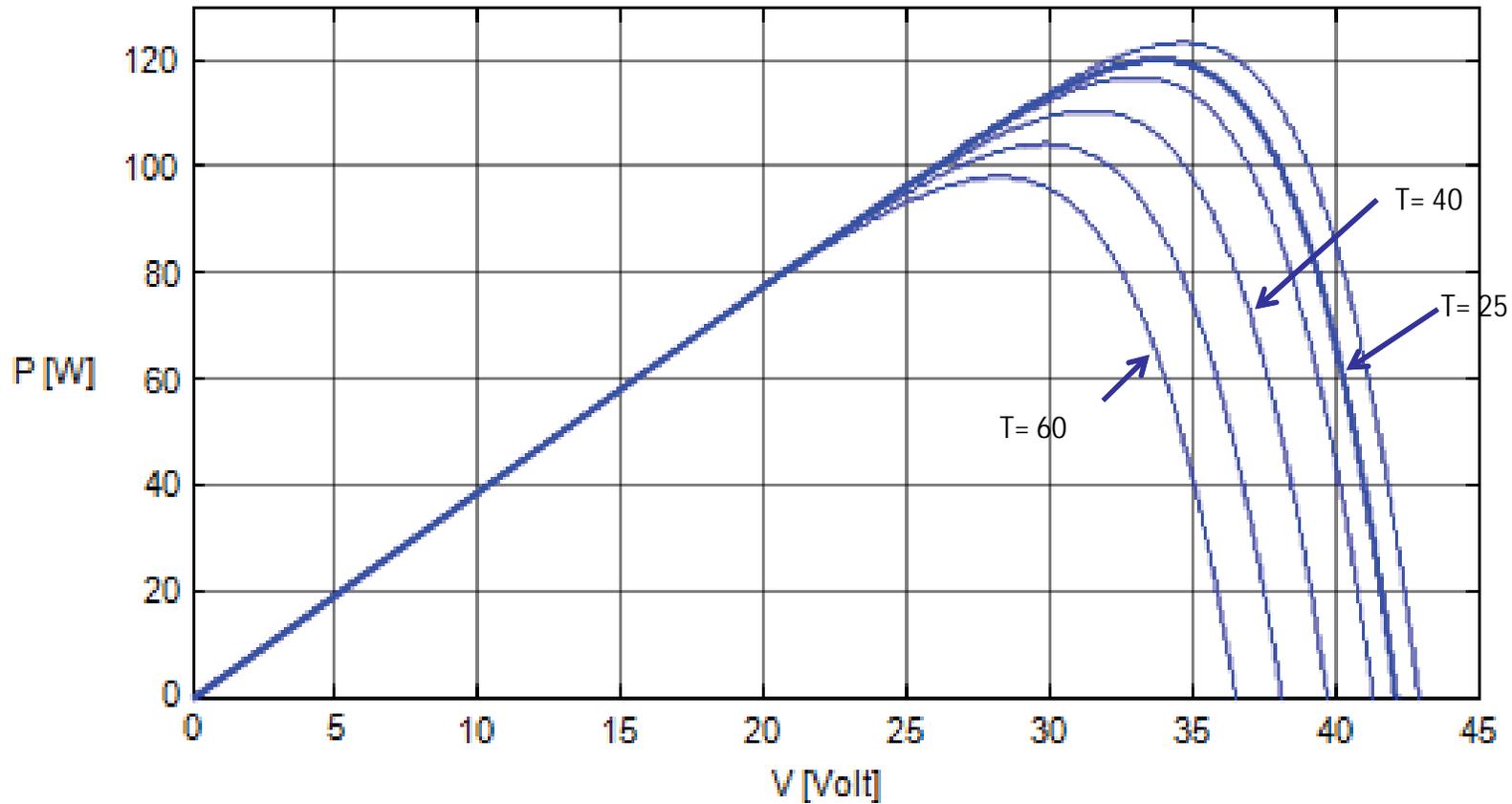
Success is a journey, Which has no Destination

2010 IEEE International Conference on Communication Control and Computing Technologies





CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE

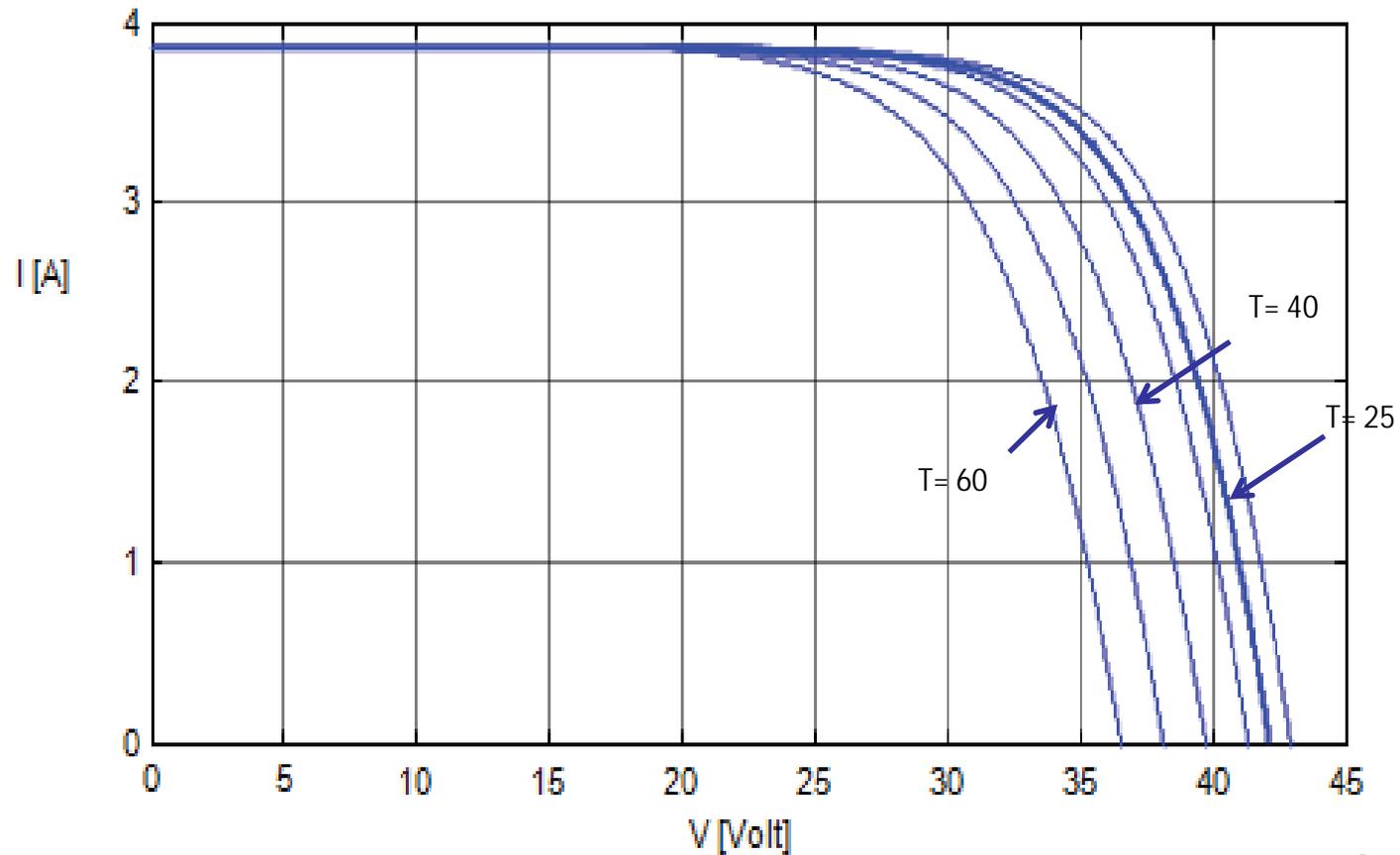


The race of quality has no finish line



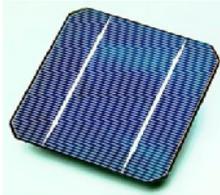


CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE

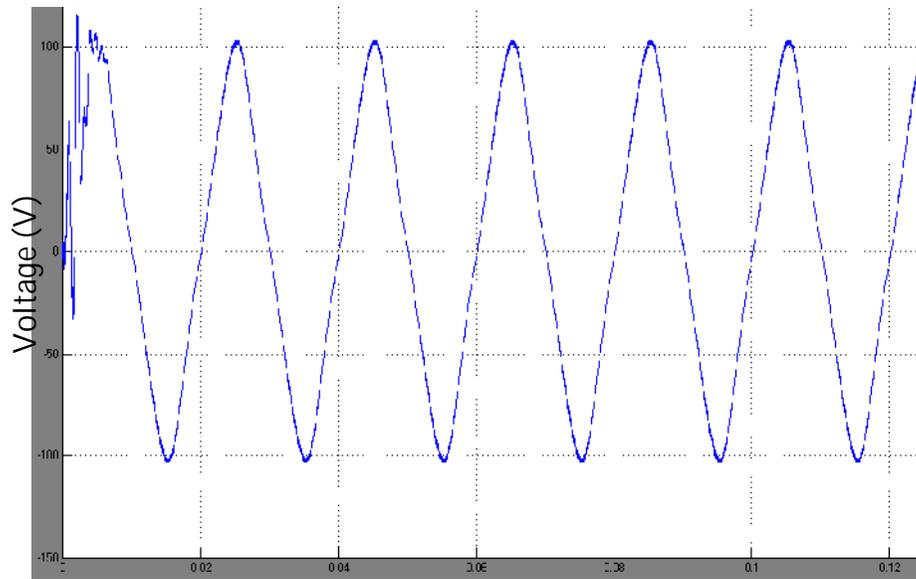


What you do today is getting you closer to what you want to be tomorrow



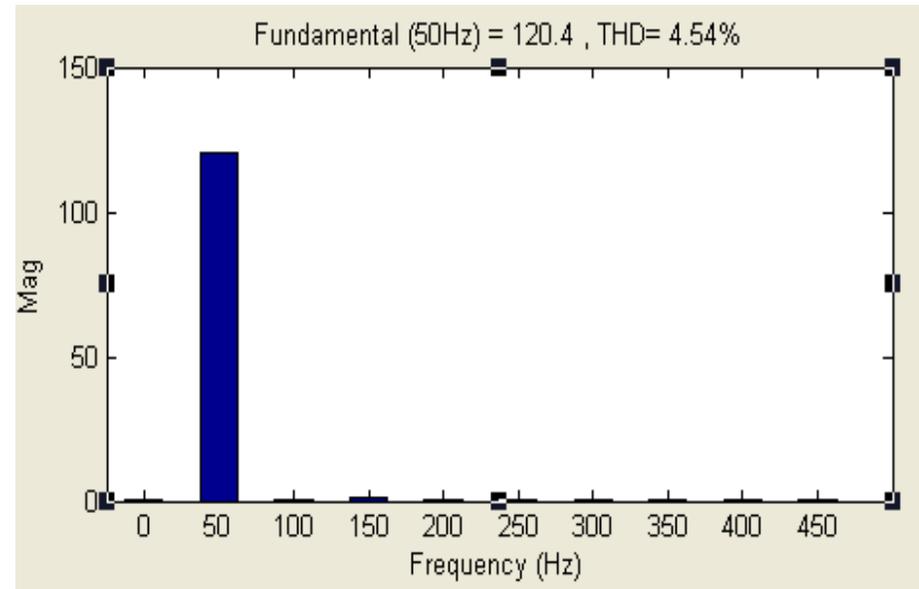


Simulation Results With Constant Irradiance and Temperature



Output voltage

Time (sec)



THD of output voltage

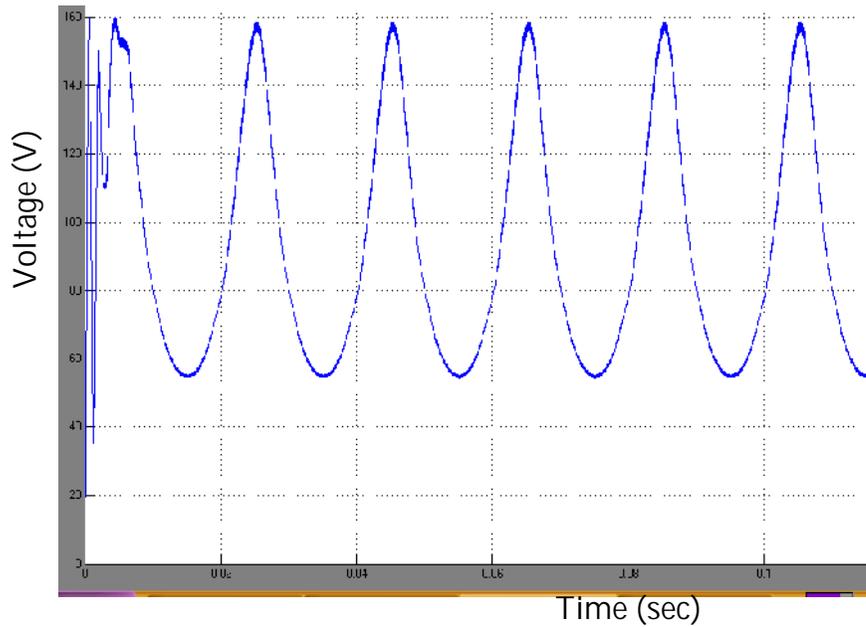


Success is a journey, Which has no Destination

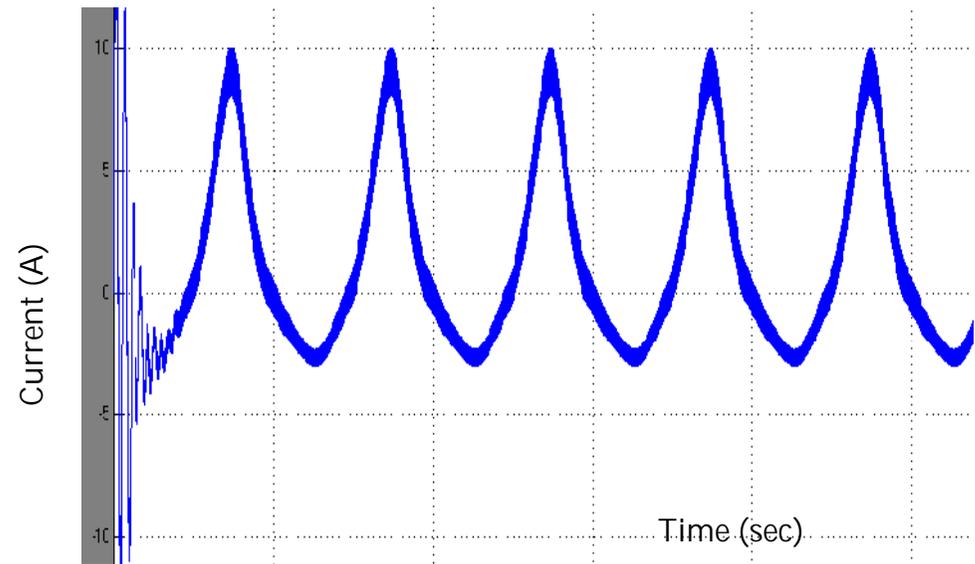




Simulation Results With Constant Irradiance and Temperature Continues....



Capacitor voltage



Inductor current



Be willing to accept temporary inconvenience for permanent improvement



