Solar powered Single Stage boost inverter with ANN based MPPT algorithm

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Presentation By

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The Journey of Thousand Miles Begins with a single step

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 Neural Networks
- 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 Neural Networks
- 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

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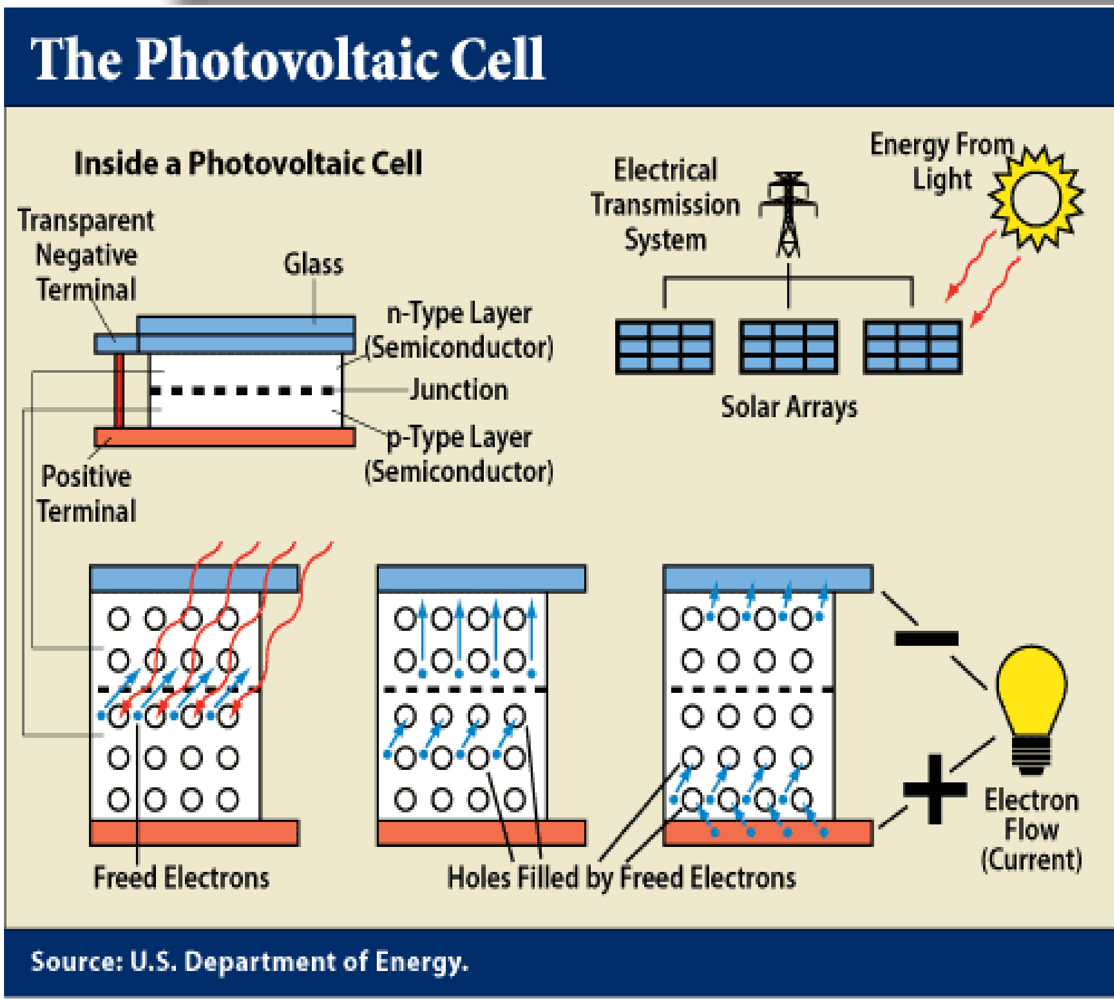
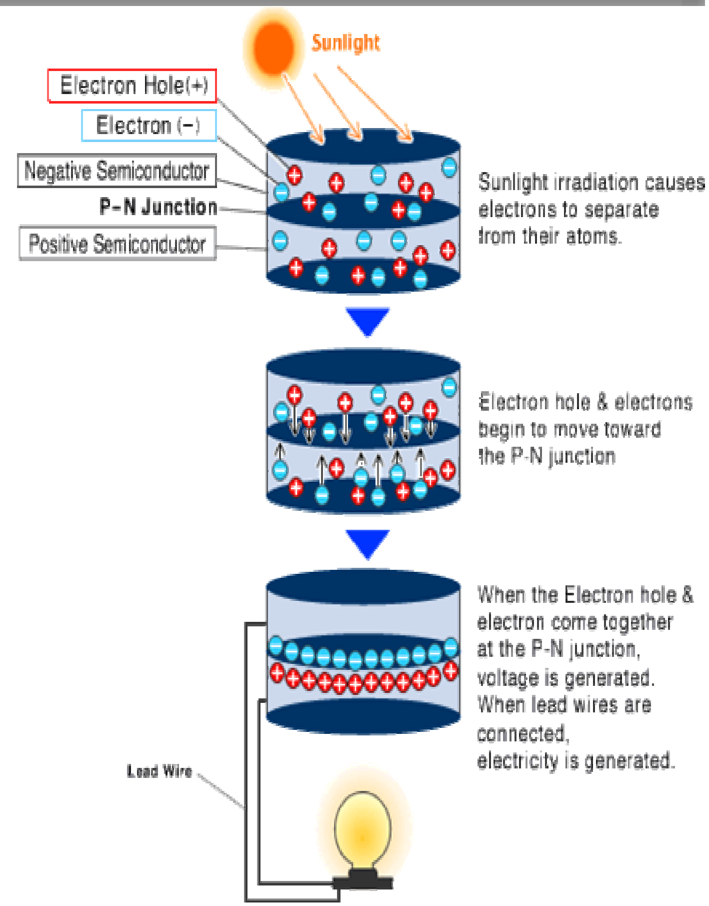
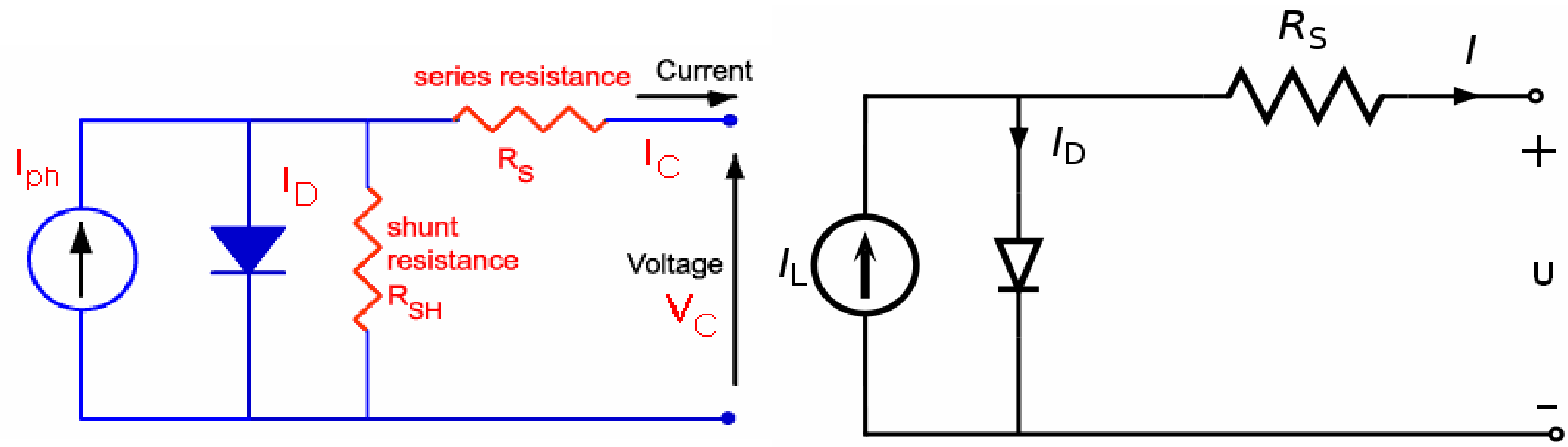
PHOTOVOLTAIC CELL WORKING PRINCIPLE





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

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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 25^0C 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

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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 $= \text{irradiance}(\text{W/m}^2)$

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

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

T_c $=$ PV cell temperature

$\text{T}_{\text{c,ref}}$ $=$ Reference Temperature $(25^0 C$ is used here)

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

Both $\text{I}_{\text{L,ref}}$ and $\mu_{\text{I,SC}}$ 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)

$\mathrm{I}_{mp,ref}$ = Maximum power point current at the reference condition (A)

$\mathrm{I}_{sc,ref}$ = Short circuit current at the reference condition (A)

α is a function of temperature, which is expressed as

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

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

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

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

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

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

T_a = Ambient te mperature($^0 c$)

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

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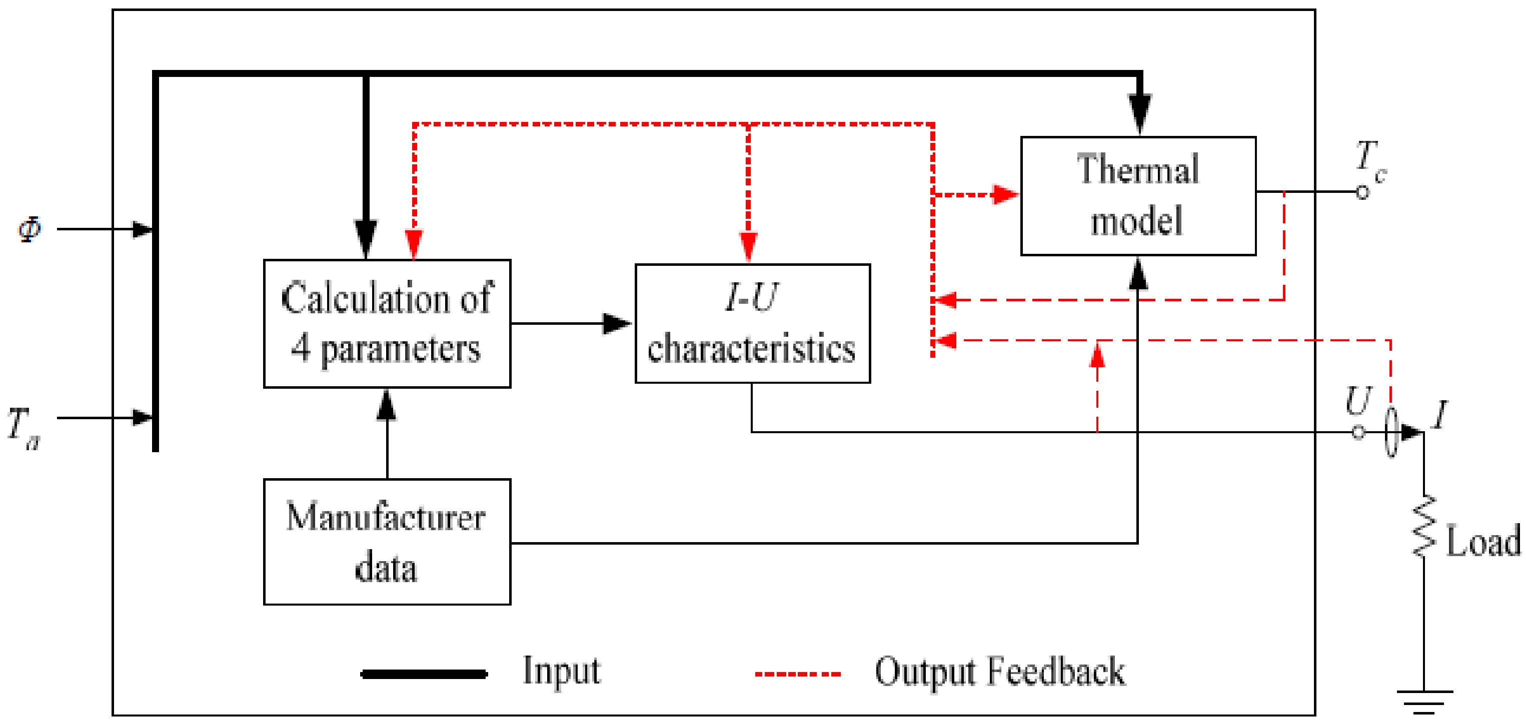
PHOTOVOLTAIC CELL MODEL PARAMETERS

$I_{L,ref}(I_{SC,ref})$	2.664 A
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
$T_{c,ref}$	25^0c

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

PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK



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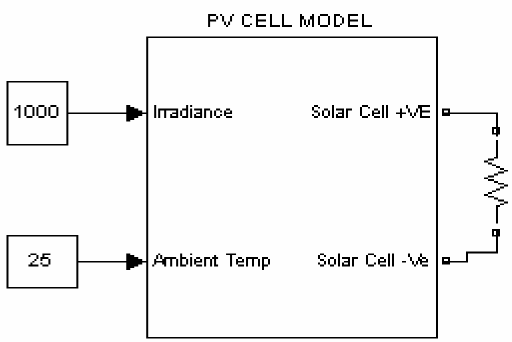
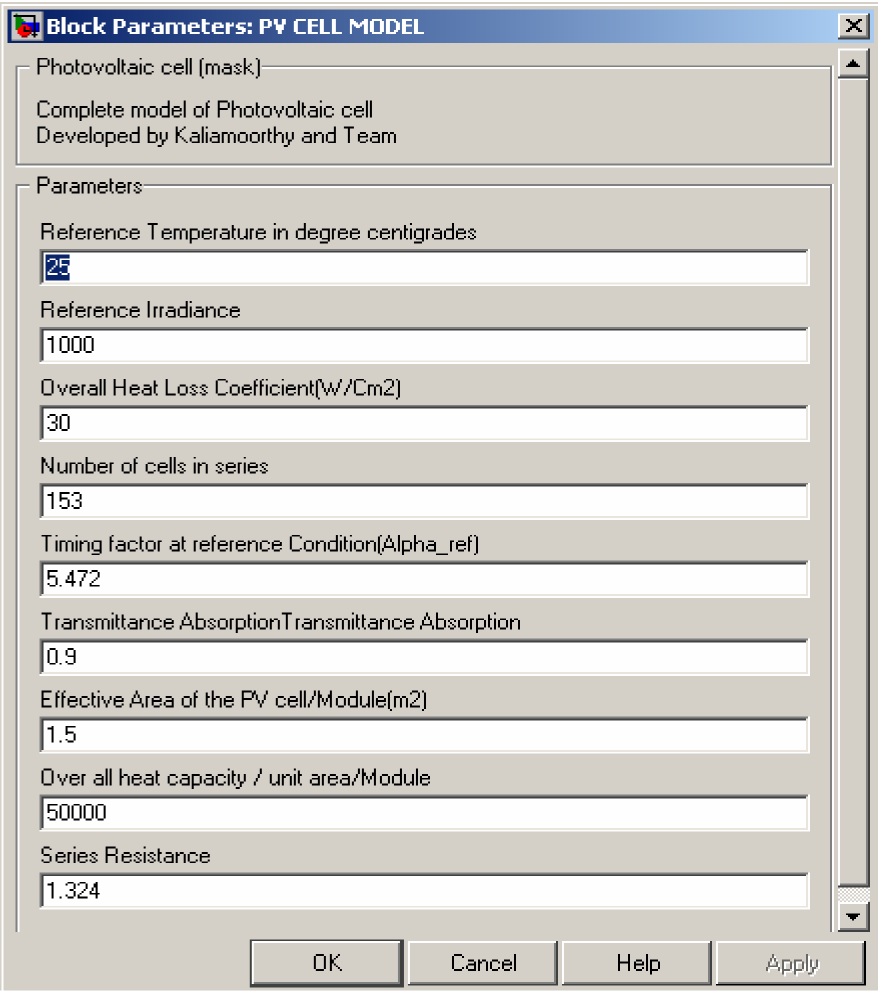
PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK





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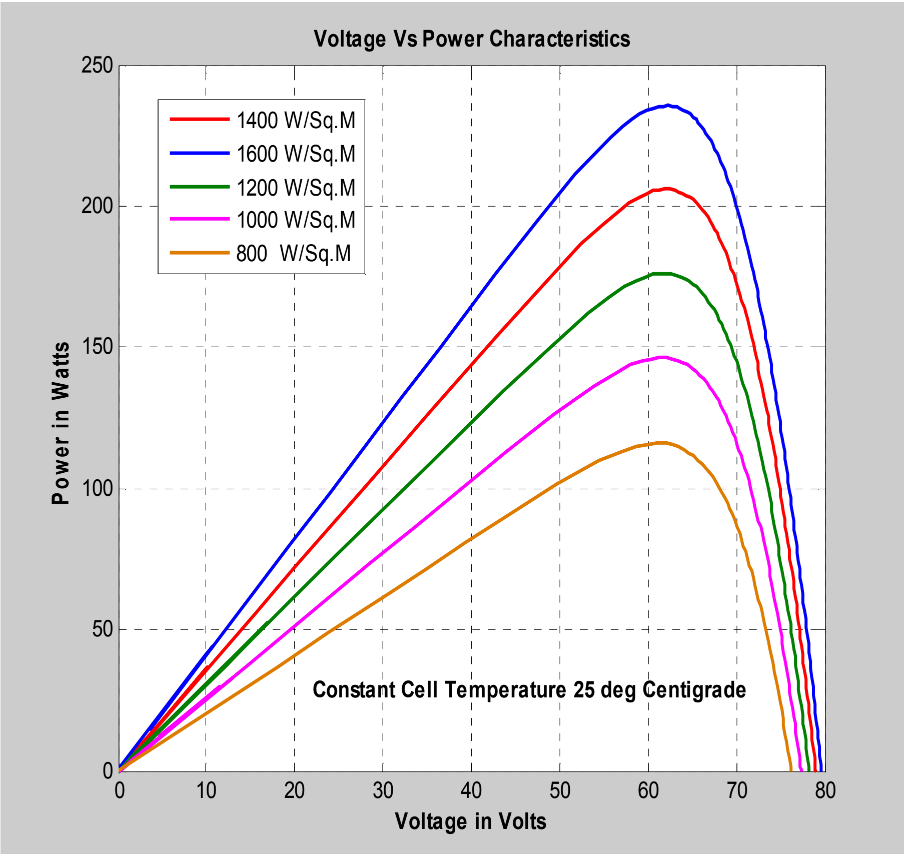
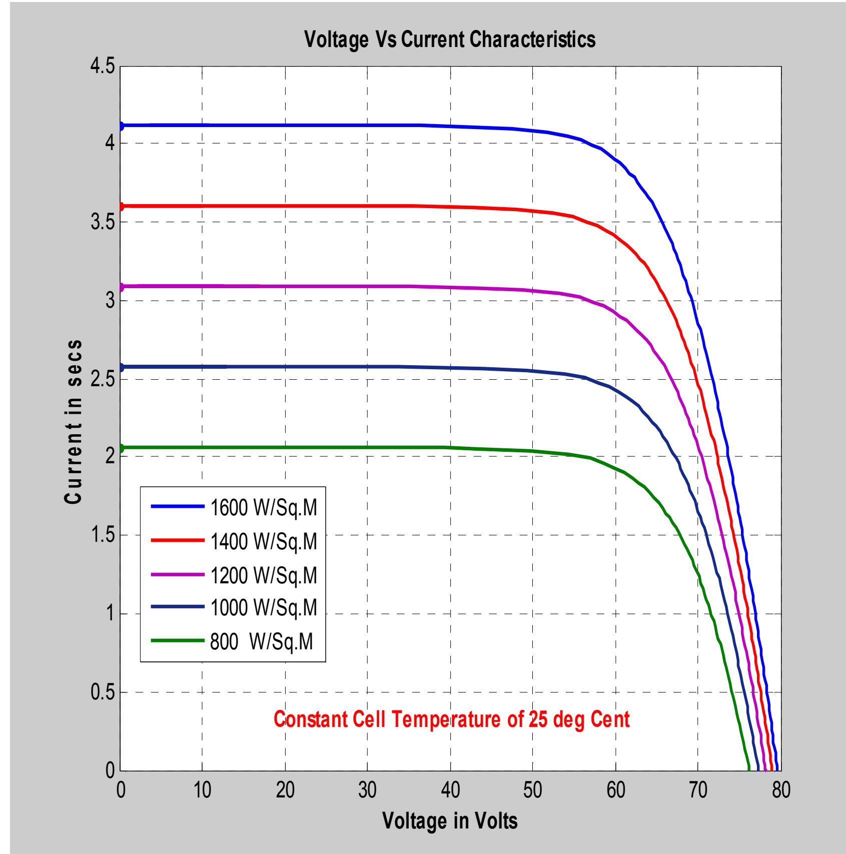
CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE





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

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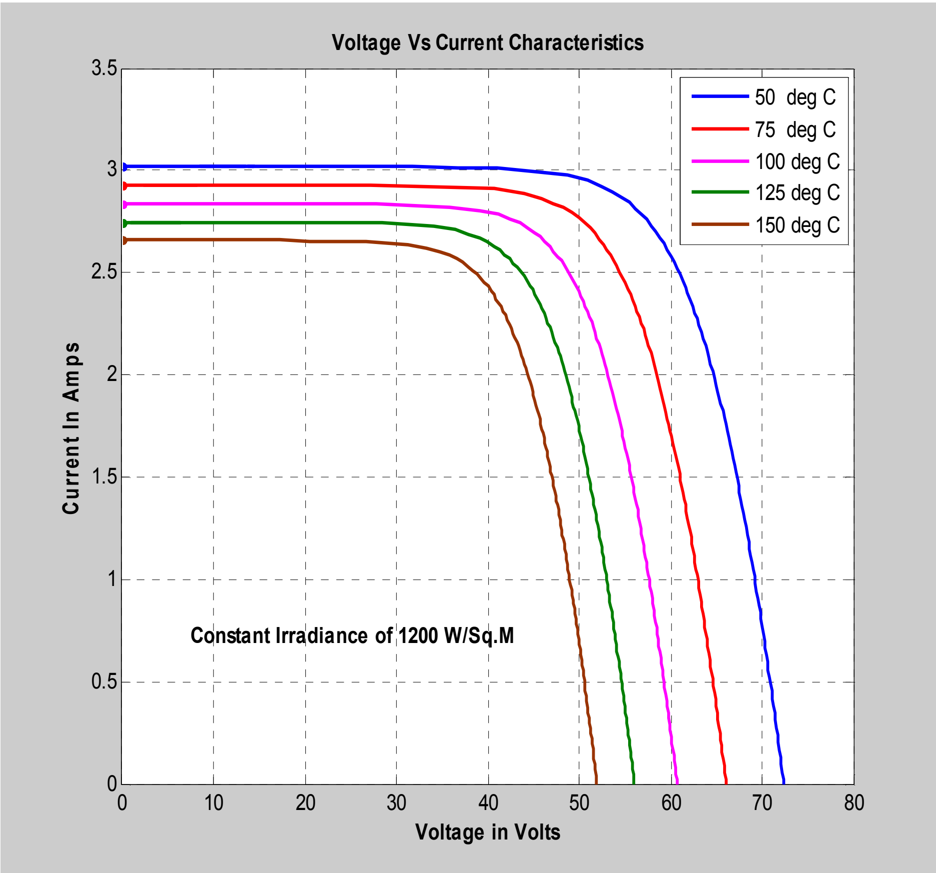
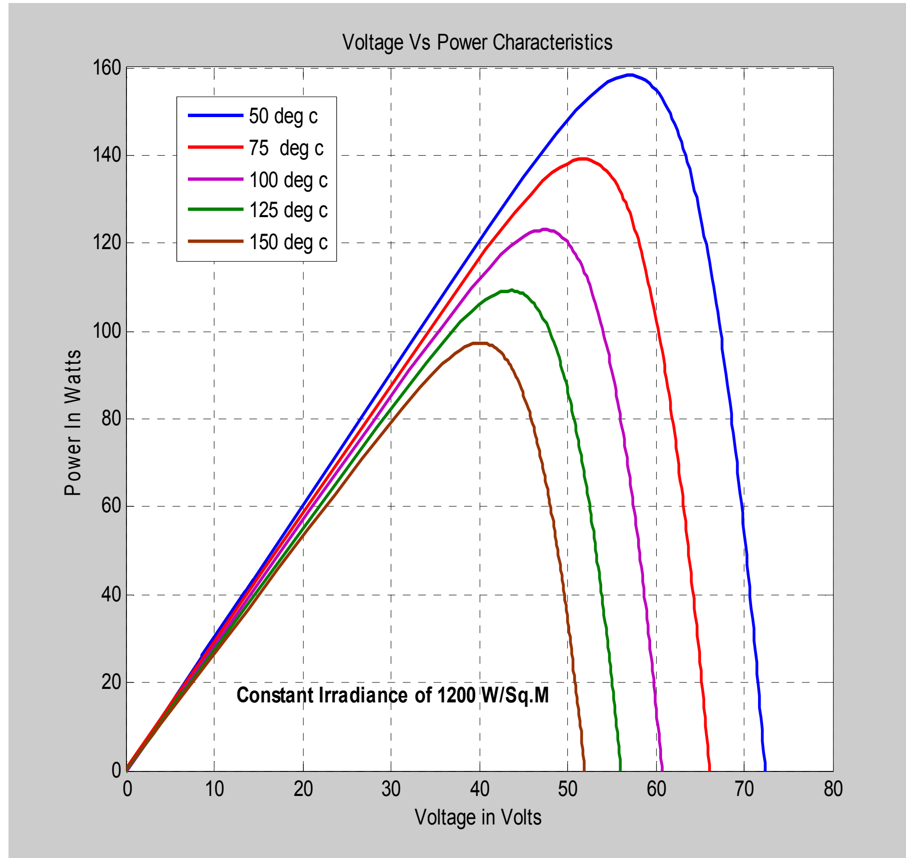
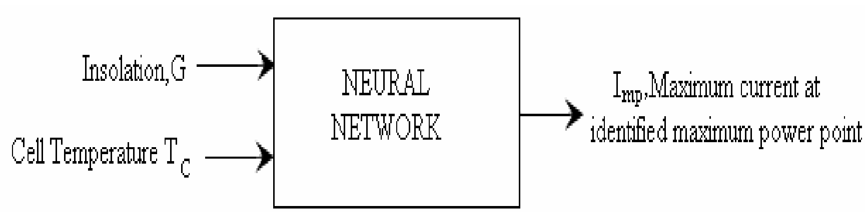
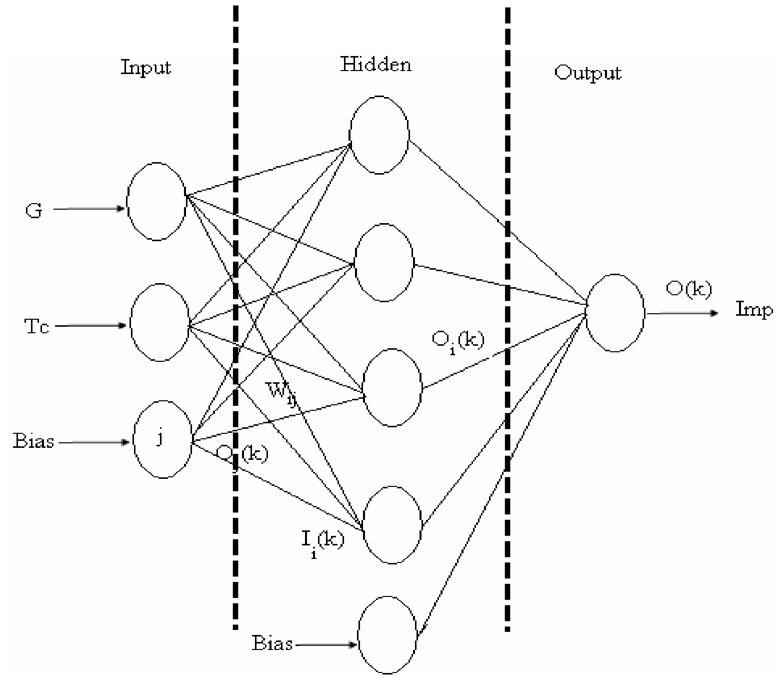
CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE





Maximum Power Point Tracking of PV cell Using Neural Networks





Transfer Function in the Input Layer : Linear

Transfer Function in the Hidden Layer : Tan Sigmoid

Transfer Function in the output Layer : Linear

Training Algorithm : Back Propagation

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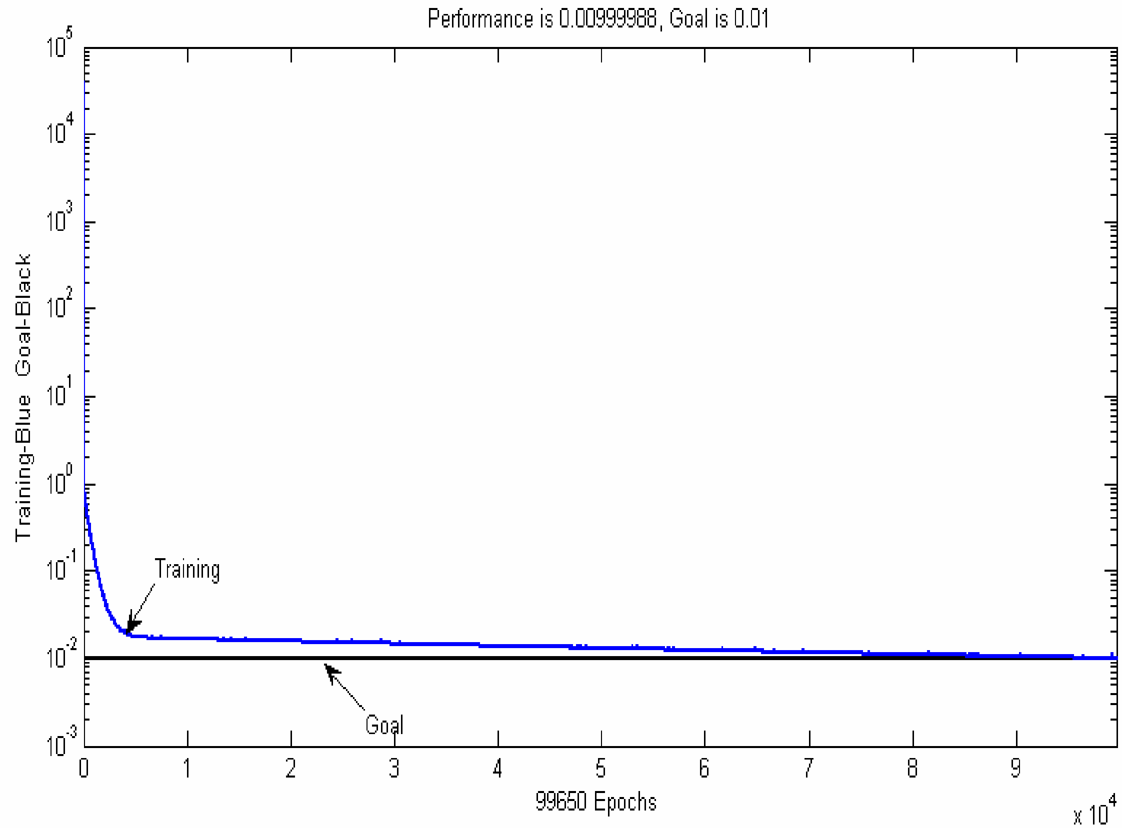
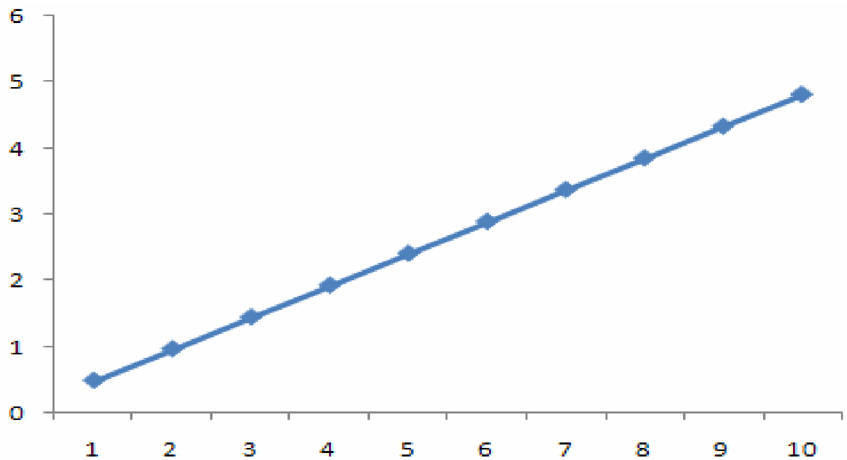
Maximum Power Point Tracking of PV cell Using Neural Networks

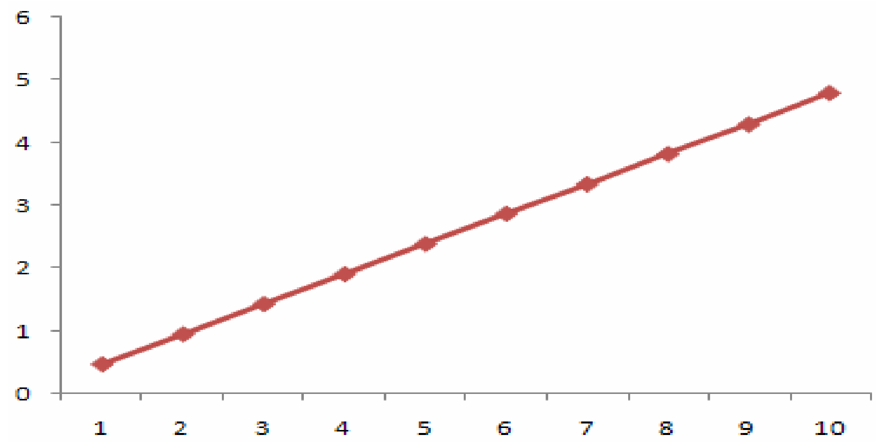
T_C	G	I_{mp} (A)	V_{mp}(V)	P(W)
25°C	200W/m²	.477	56.5	27.3
	400W/m²	.956	59	57.4
	600W/m²	1.437	62.2	88.4
	800W/m²	1.913	61	118.5
	1000W/m²	2.394	61.2	149.5
	1200W/m²	2.875	64.4	182
	1400W/m²	3.346	62.8	212
	1600W/m²	3.827	62	241
	1800W/m²	4.298	61.8	270



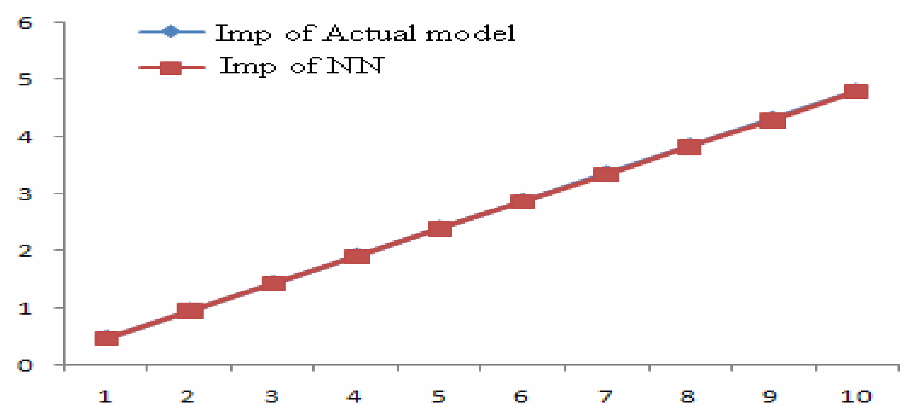
Maximum Power Point Tracking of PV cell Using Neural Networks



calculated Imp of a PV model

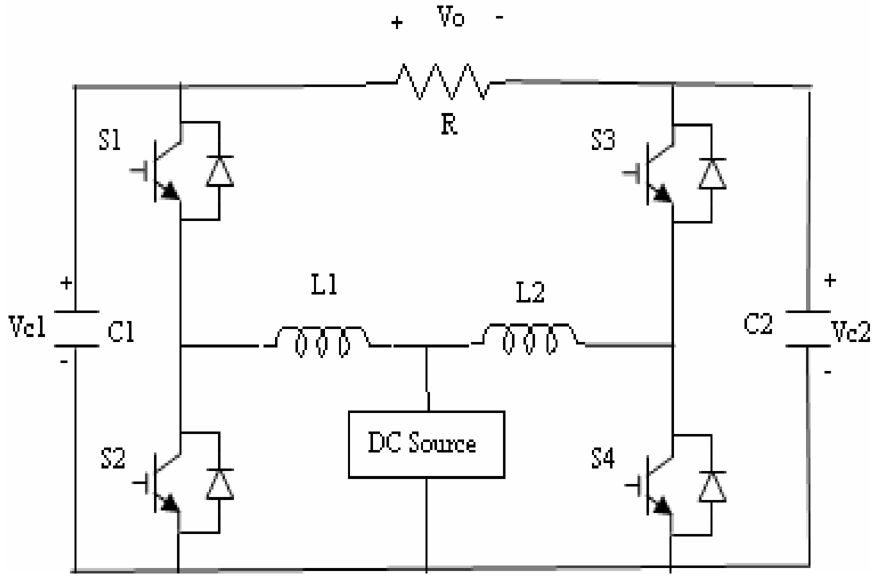


Imp of Neural Network

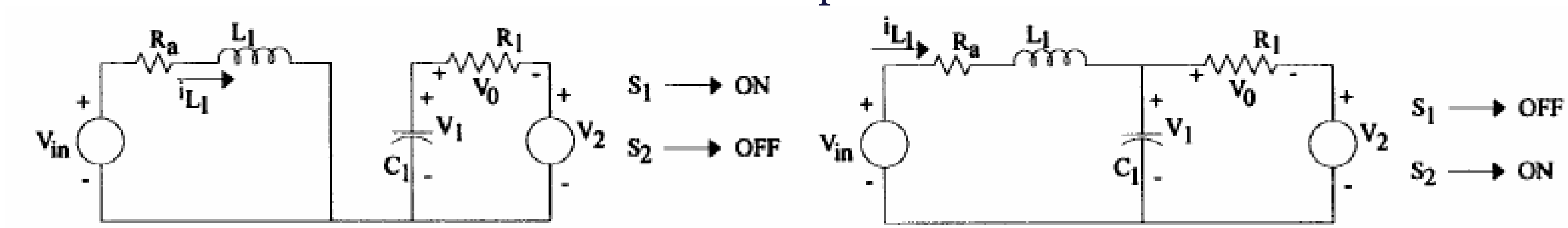


One can never consent to creep when one feels an impulse to soar – Electromagnetism –Maxwell-1865

Single Stage Boost Inverter

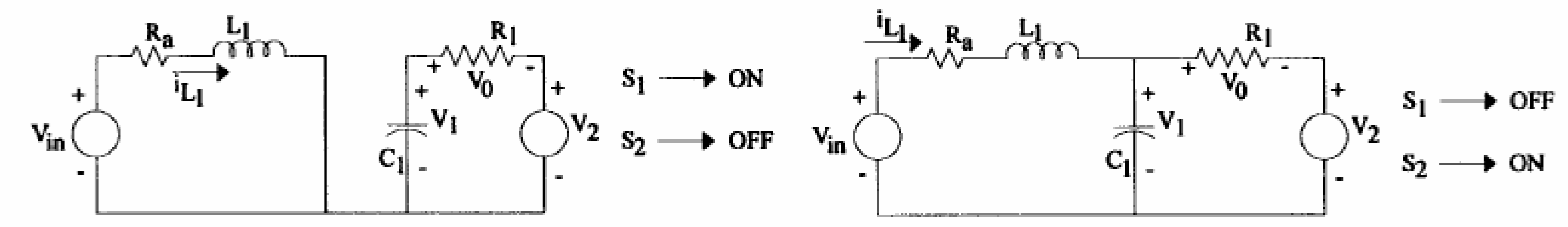


Circuit implementation



Modes of operation

Modeling of Single Stage Boost Inverter



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

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

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_1}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_2}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_1} & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & -\frac{1}{C_1R_1} & 0 & 0 \\ 0 & 0 & -\frac{R_a}{L_2} & -\frac{1}{L_2} \\ 0 & 0 & \frac{1}{C_2} & -\frac{1}{C_2R_1} \end{bmatrix} \begin{bmatrix} i_{L1} \\ V_1 \\ i_{L2} \\ V_2 \end{bmatrix} + \begin{bmatrix} \frac{V_1}{L_1} \\ -\frac{i_{L1}}{C_1} \\ \frac{V_2}{L_2} \\ -\frac{i_{L2}}{C_2} \end{bmatrix} \gamma + \begin{bmatrix} \frac{V_{in}}{L_1} \\ \frac{V_2}{C_1R_1} \\ \frac{V_{in}}{L_2} \\ \frac{V_1}{C_2R_1} \end{bmatrix}$$

Where γ is the status of switches

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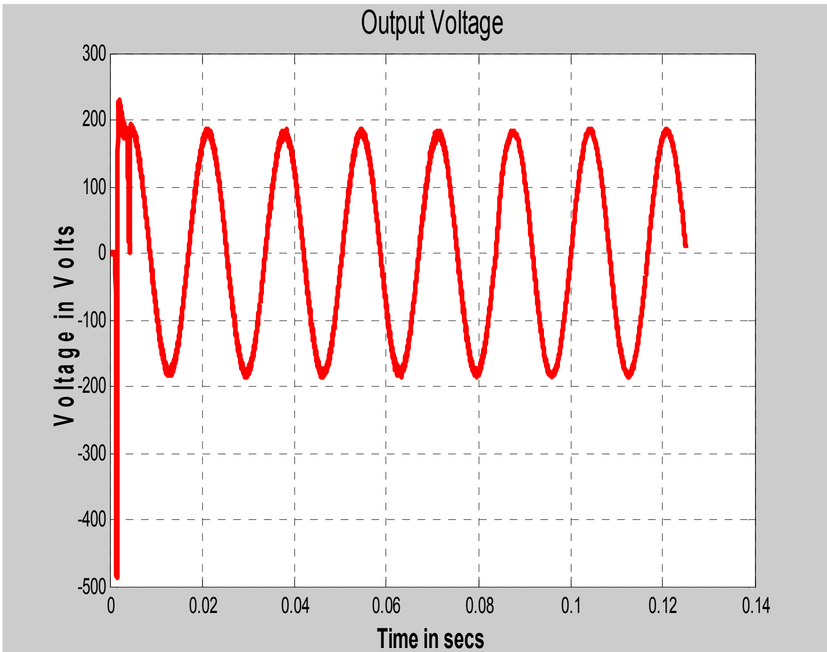
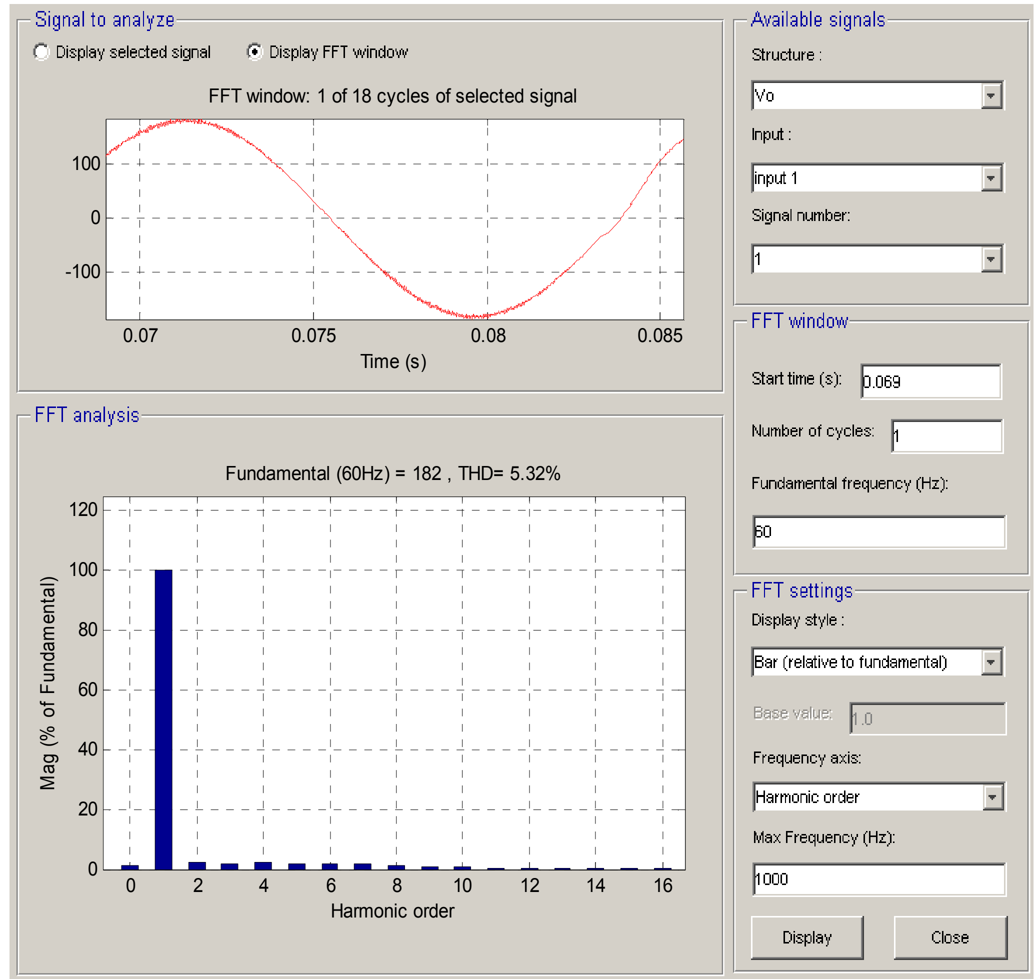
Simulation Results
With Constant Irradiance and Temperature





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

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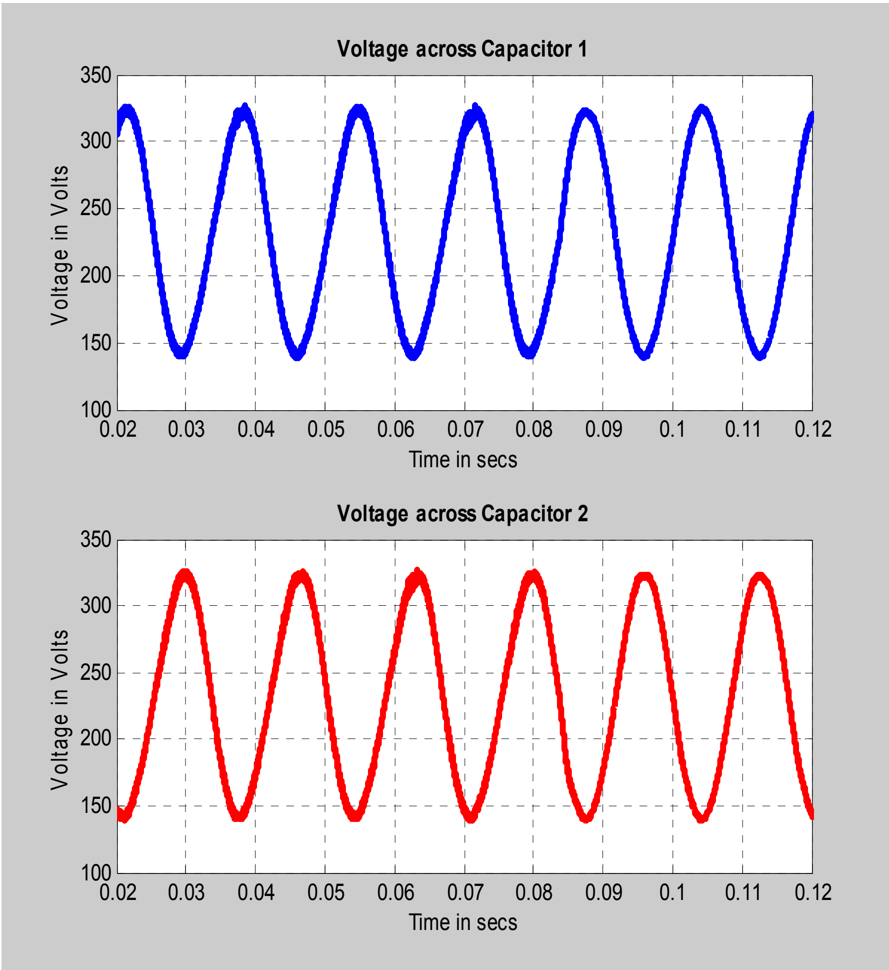
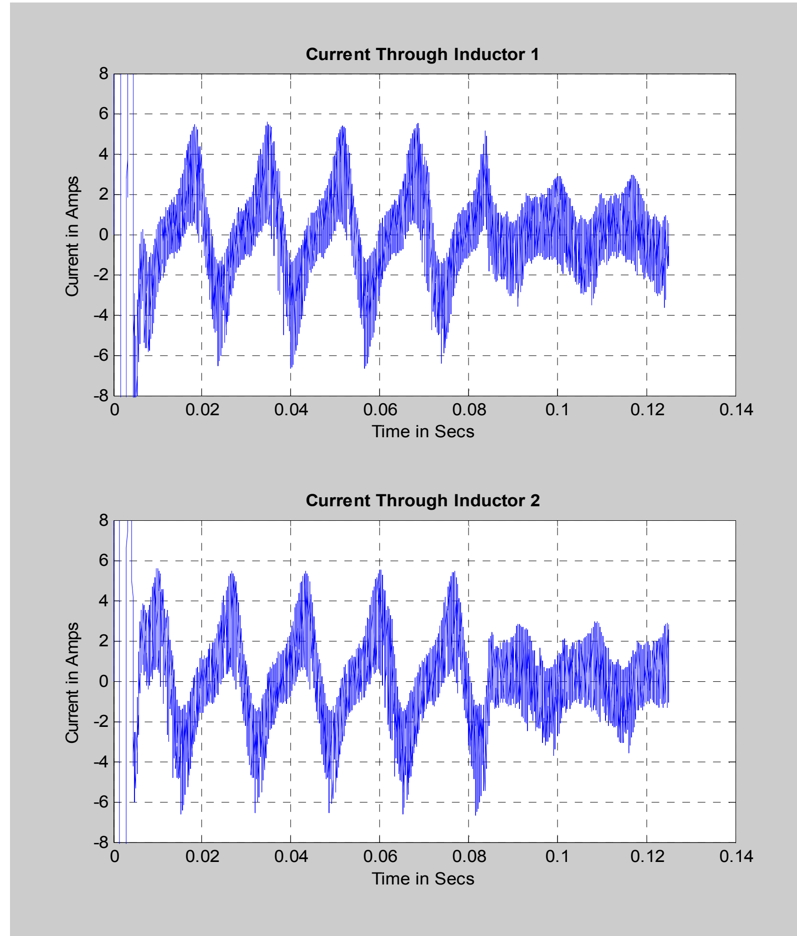
Simulation Results
With Constant Irradiance and Temperature Continues….





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

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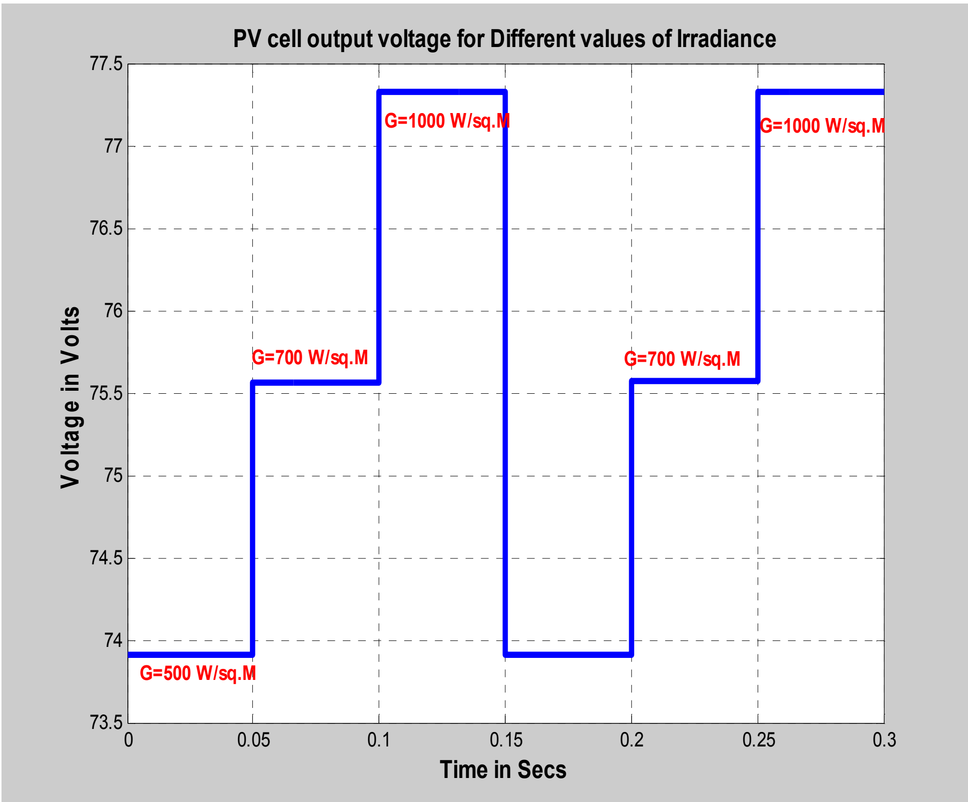
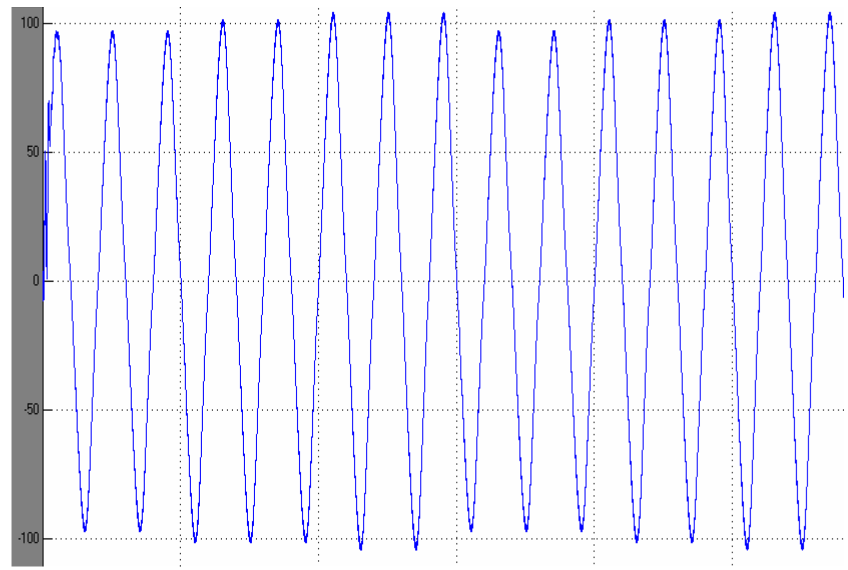
Simulation Results
With Variable Irradiance and Constant Temperature





Time (sec)

Output voltage

PV panel voltage

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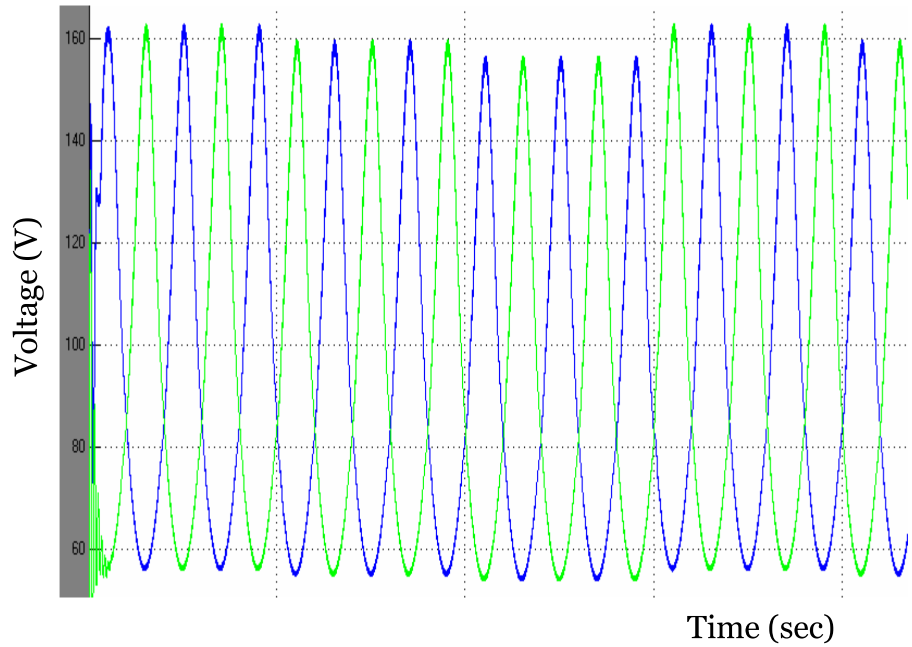
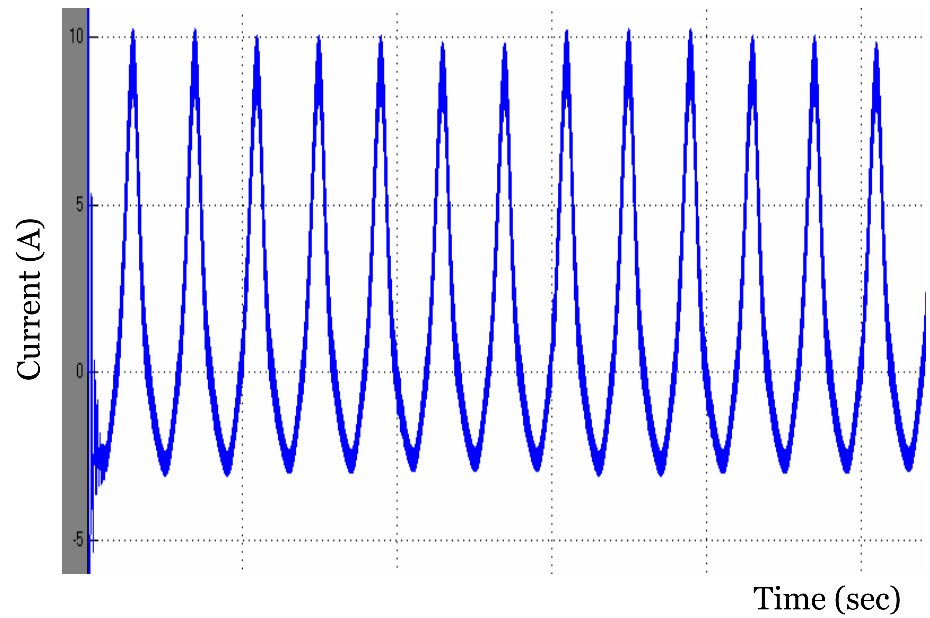
Simulation Results
With Variable Irradiance and Constant Temperature Continues…



Capacitor voltage



Inductor current

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

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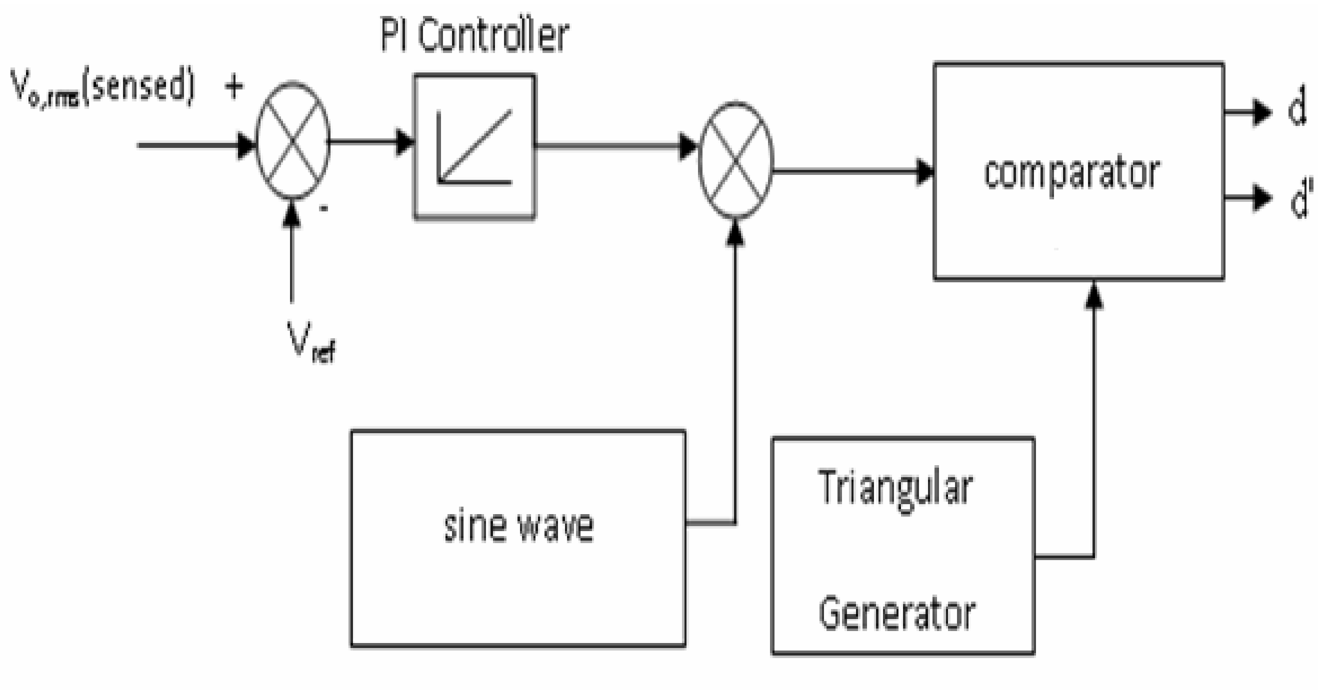
PI Controller Fed Single Stage Boost Inverter



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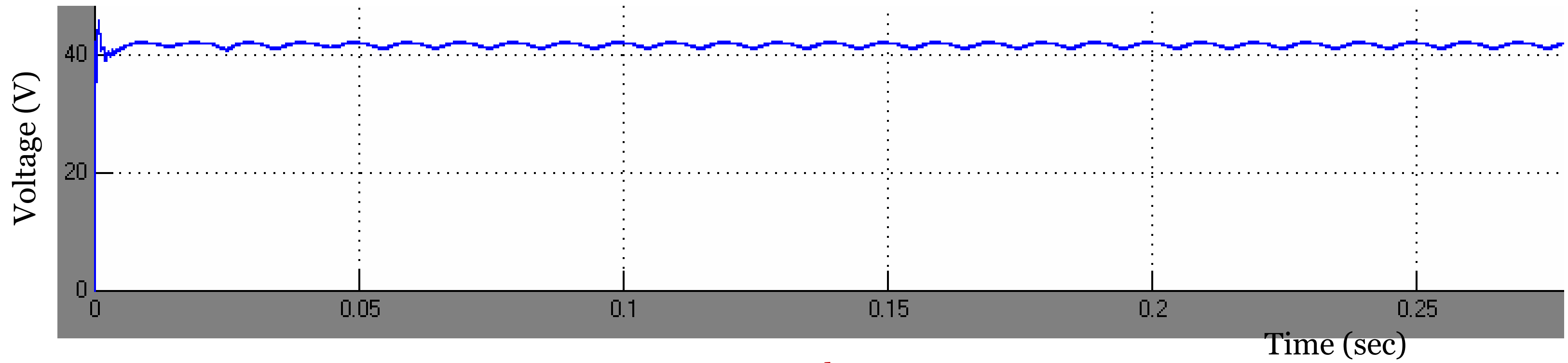
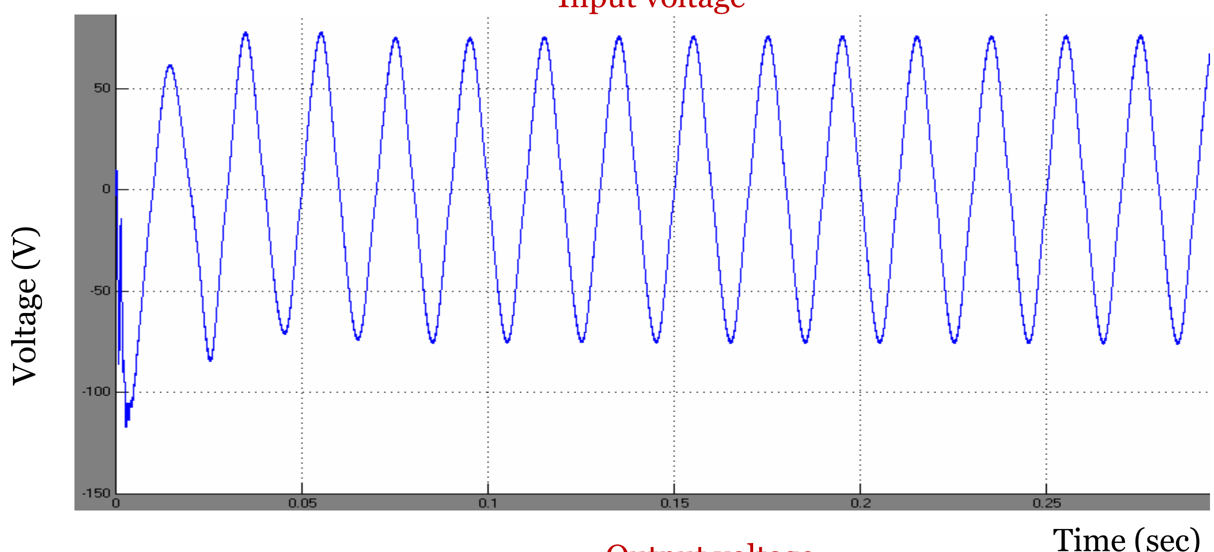
Simulation of PI Controller
With Constant Irradiance and Temperature



Input voltage



Output voltage

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

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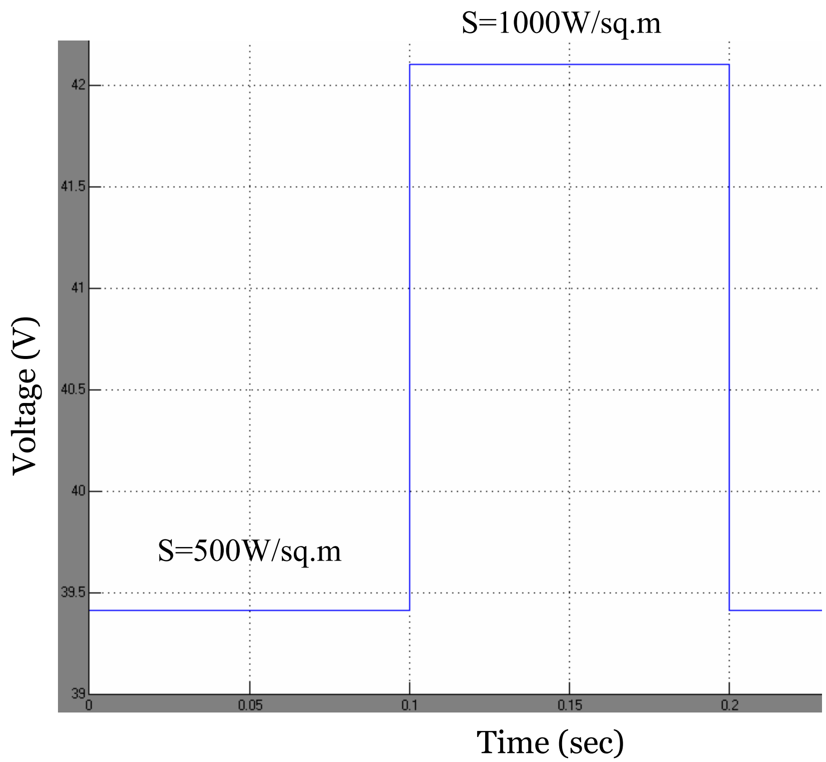
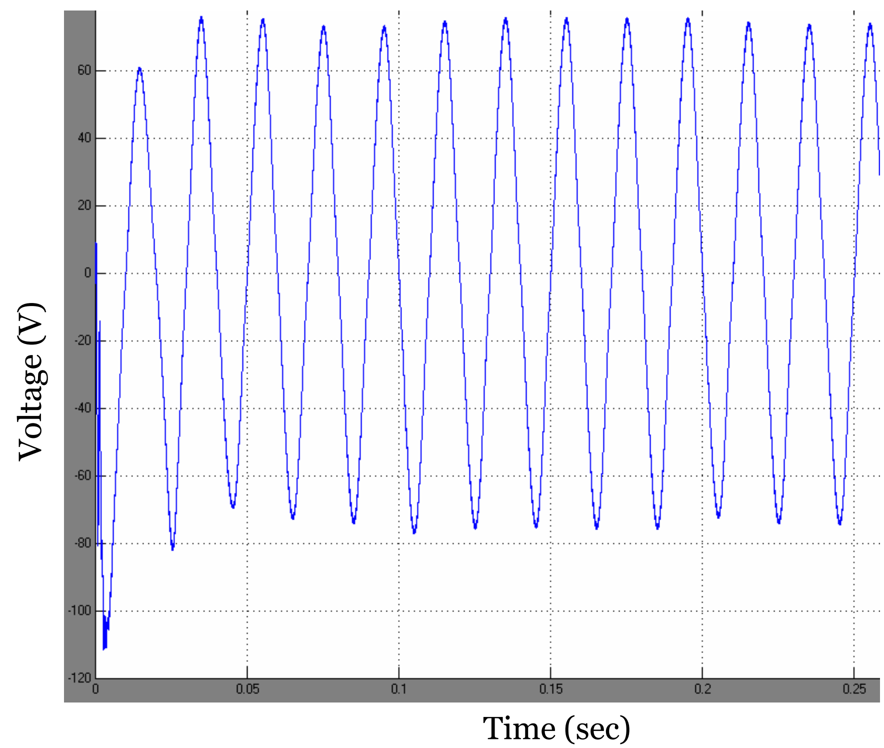
Simulation Results
With Variable Irradiance and Constant Temperature



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

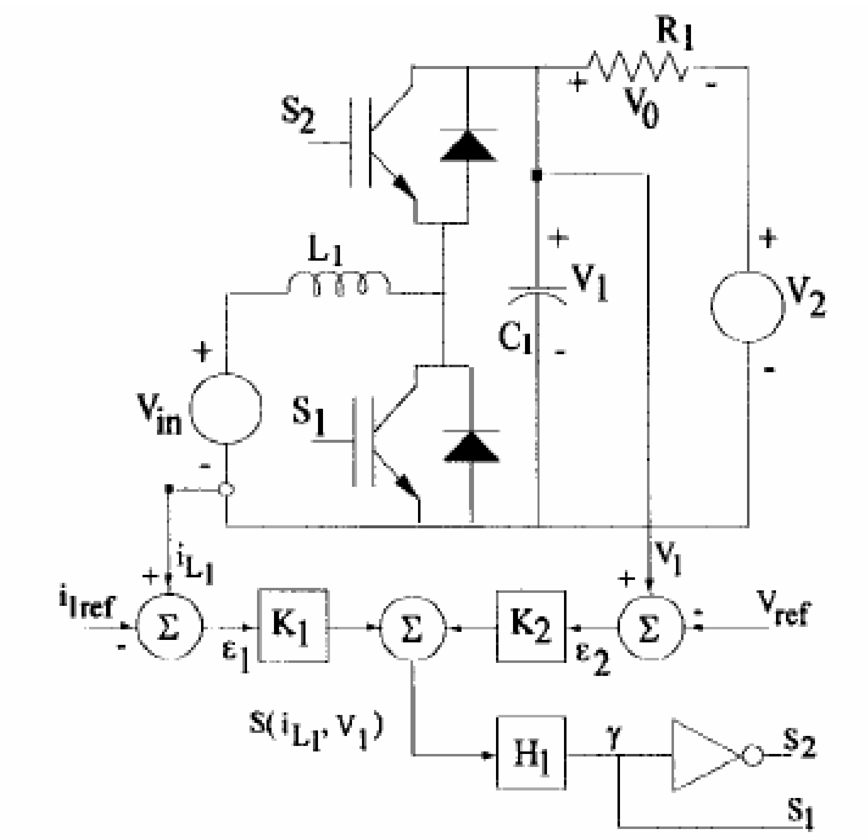
$$\varepsilon_1 = i_{L1} - i_{Lref}$$

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

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

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 achieved.

Sliding Mode Controller Continued….



Sliding mode controller scheme

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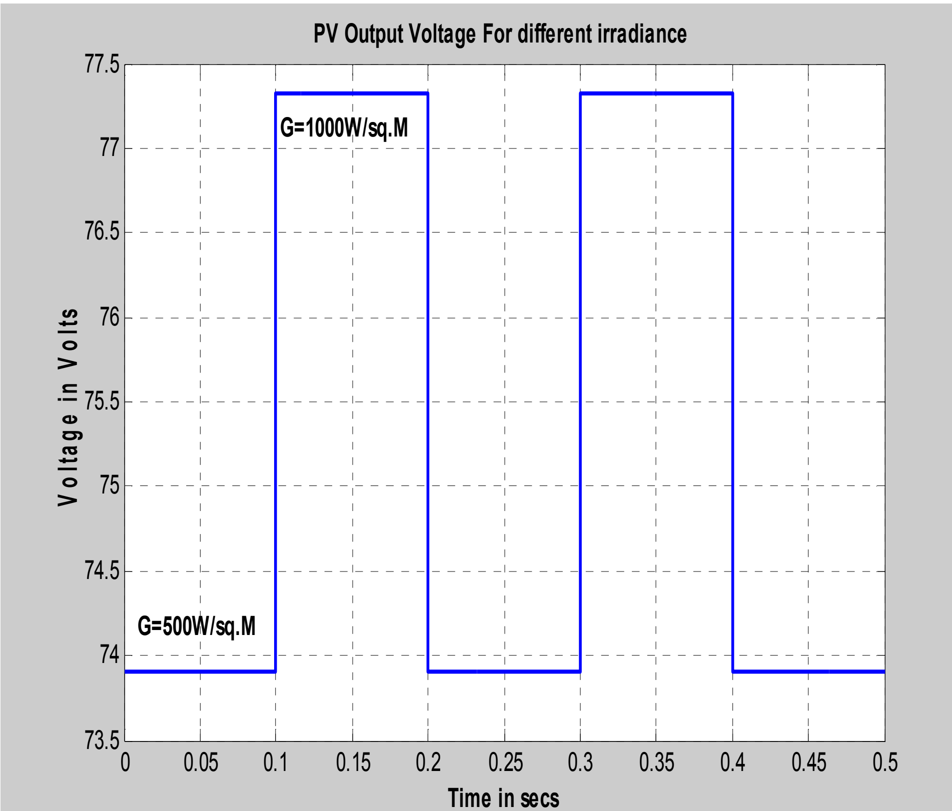
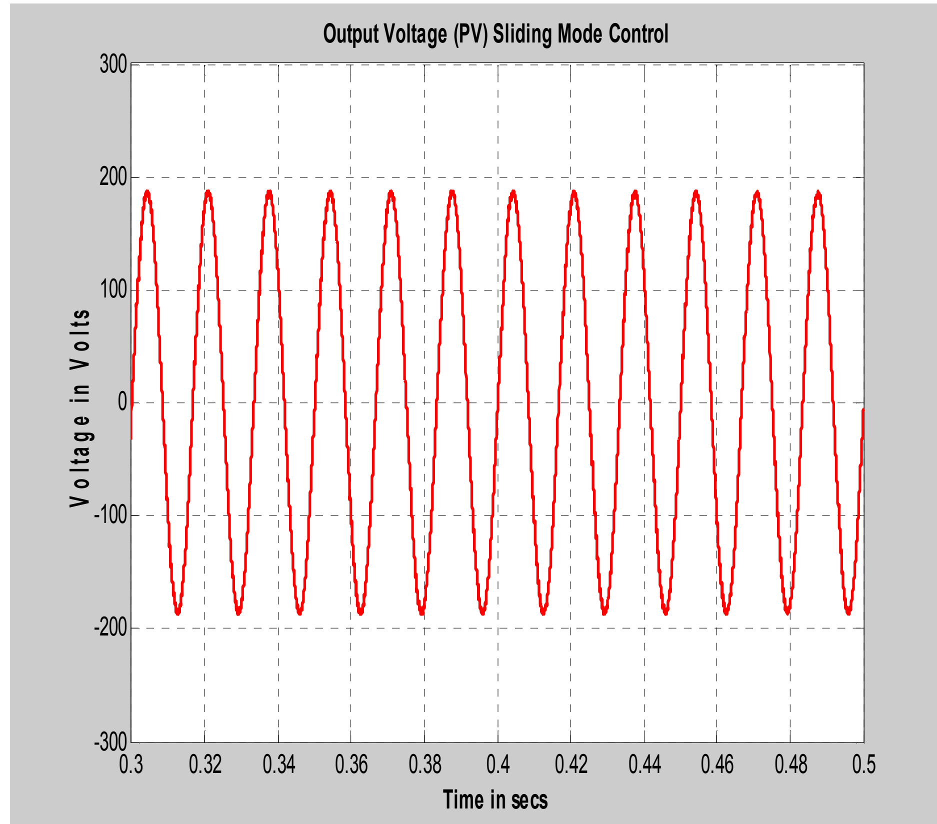
Simulation Results for Sliding Mode Controller With Variable Irradiance





PV panel voltage

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

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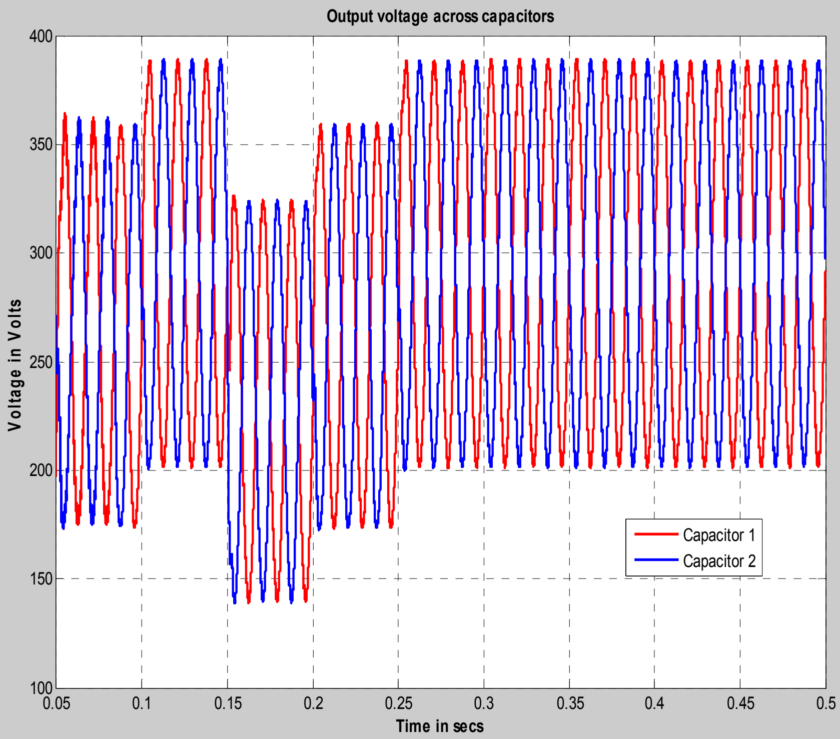
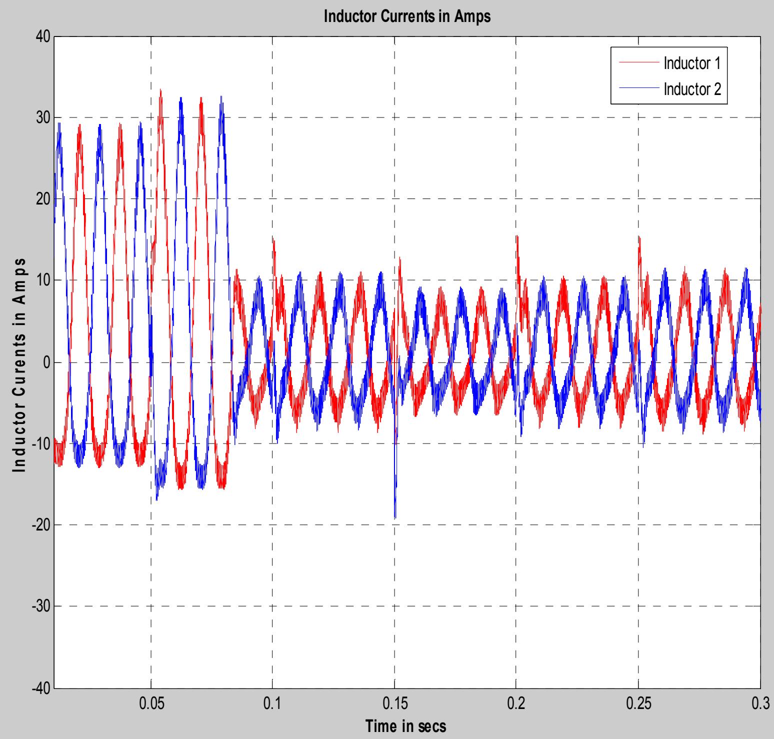
Simulation Results for Sliding Mode Controller With Variable Irradiance continues….





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

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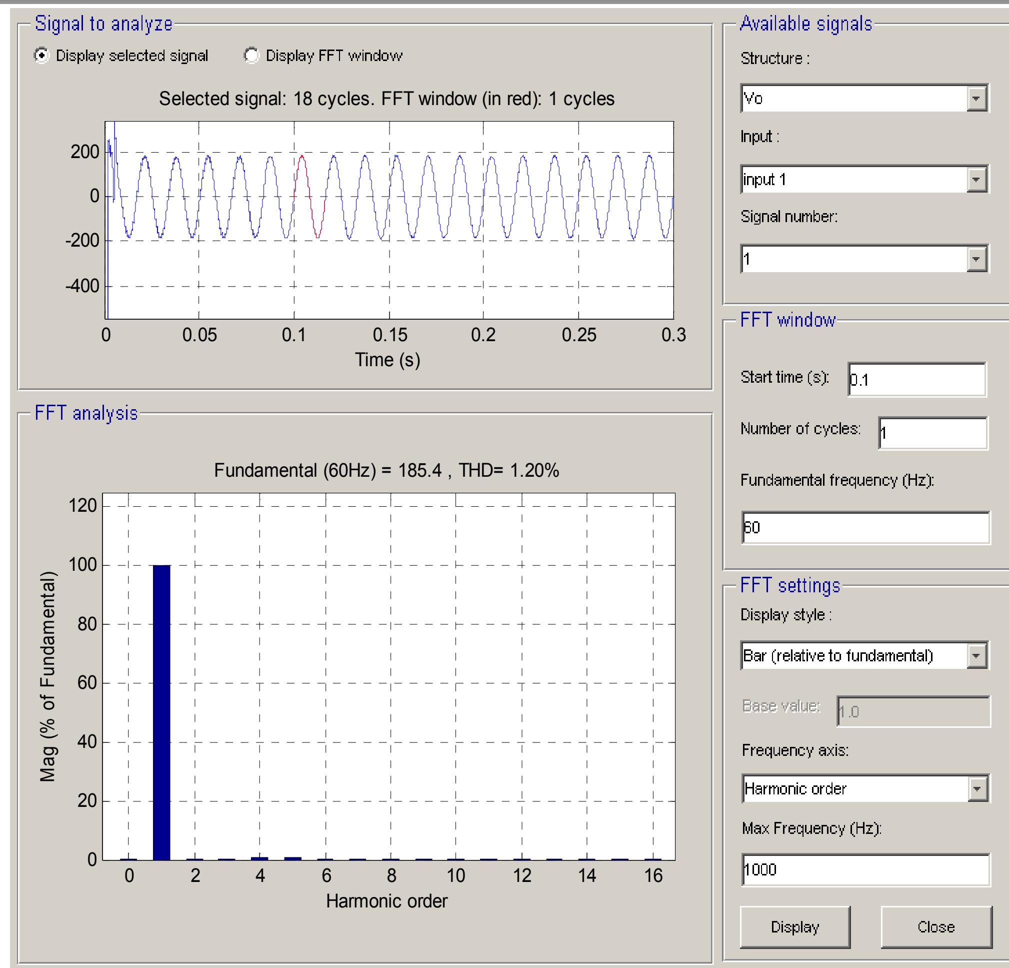
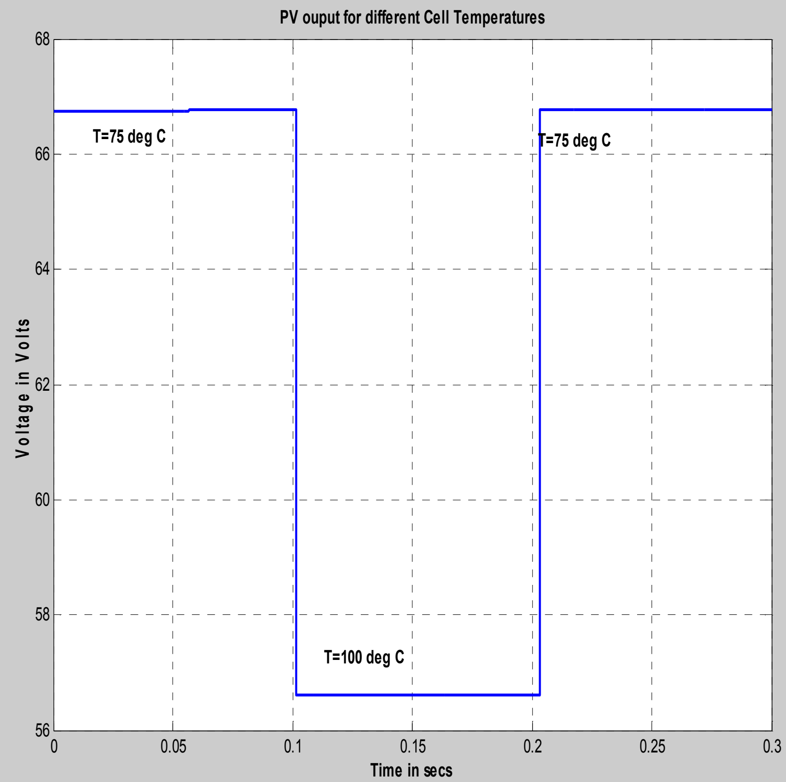
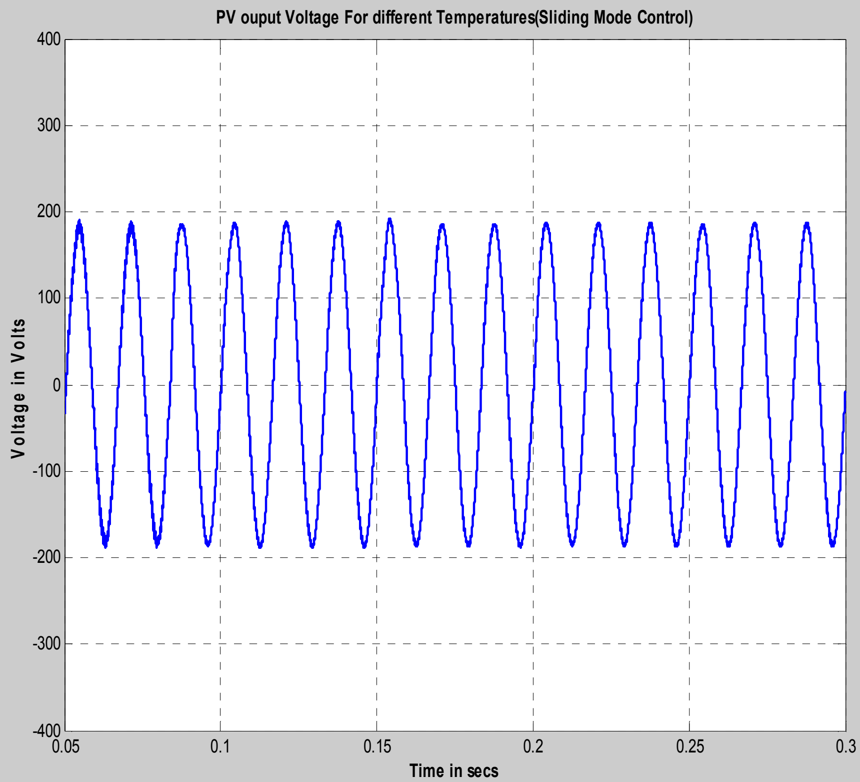
Simulation Results for Sliding Mode Controller With Variable Irradiance continues….



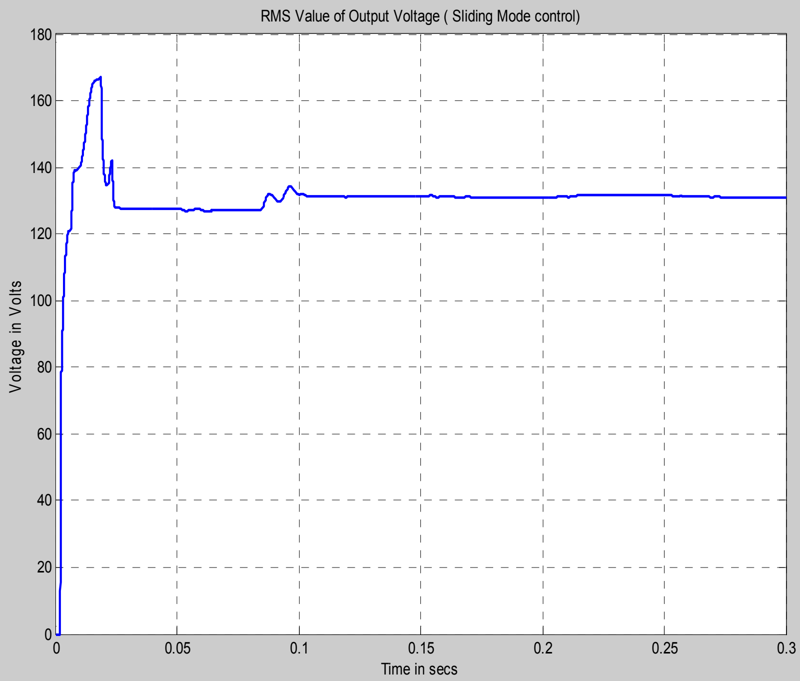
Simulation Results for Sliding Mode Controller With Variable Temperature continues….

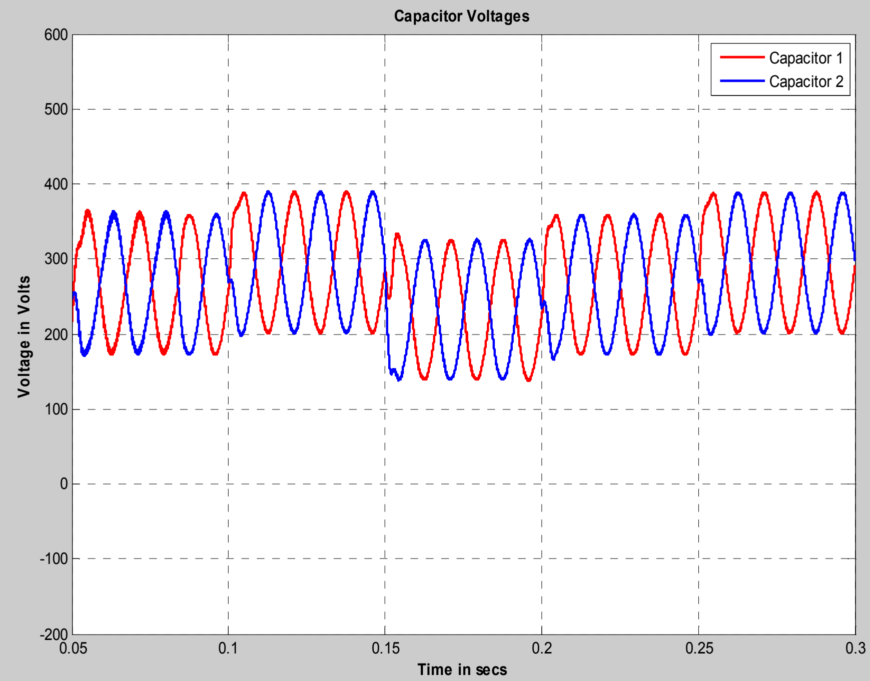




Presented By: M.Kaliamoorthy,AP,PSNACET,EEE

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





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

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