



# Solar powered Single Stage boost inverter with ANN based MPPT algorithm



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Presentation By

Mr. M.Kaliamoorthy,  
Assistant Professor

Department of Electrical and Electronics Engineering  
PSNA College of Engineering and Technology  
Dindigul, Tamilnadu-624622

Tel: 9865065166

E-Mail: [kaliasgoldmedal@gmail.com](mailto:kaliasgoldmedal@gmail.com), [kalias\\_ifet@yahoo.com](mailto:kalias_ifet@yahoo.com)

Website: [www.kaliasgoldmedal.yolasite.com](http://www.kaliasgoldmedal.yolasite.com)

Paper Number : 371



The Journey of Thousand Miles Begins with a single step





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



## 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



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 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



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

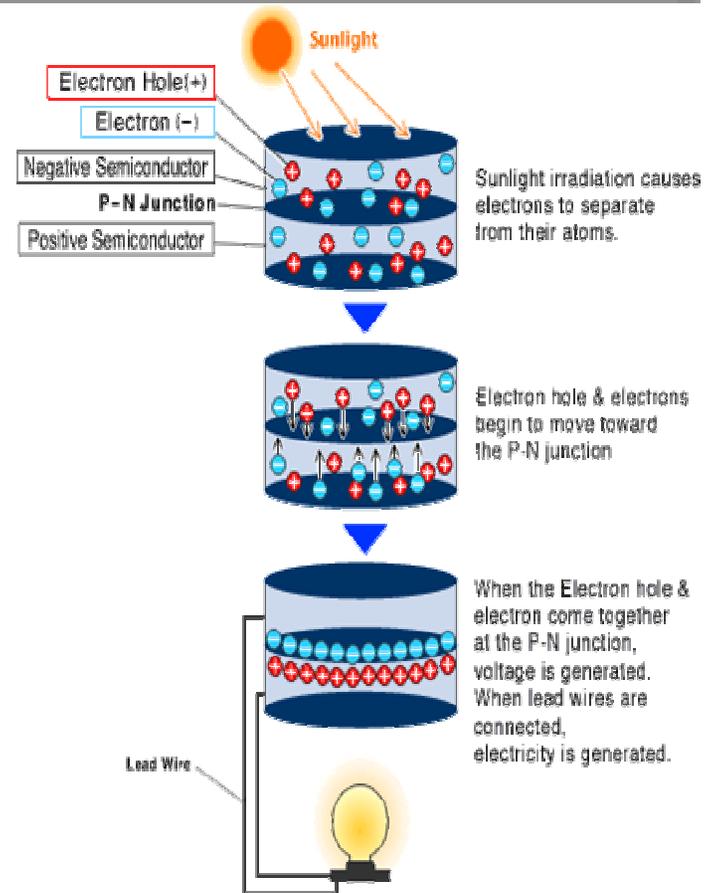
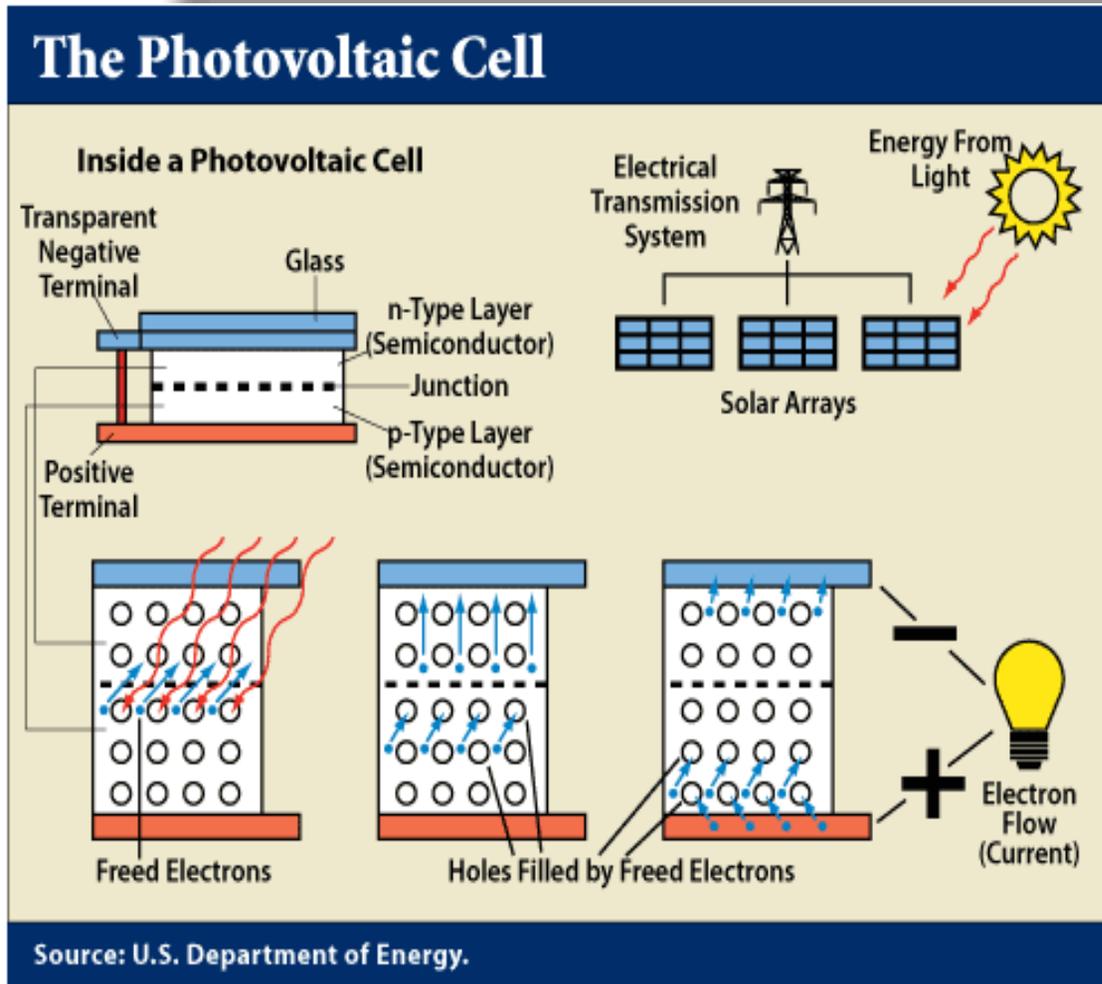




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# PHOTOVOLTAIC CELL WORKING PRINCIPLE

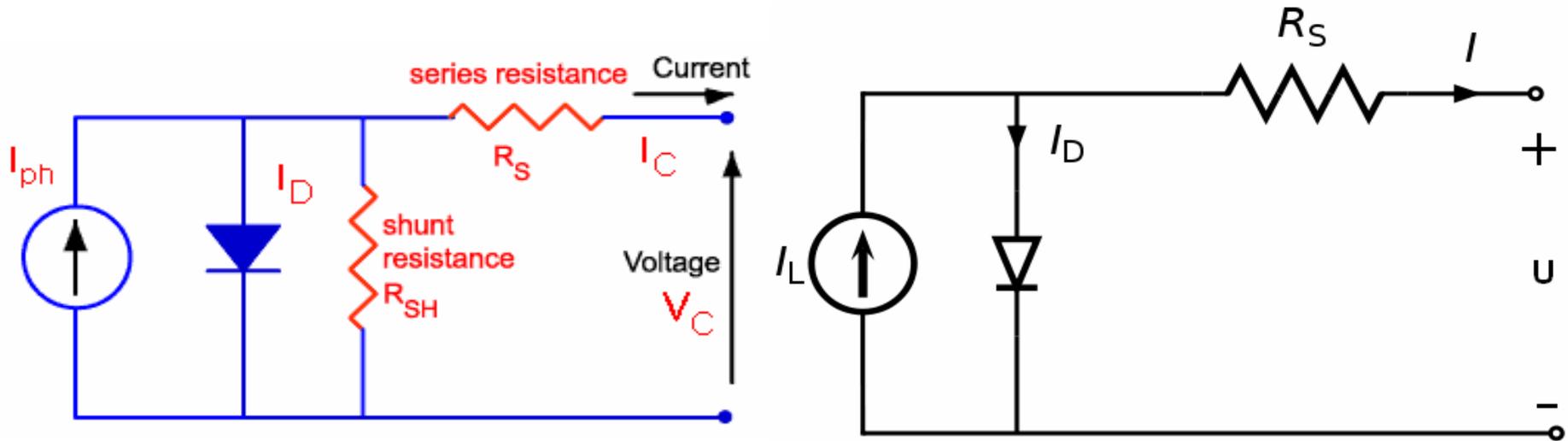


Workship the creator not his creation- Edmond Becquerel ,1889 Electricity From Sun





# PHOTOVOLTAIC CELL MODELING



From the figure

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

Where I=Output Current In Amps

I<sub>p</sub>=light Current Or Photo Generated Current In Amps

I<sub>D</sub>= 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°C  $nkT/q = 0.0259$  volts =  $\alpha$

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



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

$\phi_{ref}$  = 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  $25^\circ \text{C}$ )

$T_c$  = PV cell temperature

$T_{c,ref}$  = Reference Temperature ( $25^\circ \text{C}$  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)

$\alpha_{ref}$  = The value of  $\alpha$  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 $\alpha$

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

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)

$\alpha$  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 PV cell/ Module ( $m^2$ )





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## PHOTOVOLTAIC CELL MODEL PARAMETERS

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

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

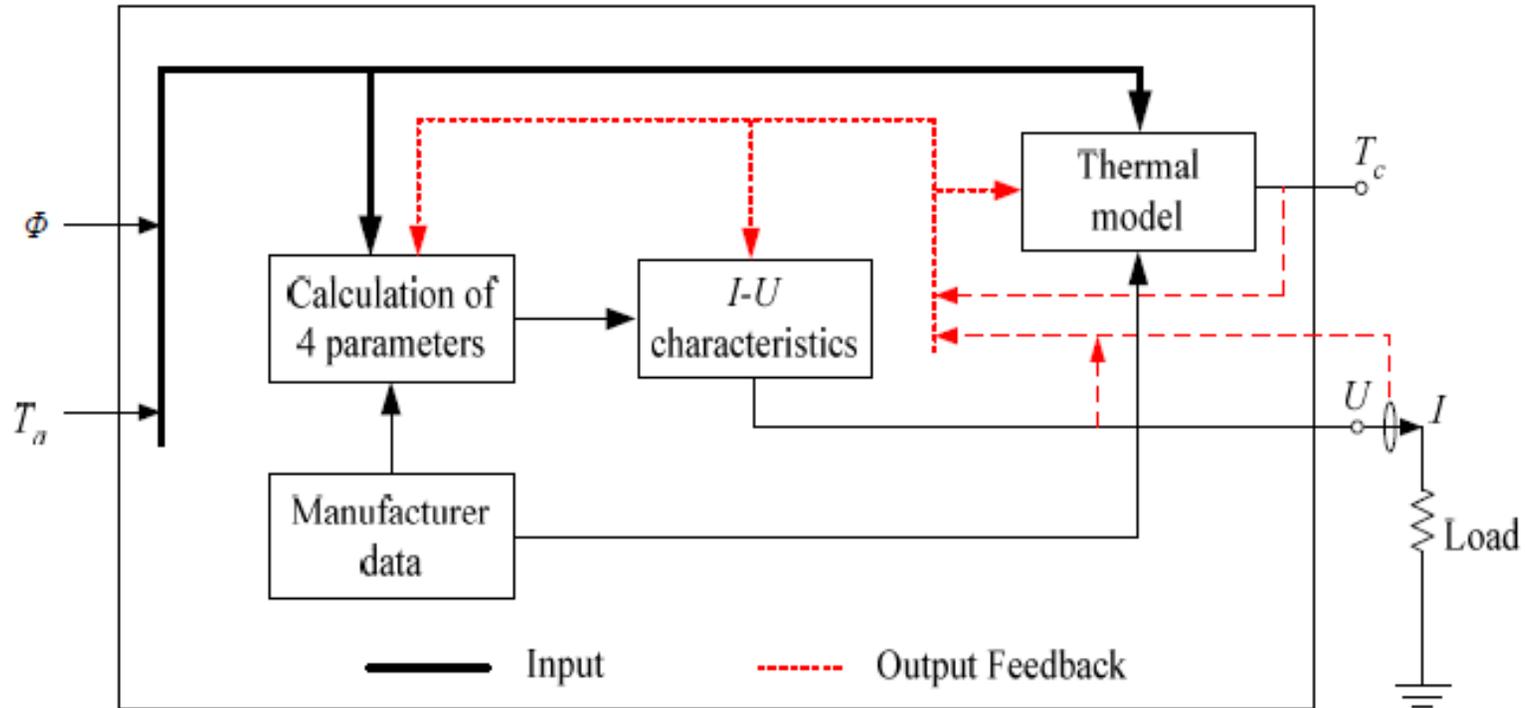


Be willing to accept temporary inconvenience for permanent improvement –Dynamo-Michael Faraday-1832





# PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK

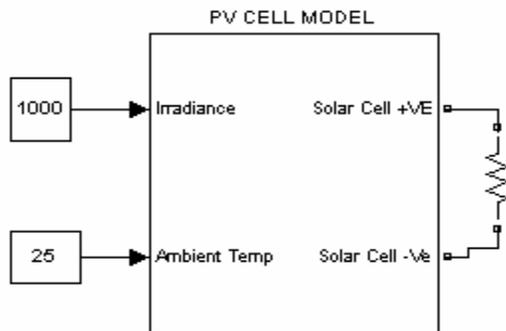




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# PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK



**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(A<sub>alpha\_ref</sub>)  
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



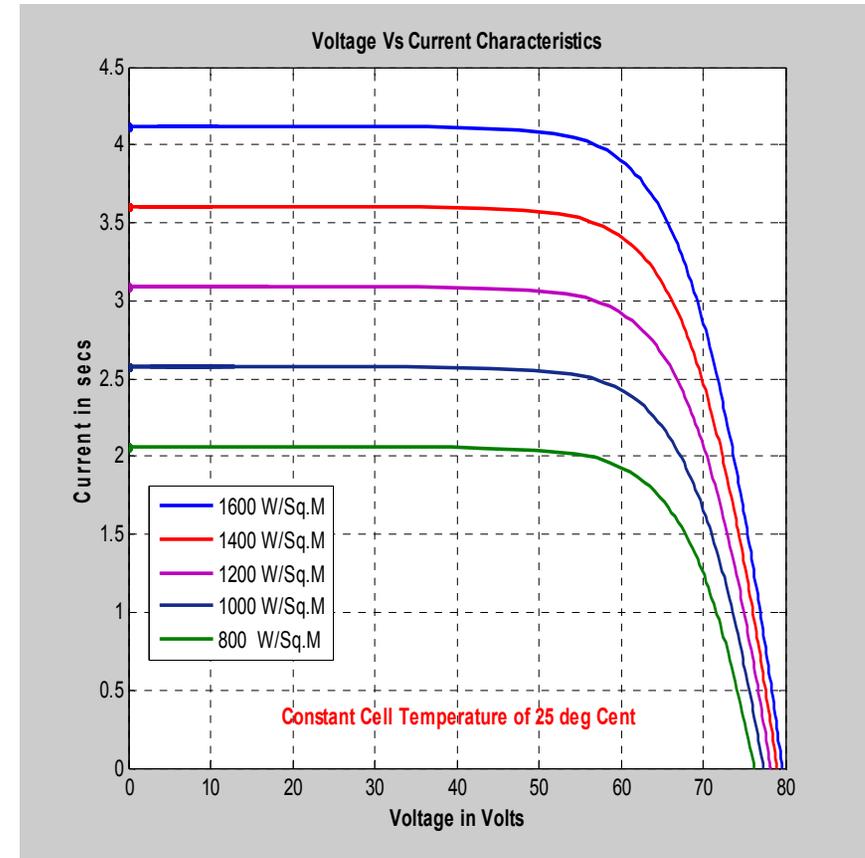
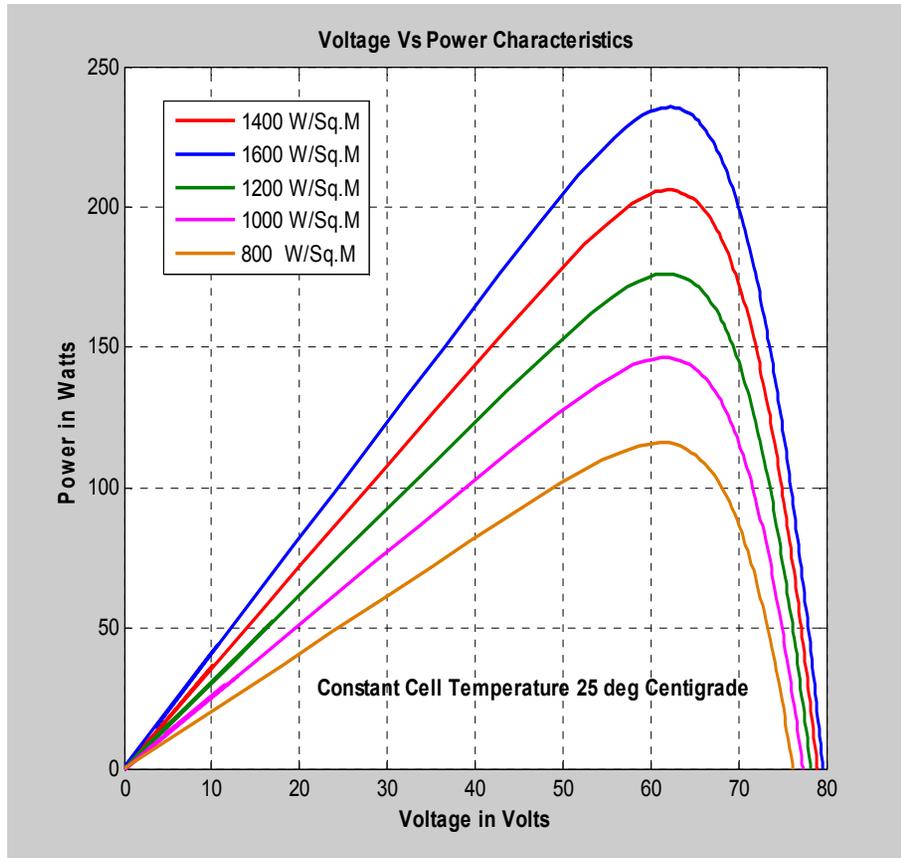
Distance lends enchantment to the view –CRO- Karl Ferdinand Braun- 1897





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# CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE



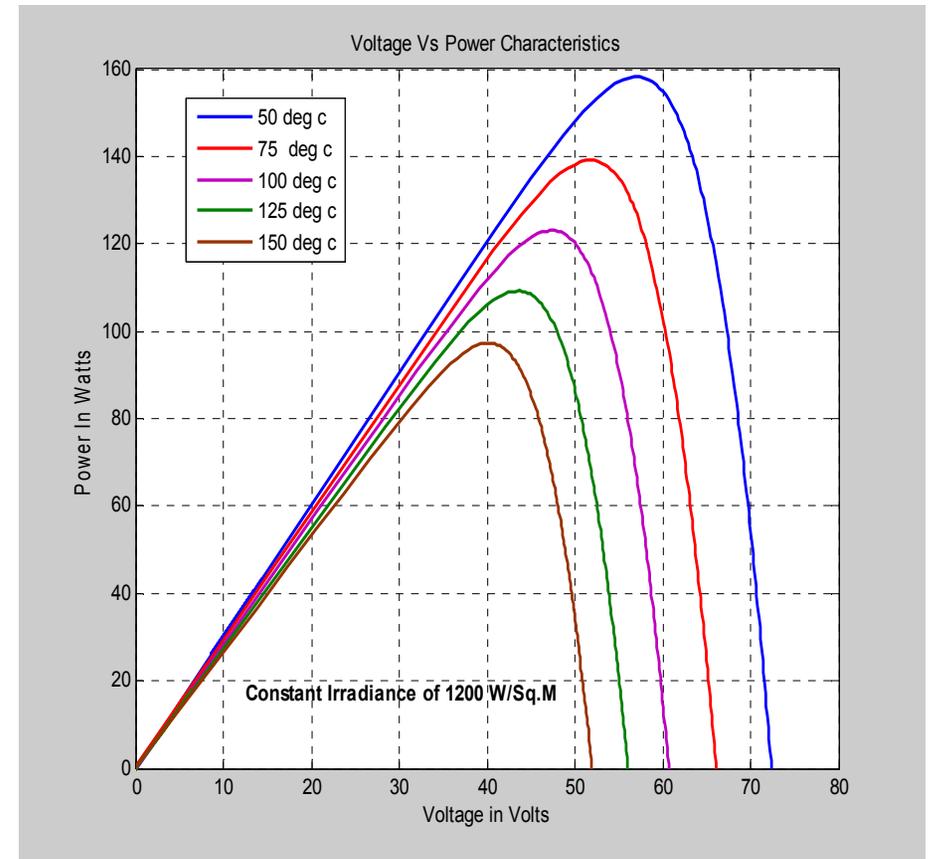
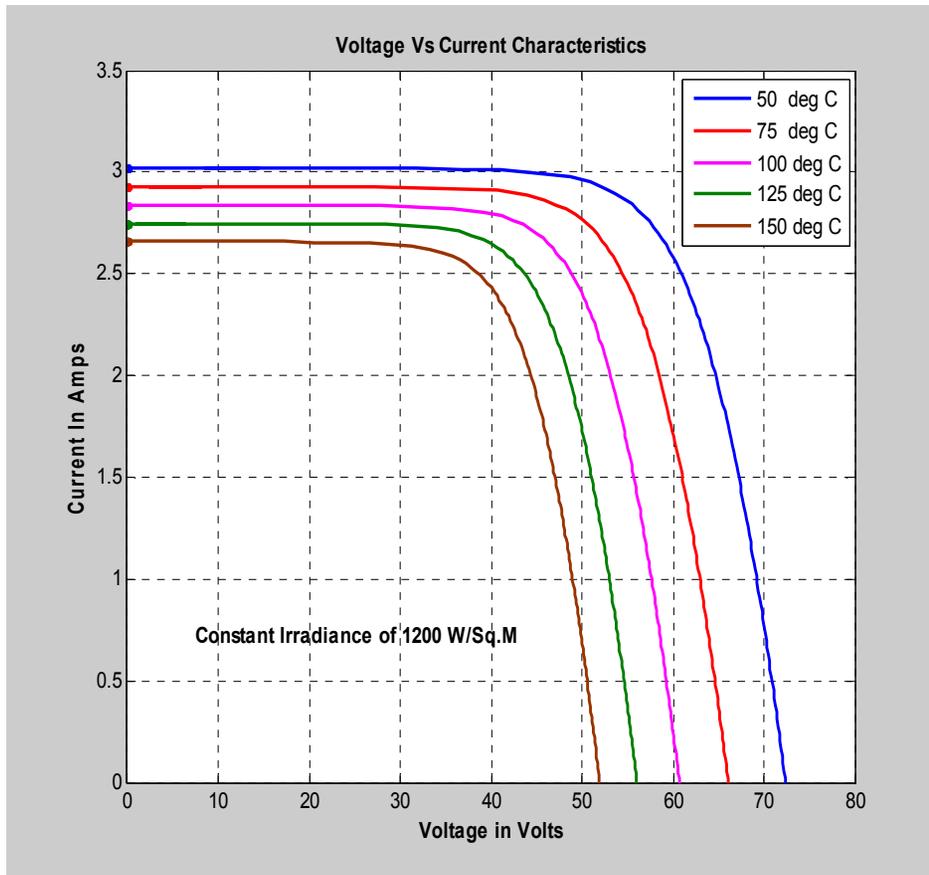
Everyone wants to go to heaven but nobody wants to die - Megger – Evershed - 1905





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# CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE



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

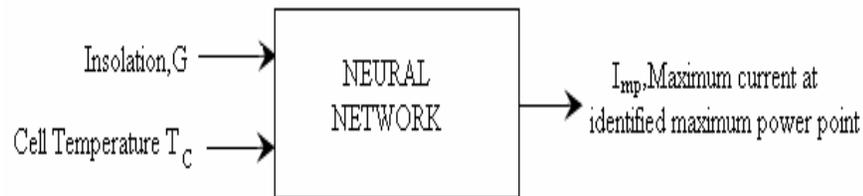
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# Maximum Power Point Tracking of PV cell Using Neural Networks

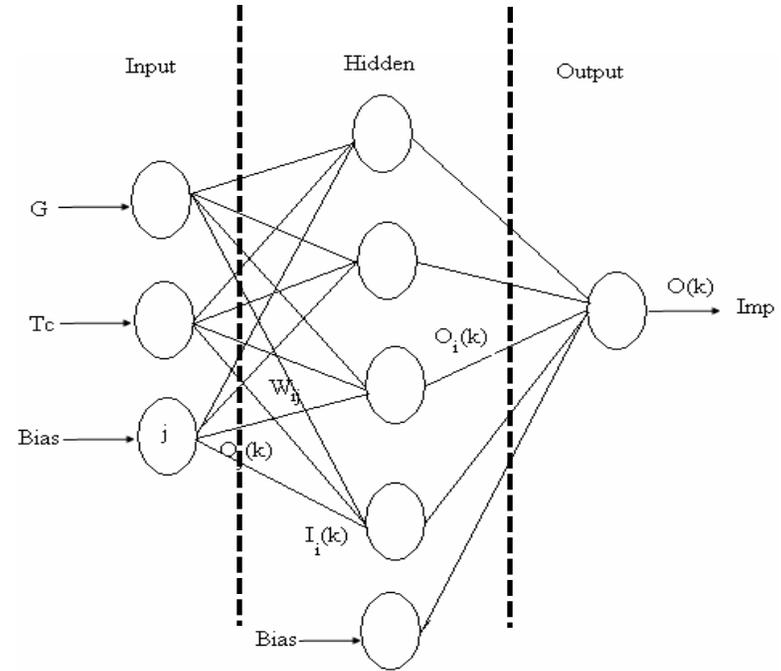


**Transfer Function in the Input Layer : Linear**

**Transfer Function in the Hidden Layer : Tan Sigmoid**

**Transfer Function in the output Layer : Linear**

**Training Algorithm : Back Propagation**



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

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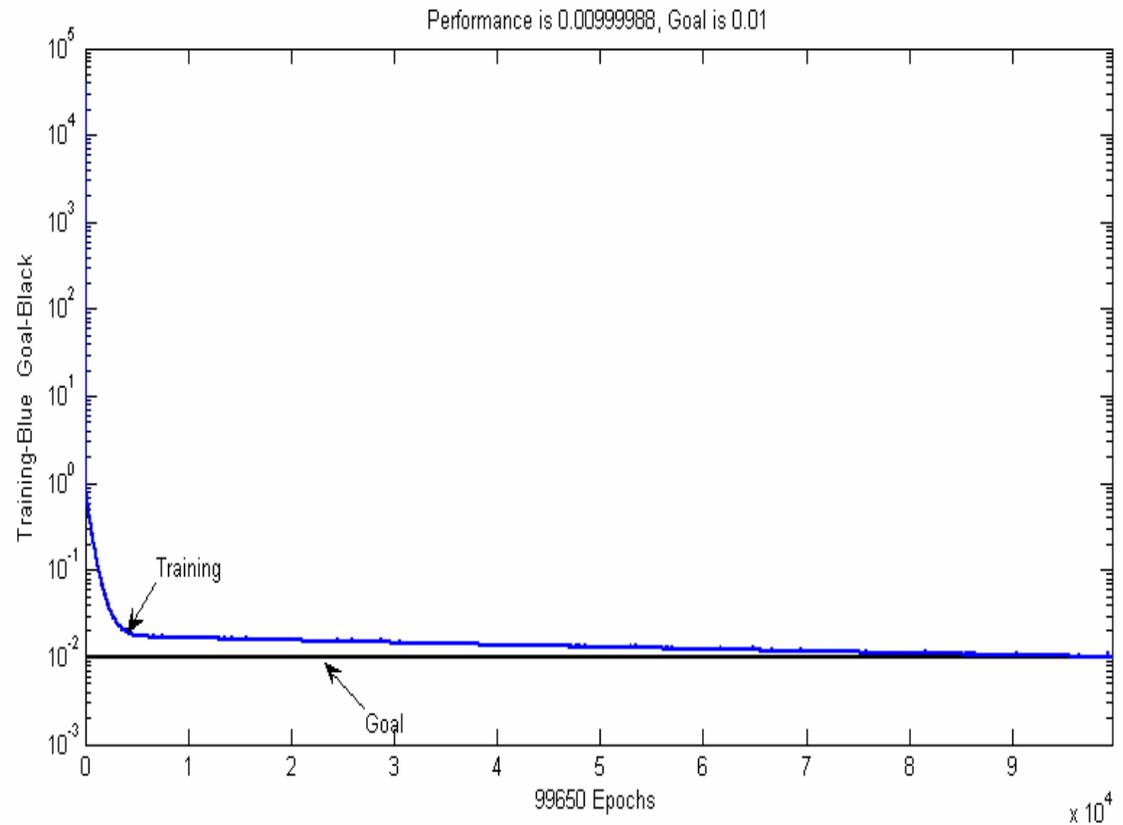


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# Maximum Power Point Tracking of PV cell Using Neural Networks

$T_c$	G	$I_{mp}$ (A)	$V_{mp}$ (V)	P(W)
25°C	200W/m <sup>2</sup>	.477	56.5	27.3
	400W/m <sup>2</sup>	.956	59	57.4
	600W/m <sup>2</sup>	1.437	62.2	88.4
	800W/m <sup>2</sup>	1.913	61	118.5
	1000W/m <sup>2</sup>	2.394	61.2	149.5
	1200W/m <sup>2</sup>	2.875	64.4	182
	1400W/m <sup>2</sup>	3.346	62.8	212
	1600W/m <sup>2</sup>	3.827	62	241
	1800W/m <sup>2</sup>	4.298	61.8	270



History repeats itself - Electrolytic capacitor- Julius Edgar-1928

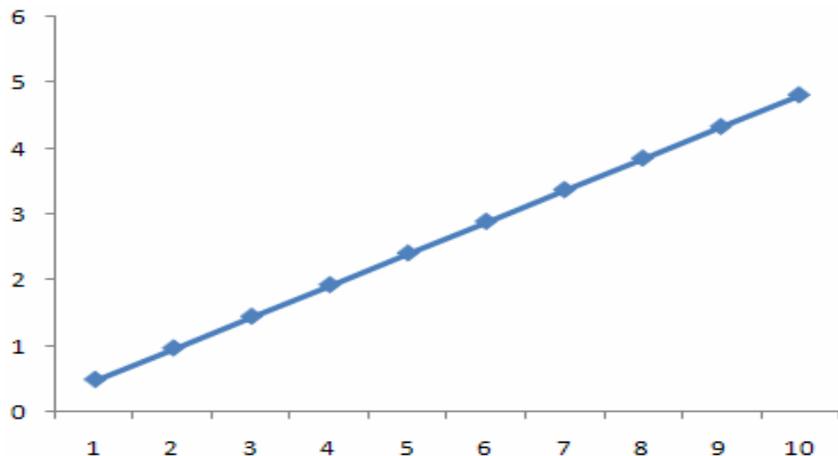




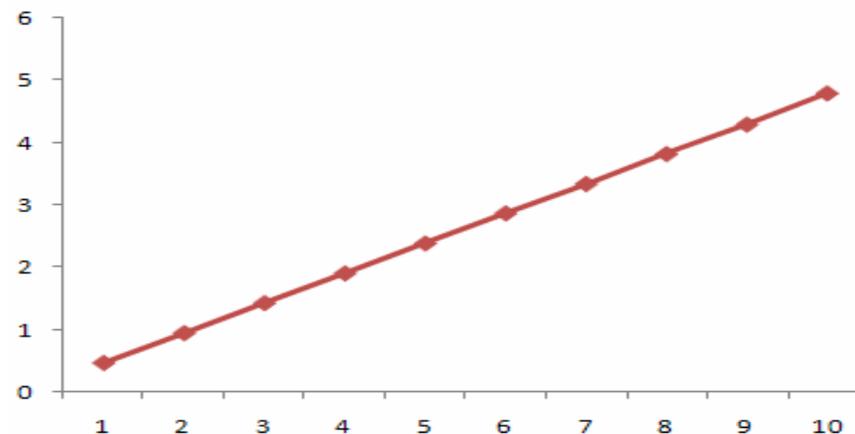
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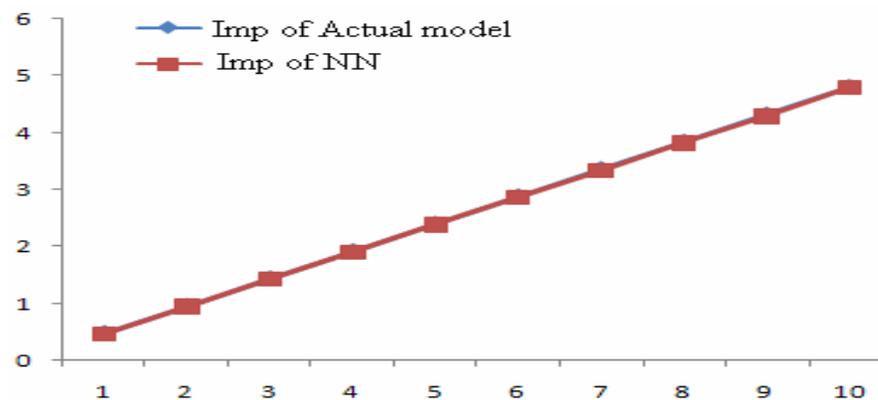
# Maximum Power Point Tracking of PV cell Using Neural Networks



calculated Imp of a PV model



Imp of Neural Network

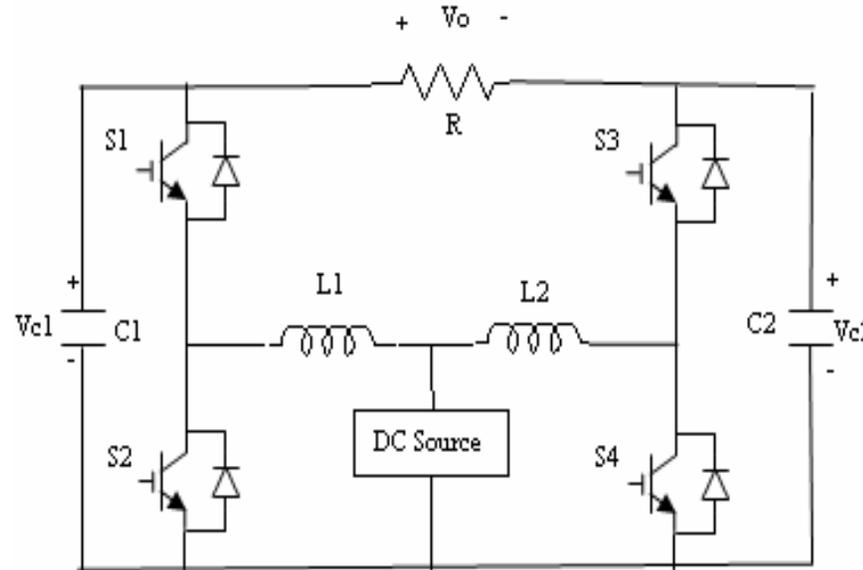


One can never consent to creep when one feels an impulse to soar – Electromagnetism –Maxwell-1865

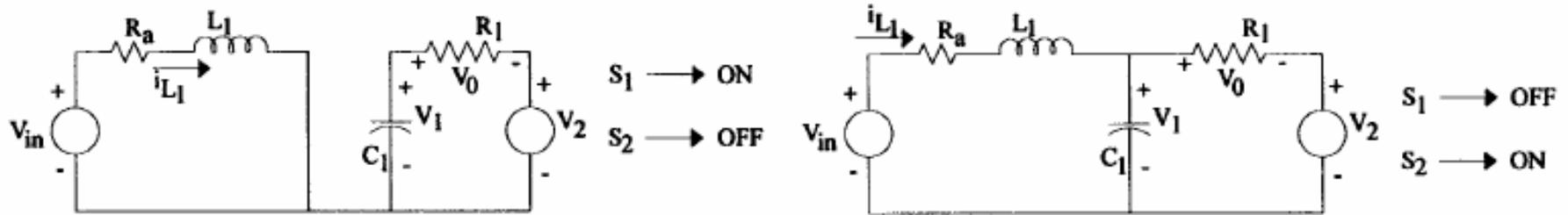




# Single Stage Boost Inverter



Circuit implementation



Modes of operation

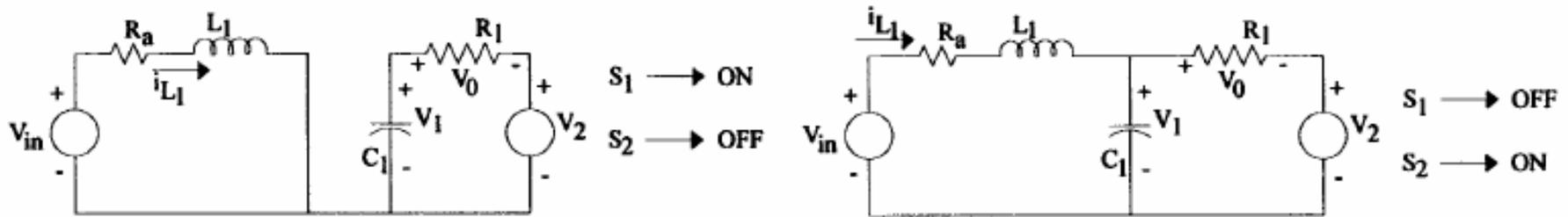


Don't sit like a rock work like a clock- Fluorescent Lamp –Edmund Germer - 1926





## 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

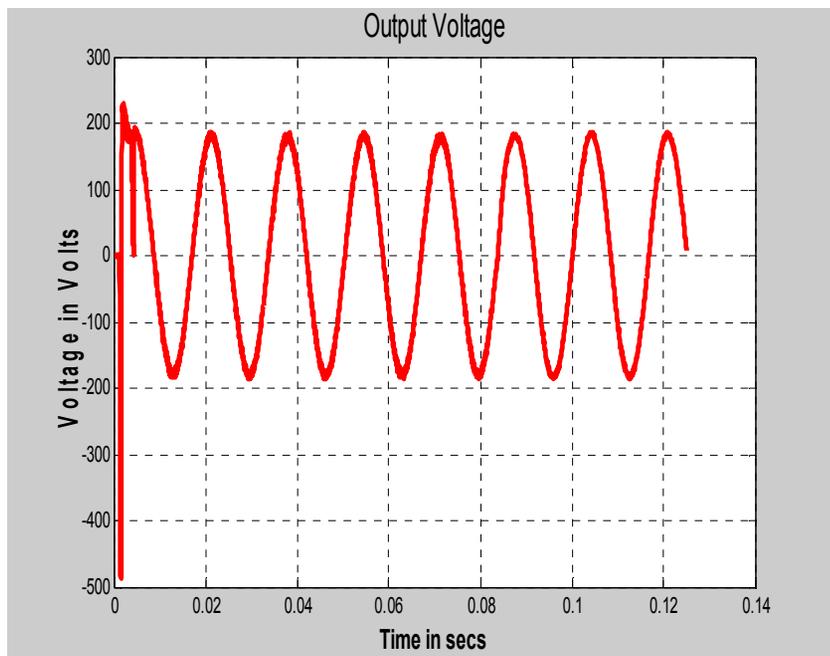
$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_1}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_2}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_1} & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & -\frac{1}{C_1 R_1} & 0 & 0 \\ 0 & 0 & -\frac{R_a}{L_2} & -\frac{1}{L_2} \\ 0 & 0 & \frac{1}{C_2} & -\frac{1}{C_2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

Where  $\gamma$  is the status of switches



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# Simulation Results With Constant Irradiance and Temperature



Signal to analyze

Display selected signal    Display FFT window

FFT window: 1 of 18 cycles of selected signal

Available signals

Structure : Vo

Input : Input 1

Signal number : 1

FFT window

Start time (s): 0.069

Number of cycles: 1

Fundamental frequency (Hz): 60

FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Harmonic order

Max Frequency (Hz): 1000

Display   Close

FFT analysis

Fundamental (60Hz) = 182 , THD= 5.32%



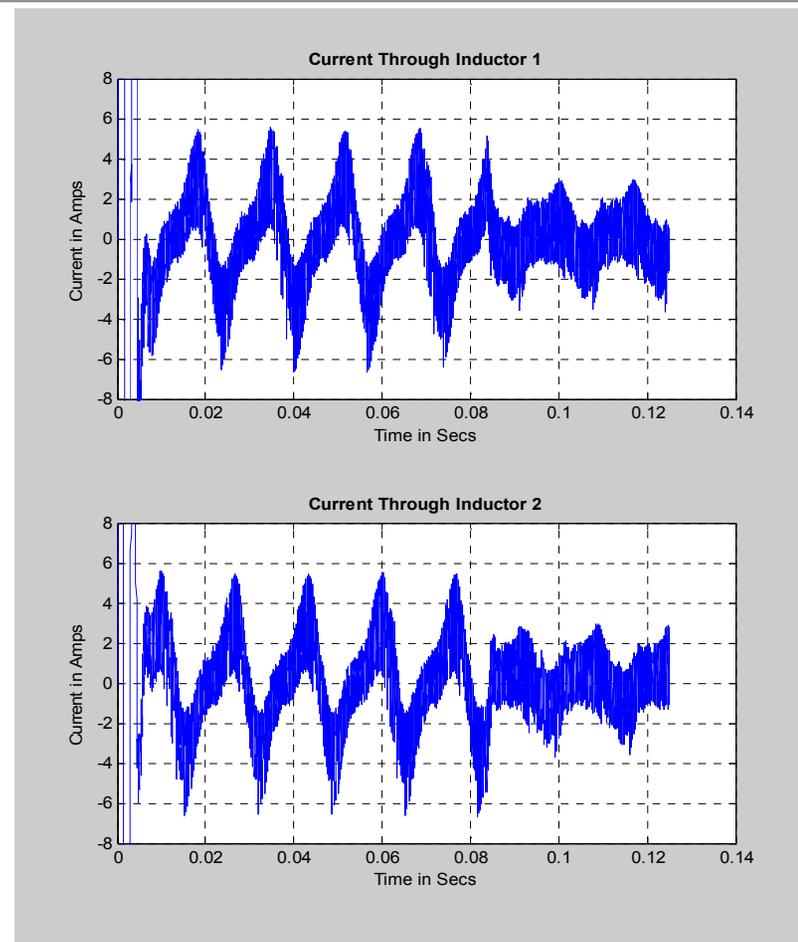
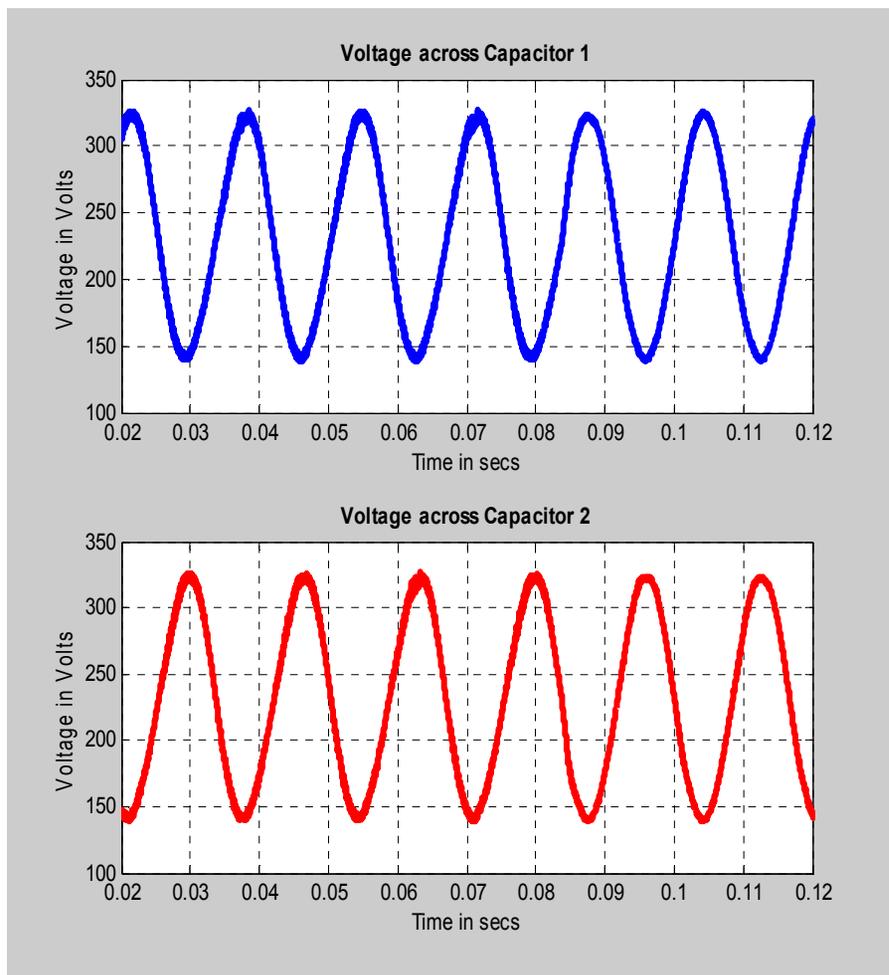
A man is as old as he feels - Hybrid Vehicle –Ferdinand Porsche-1899





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



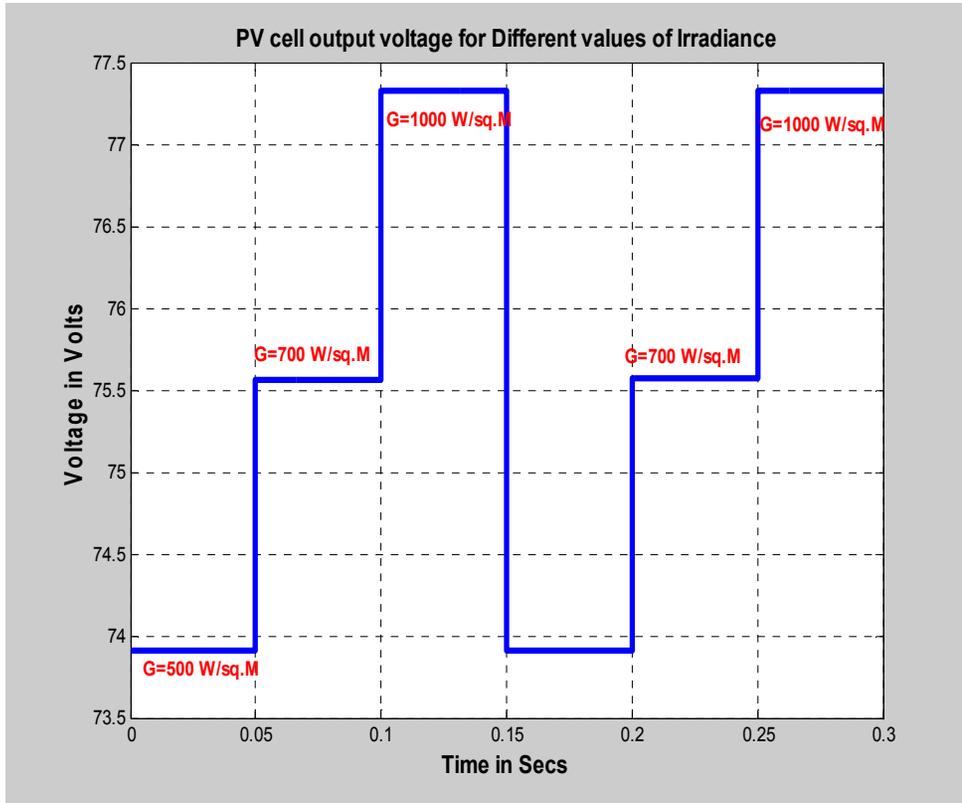
Be willing to accept temporary inconvenience for permanent improvement- Logic gates-Charles Babbage -1837



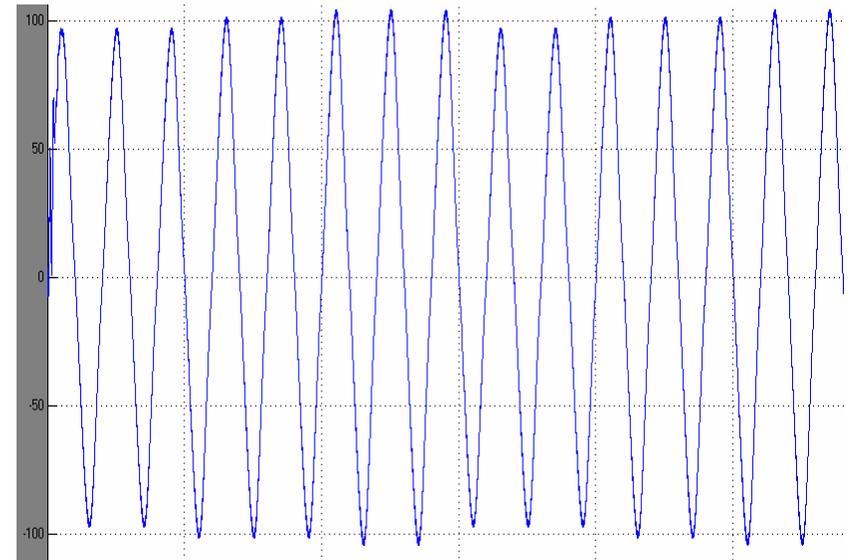


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# Simulation Results With Variable Irradiance and Constant Temperature



PV panel voltage



Time (sec)

Output voltage



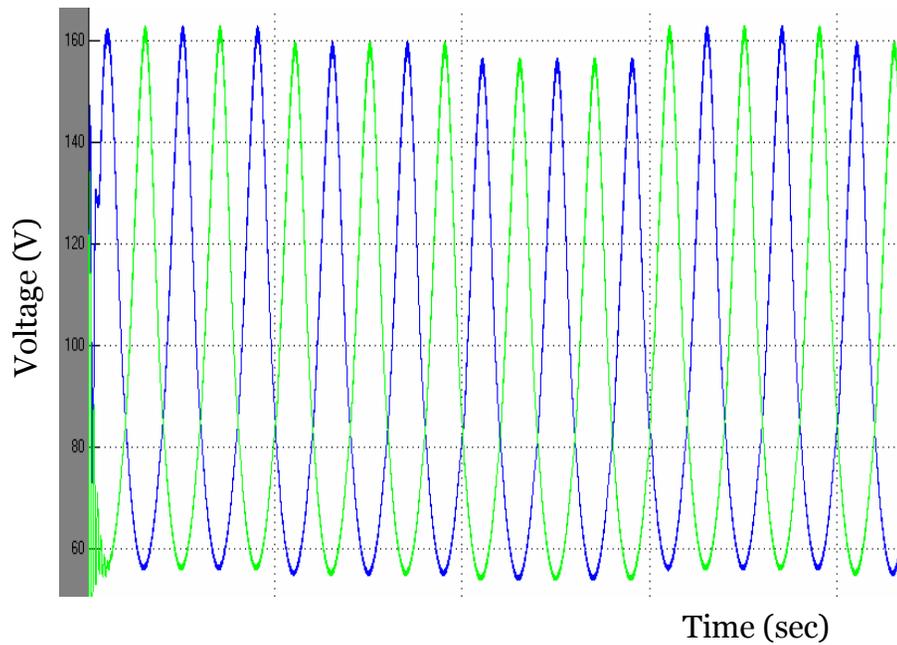
Believing in yourself is the first step to success- Neon Lamp –Georges Claude-1910



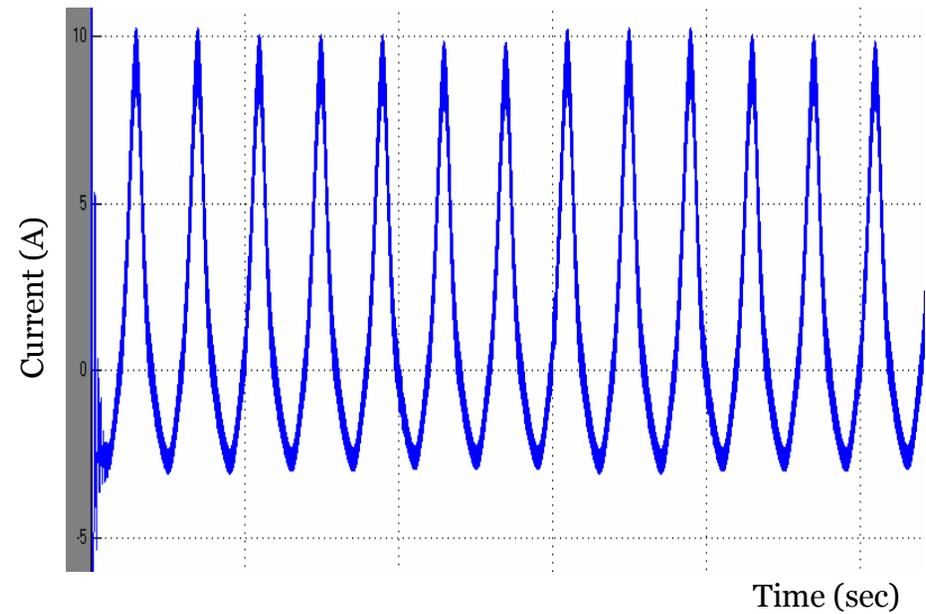


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# Simulation Results With Variable Irradiance and Constant Temperature Continues...



Capacitor voltage



Inductor current

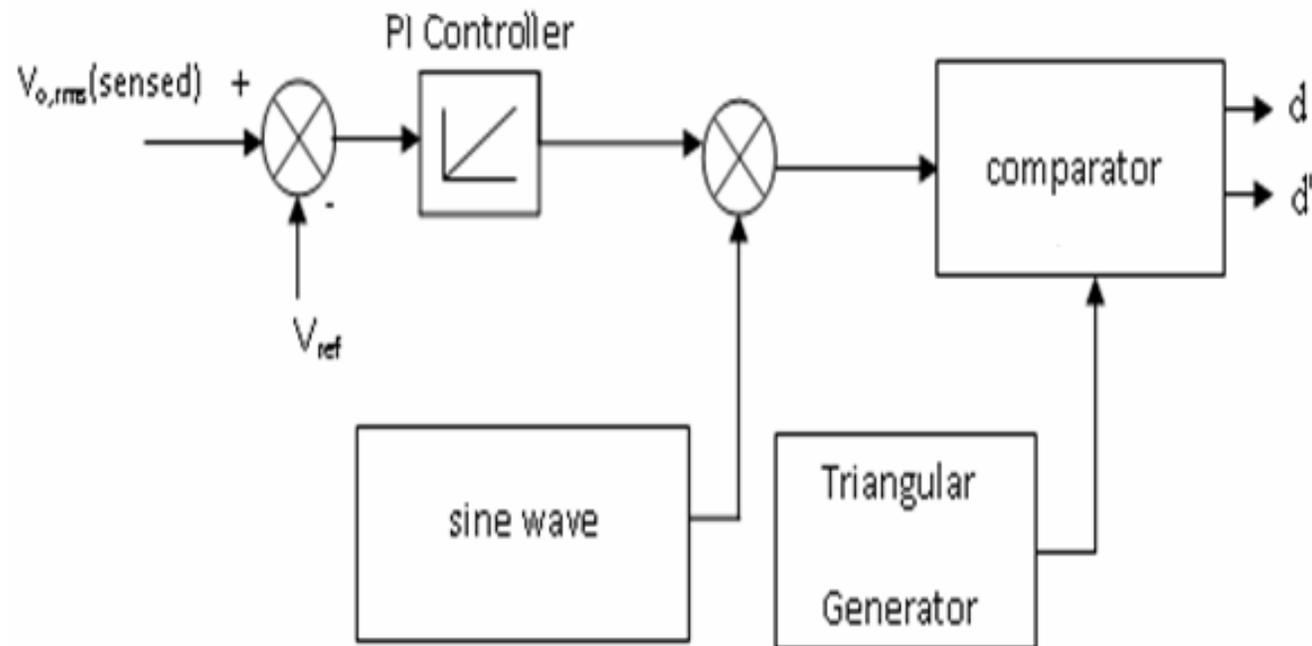


A hungry man is an angry man -Pager-AI Gross-1949





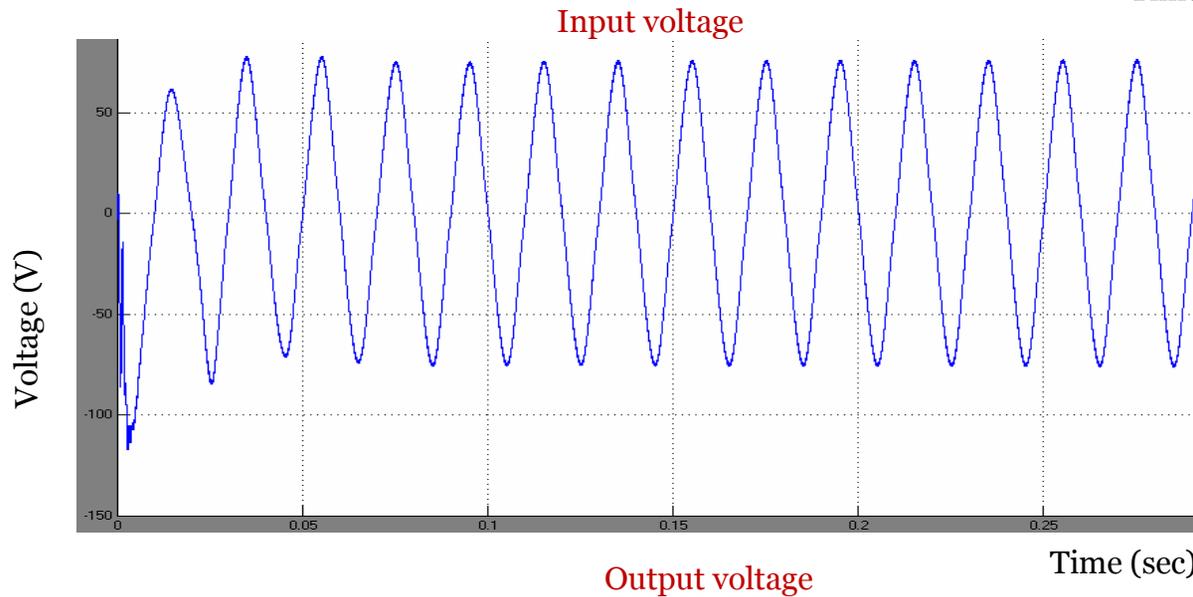
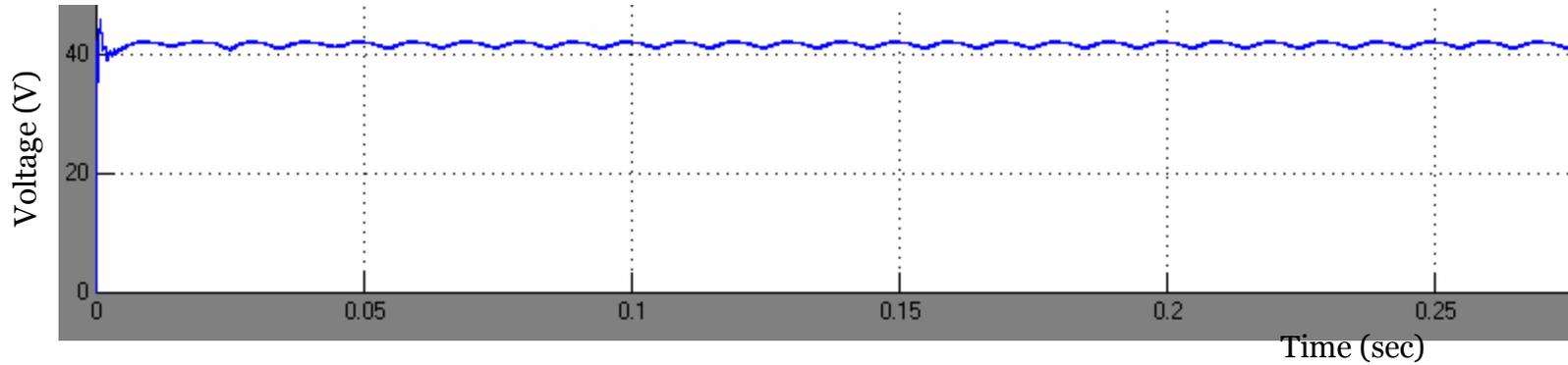
## PI Controller Fed Single Stage Boost Inverter





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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

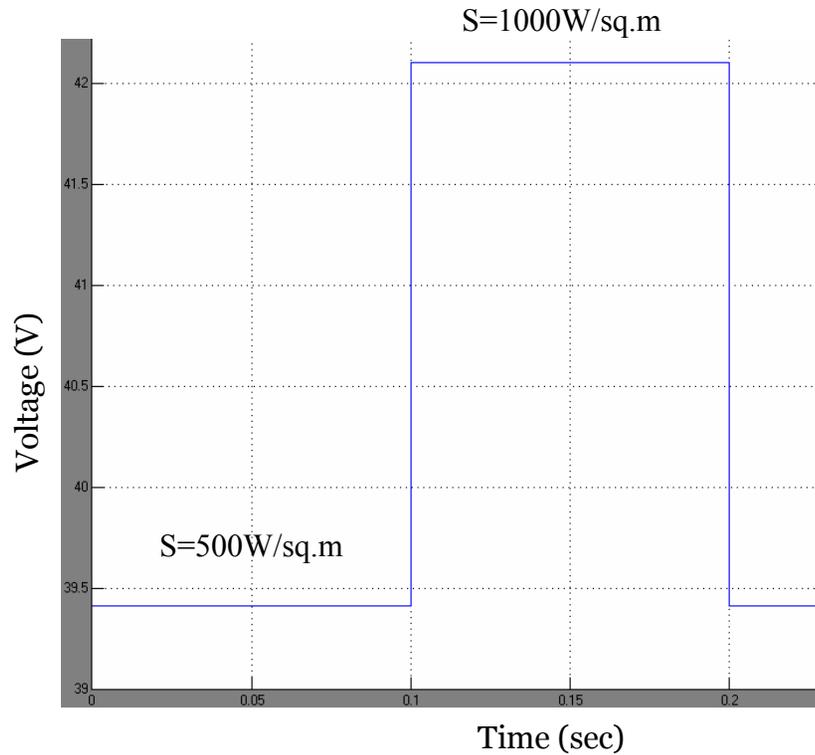
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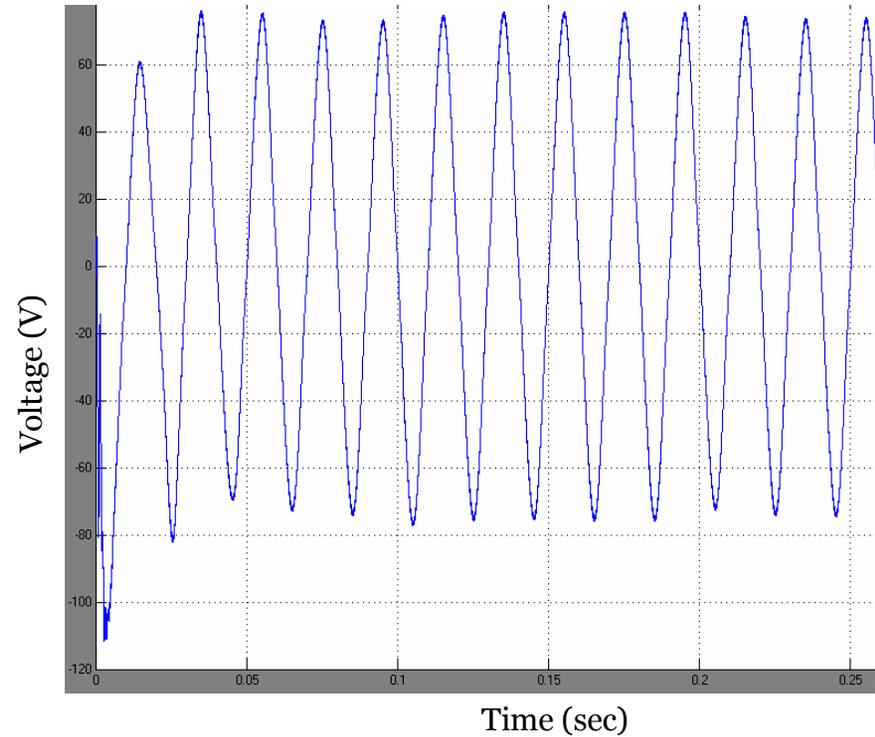


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# Simulation Results With Variable Irradiance and Constant Temperature



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  $\varepsilon_I$  (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,  $\varepsilon_1$  is the feedback current error,  $\varepsilon_2$  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.



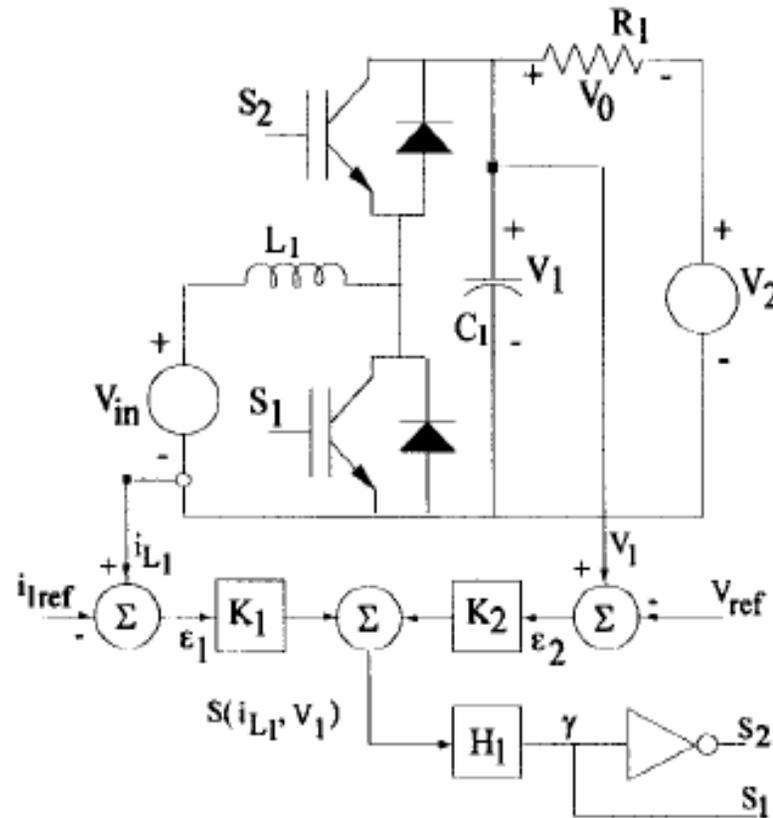
Never judge a book by its cover - Radio Guglielmo-1901

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## Sliding Mode Controller Continued....



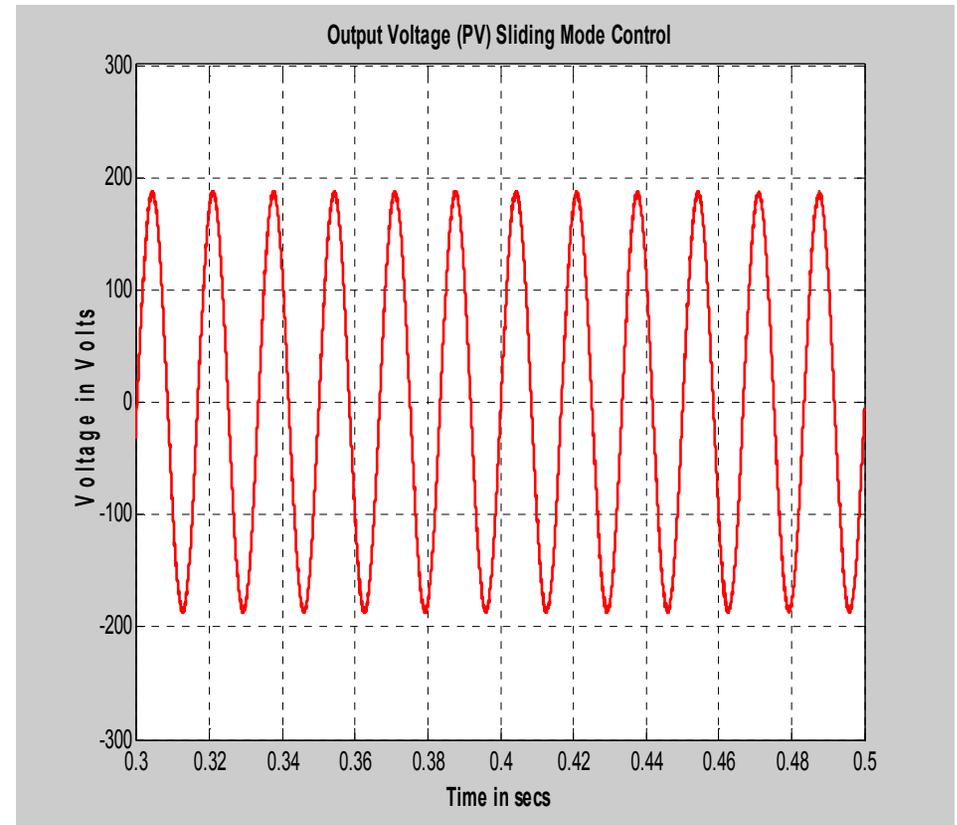
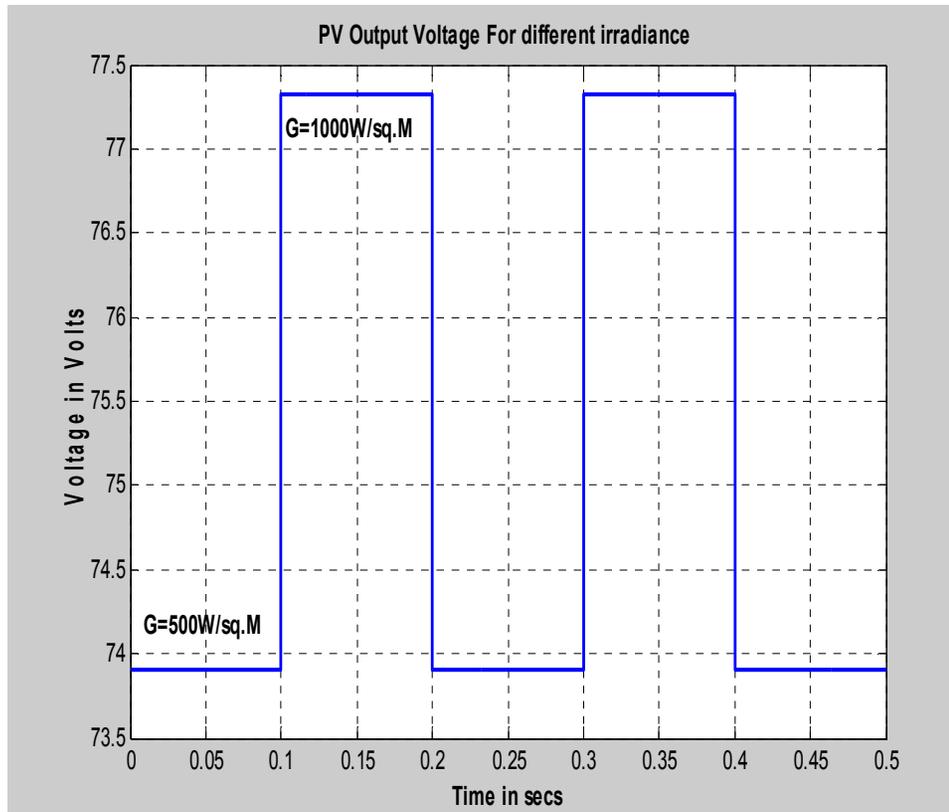
Sliding mode controller scheme



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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

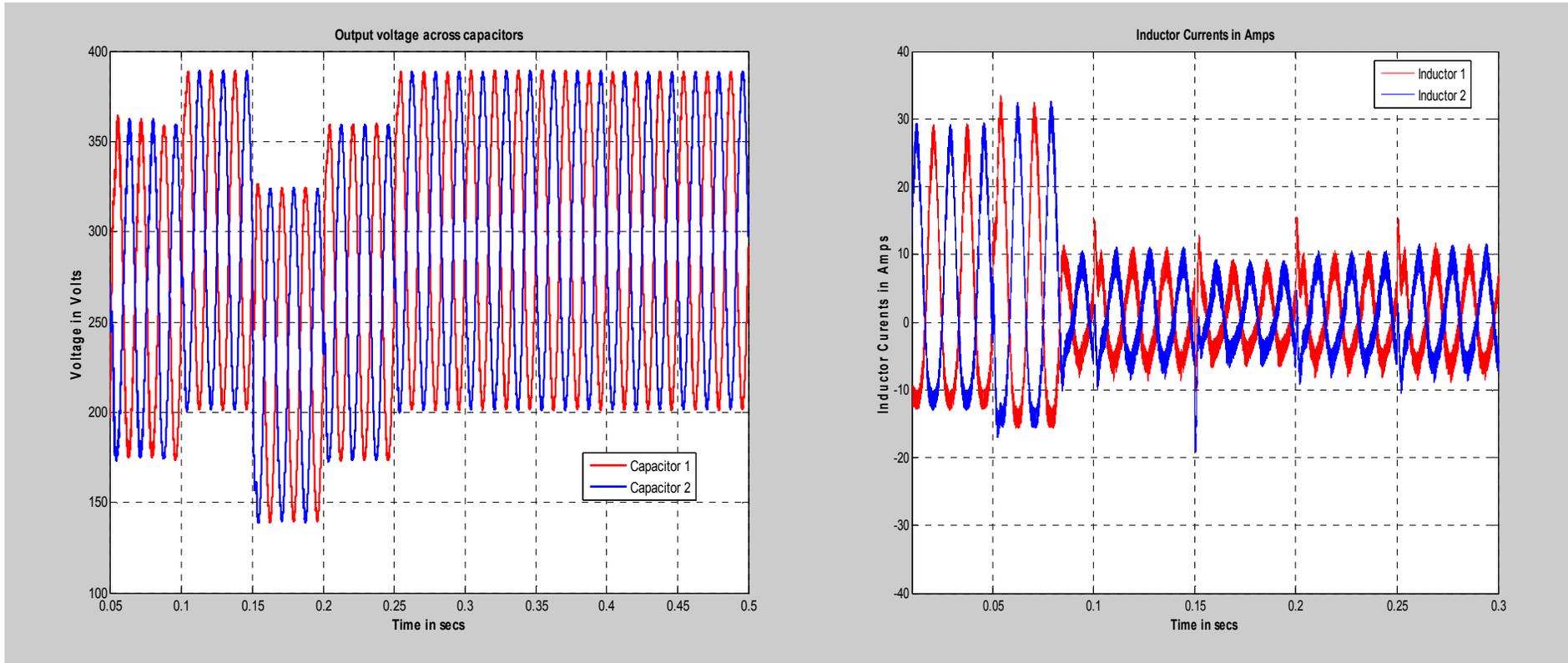
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# Simulation Results for Sliding Mode Controller With Variable Irradiance continues....



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

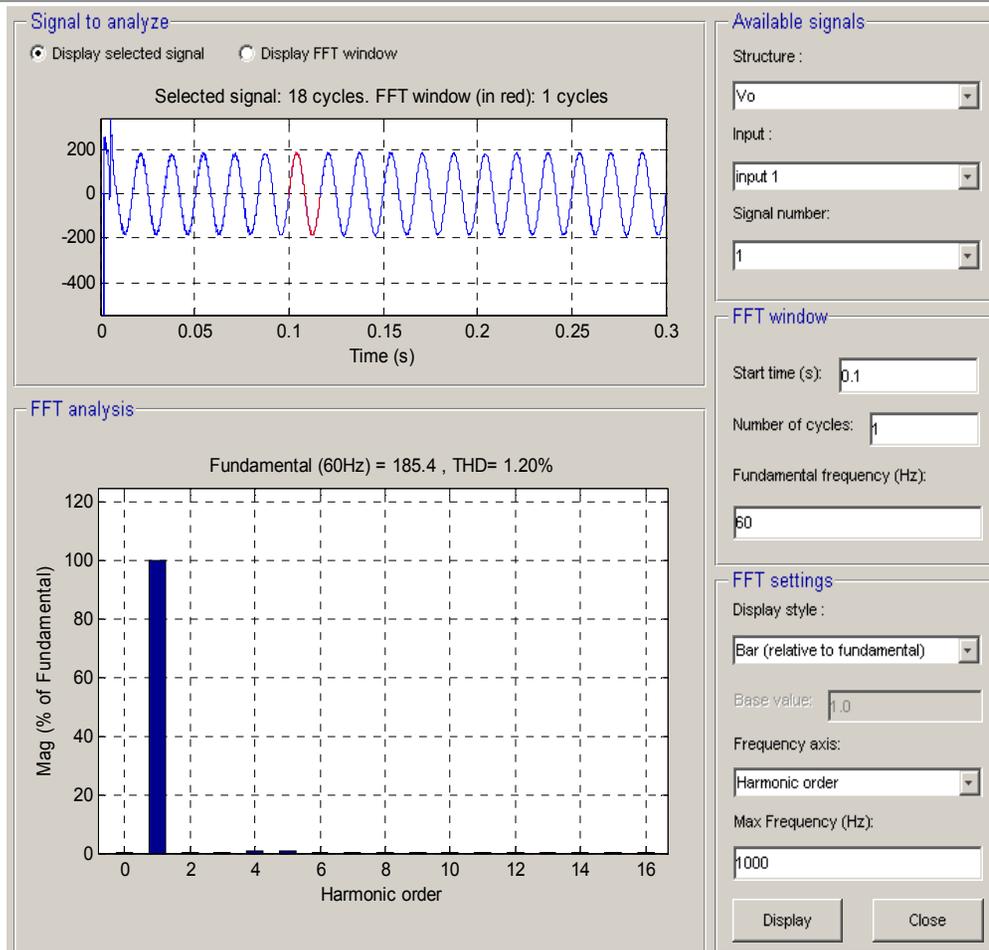
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# Simulation Results for Sliding Mode Controller With Variable Irradiance continues....



Practice makes perfect -Fax Machine-Alexander Bain-1842

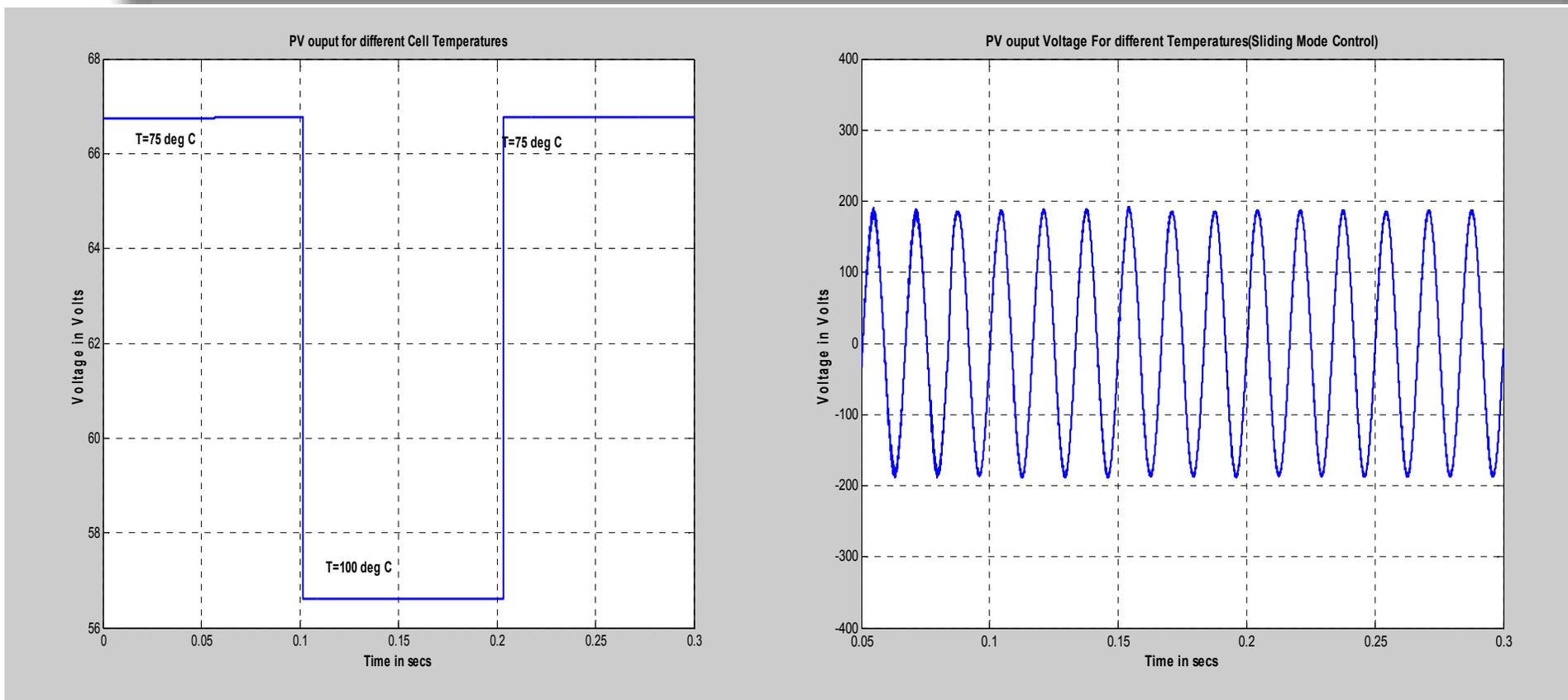
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# Simulation Results for Sliding Mode Controller With Variable Temperature continues....



Seeing is believing -Electro Magnet-William Sturgeon-1825

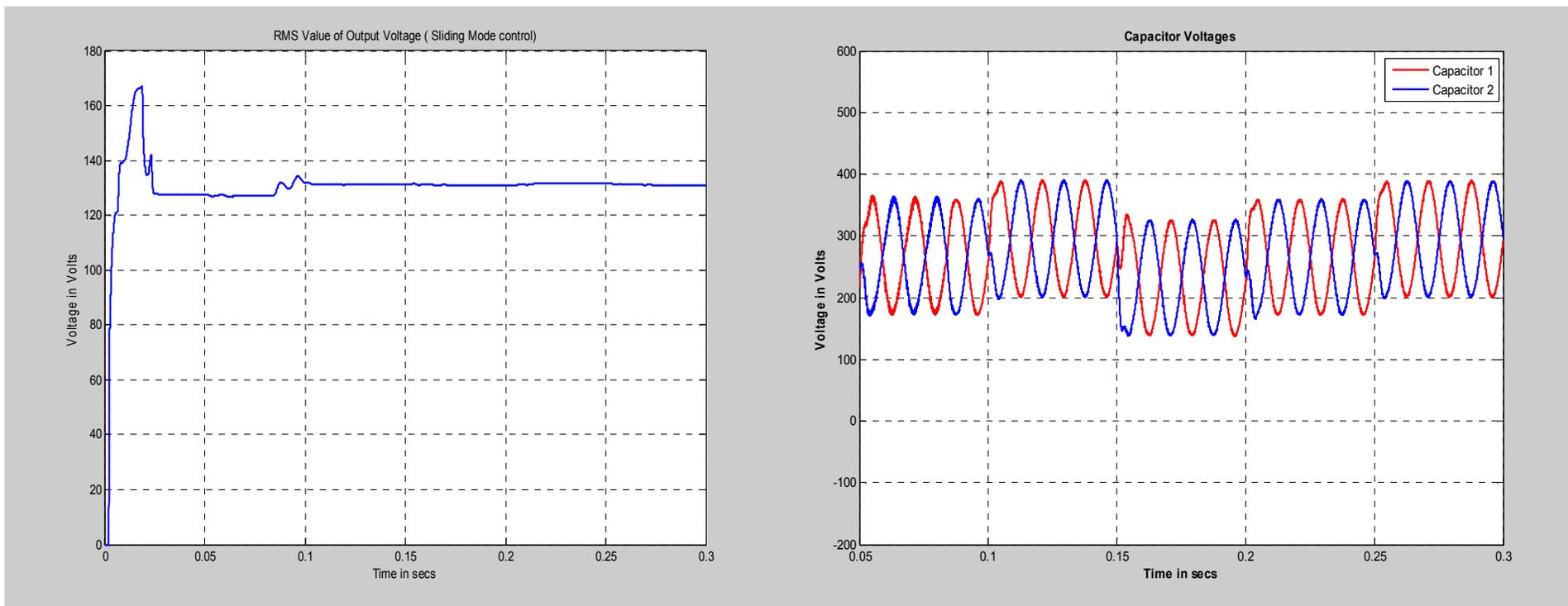
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Set a thief to catch a thief -Transistor-Brattain Walter-1947

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## Comparisons

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