



A New Single Phase PV fed Five Level Inverter Topology connected to the Grid



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Presentation By

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The Journey of Thousand Miles Begins with a single step





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Objectives of This Paper

To design a new Multilevel Inverter Topology for Photovoltaic Applications with minimum number of Switches

To Design a Control algorithm for New Topology with minimum carrier signals

To suggest a Novel Carrier for Multilevel inverters

To compare the novel carrier with Conventional Triangular Carrier (Comparison based on M_a and M_f with THD)



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

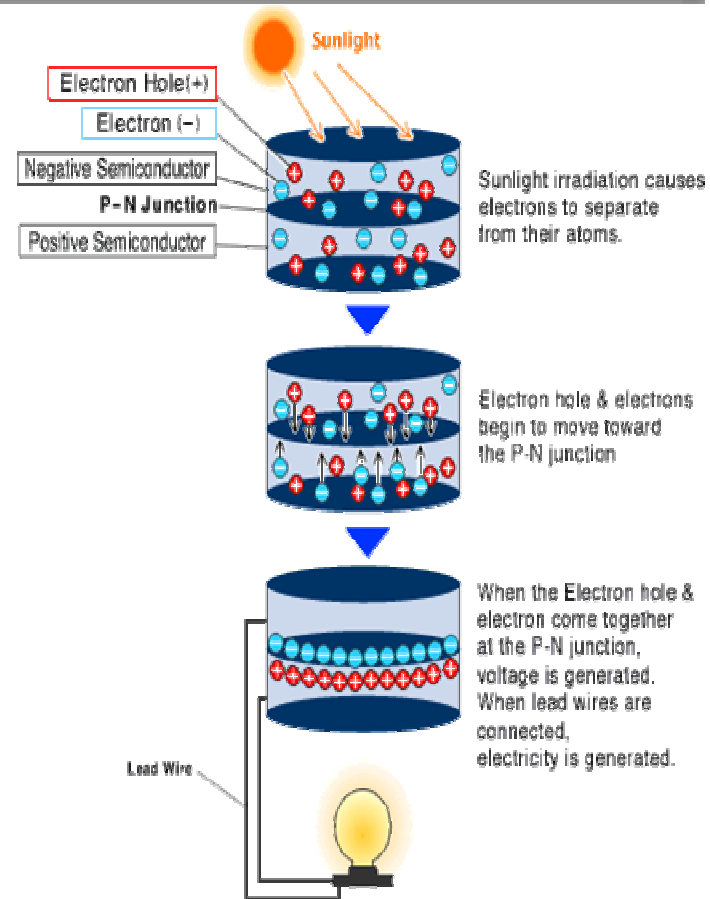
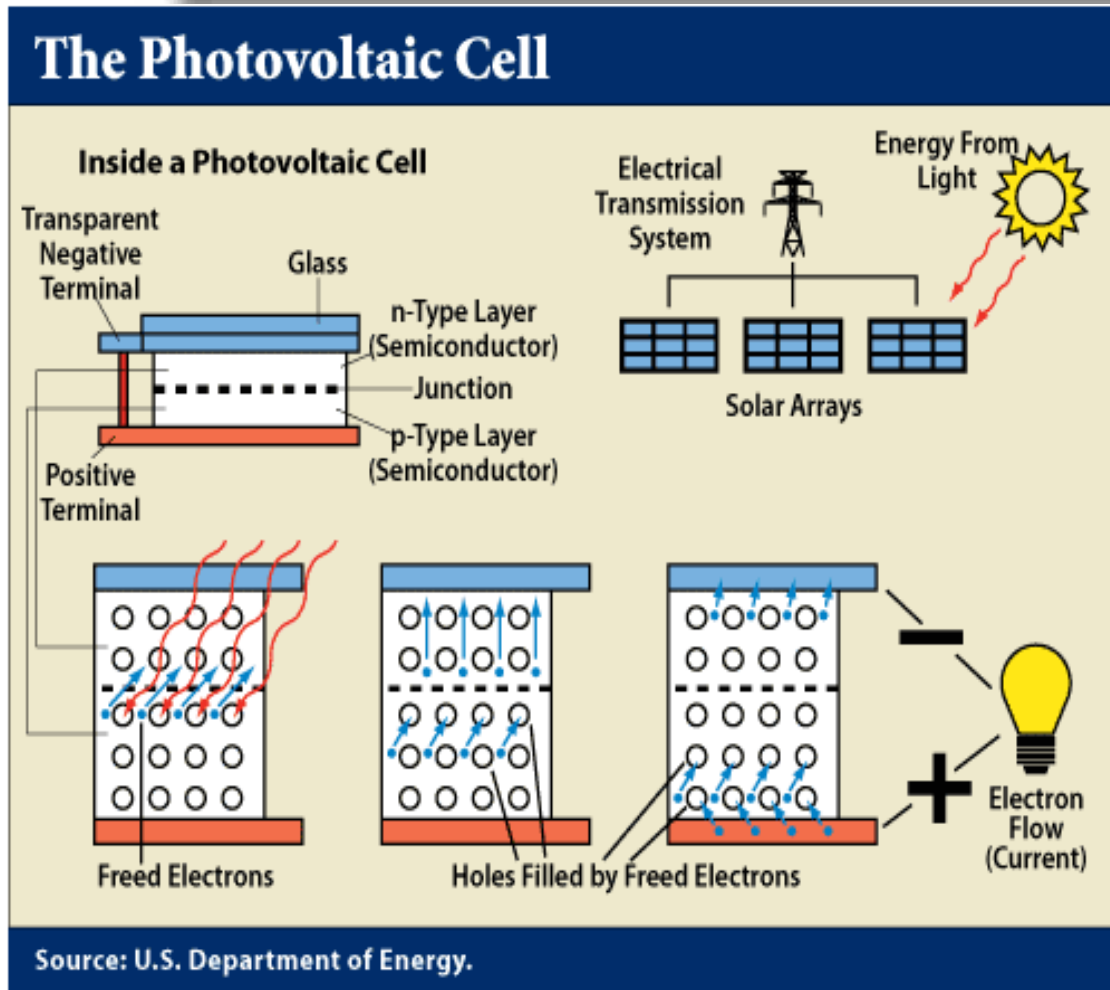




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PHOTOVOLTAIC CELL WORKING PRINCIPLE



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

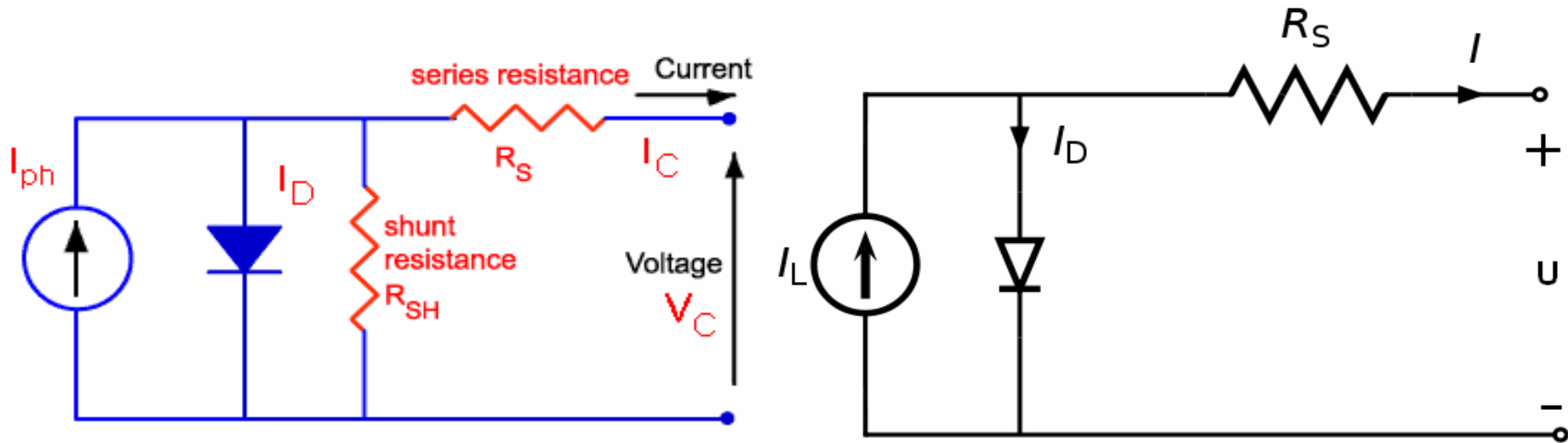




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PHOTOVOLTAIC CELL MODELING



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



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





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 = 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

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

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



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($1000 W/m^2$ is used in this study)

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

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



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





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

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



There is no age bar for learning- Electric Chair-Harold P.Brown-1888





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

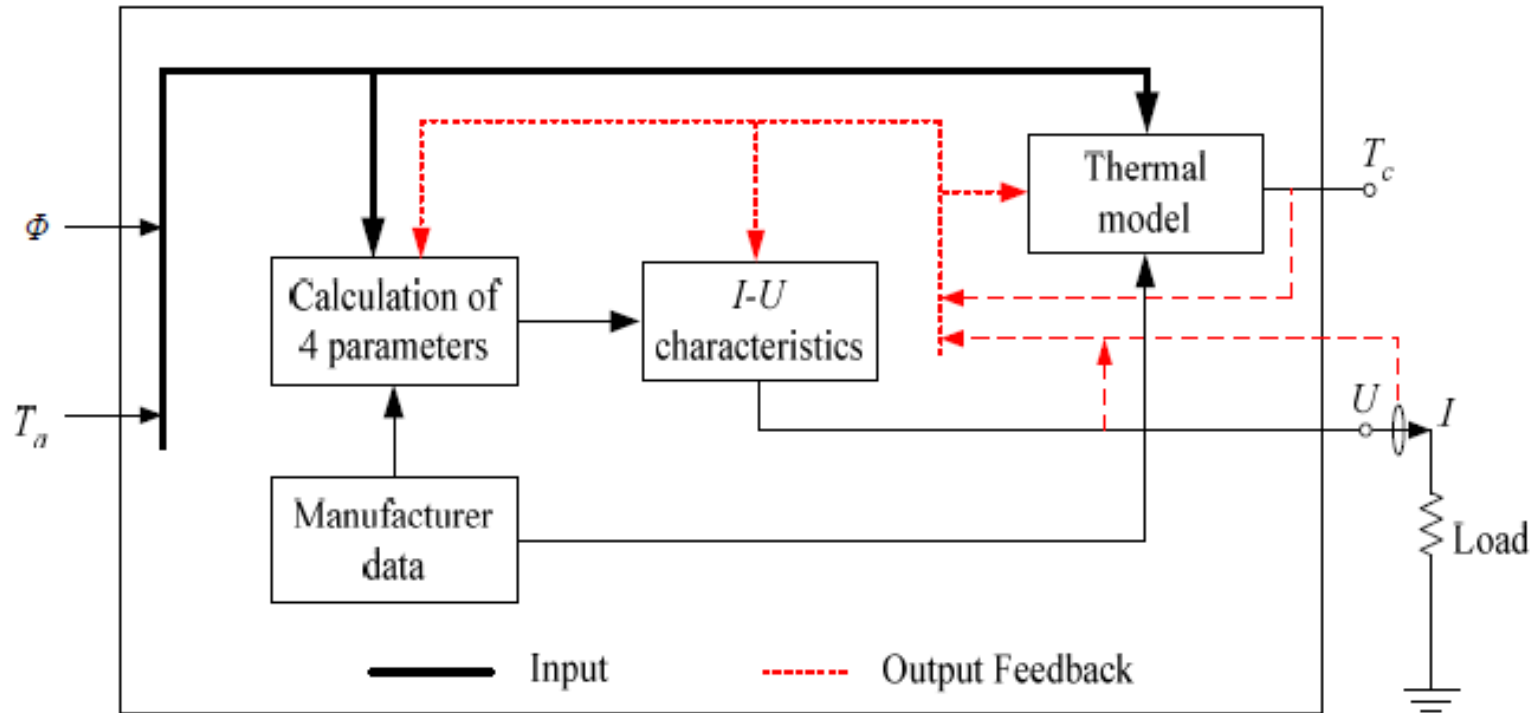


Present life is better than life coming in future – Robot- Jacques de Vaucanson-1738





PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK

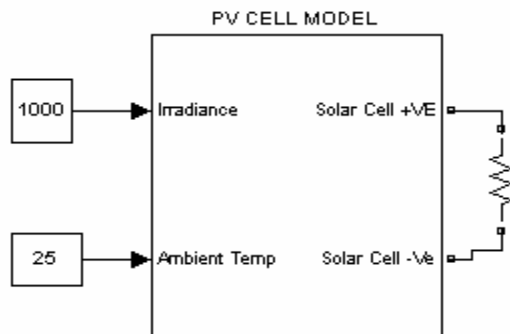




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PHOTOVOLTAIC CELL MODEL IN MATLAB/SIMULINK



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_{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



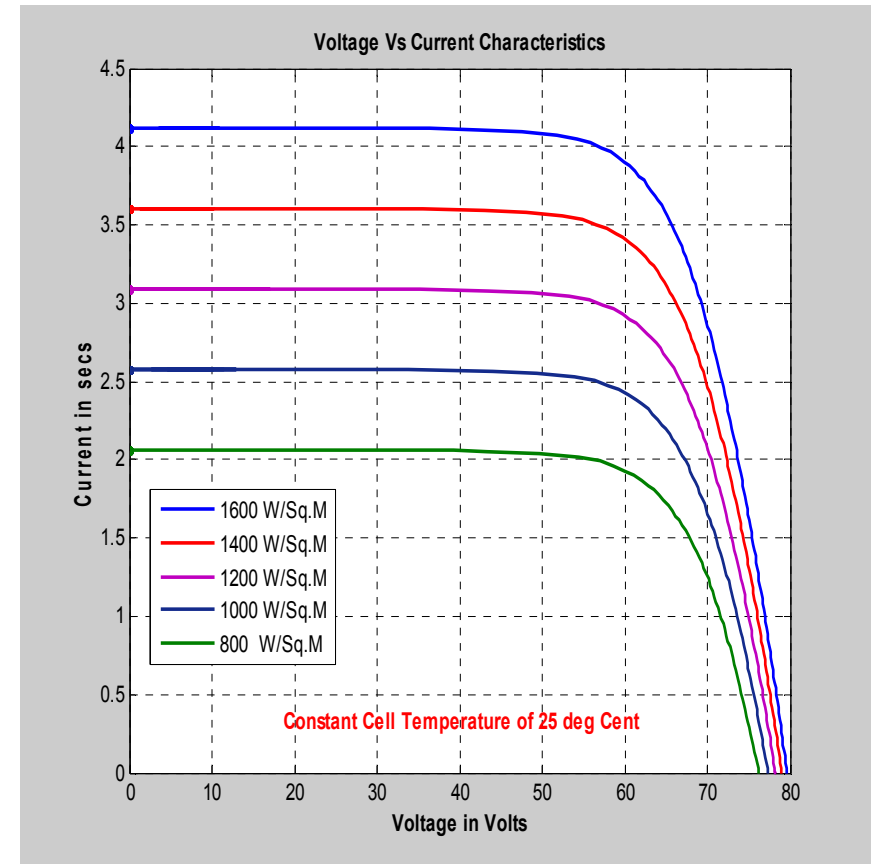
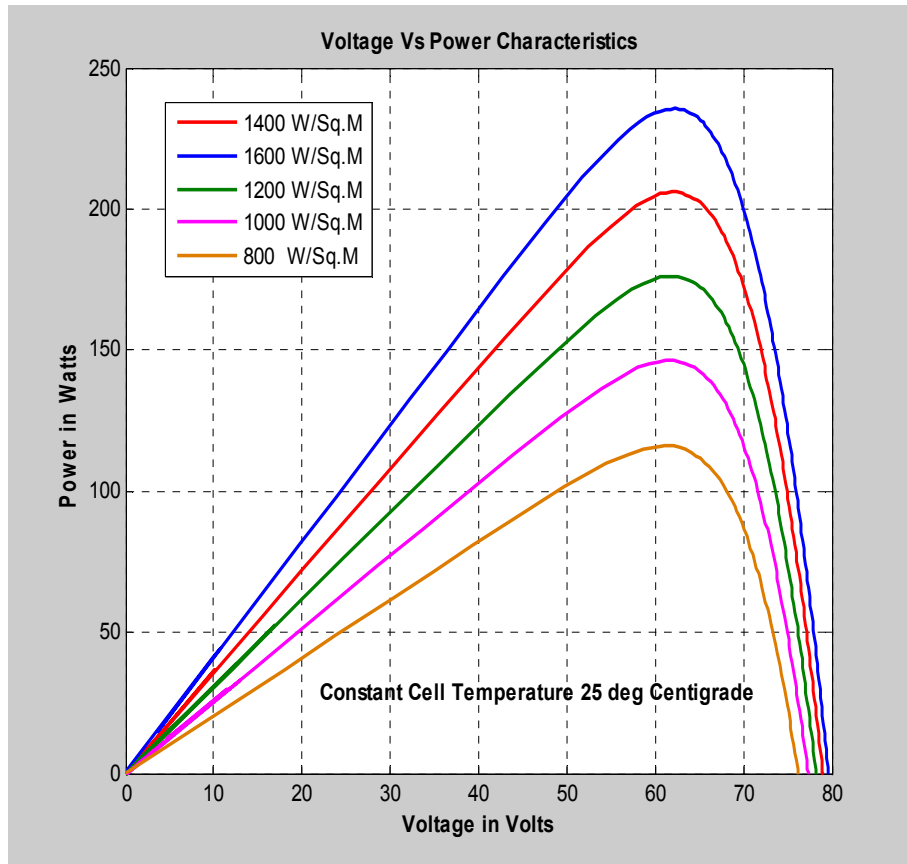
Better safe than sorry –Analog Storage Oscilloscope- Hughes-1957





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CHARACTERISTICS OF PV CELL AT CONSTANT CELL TEMPERATURE



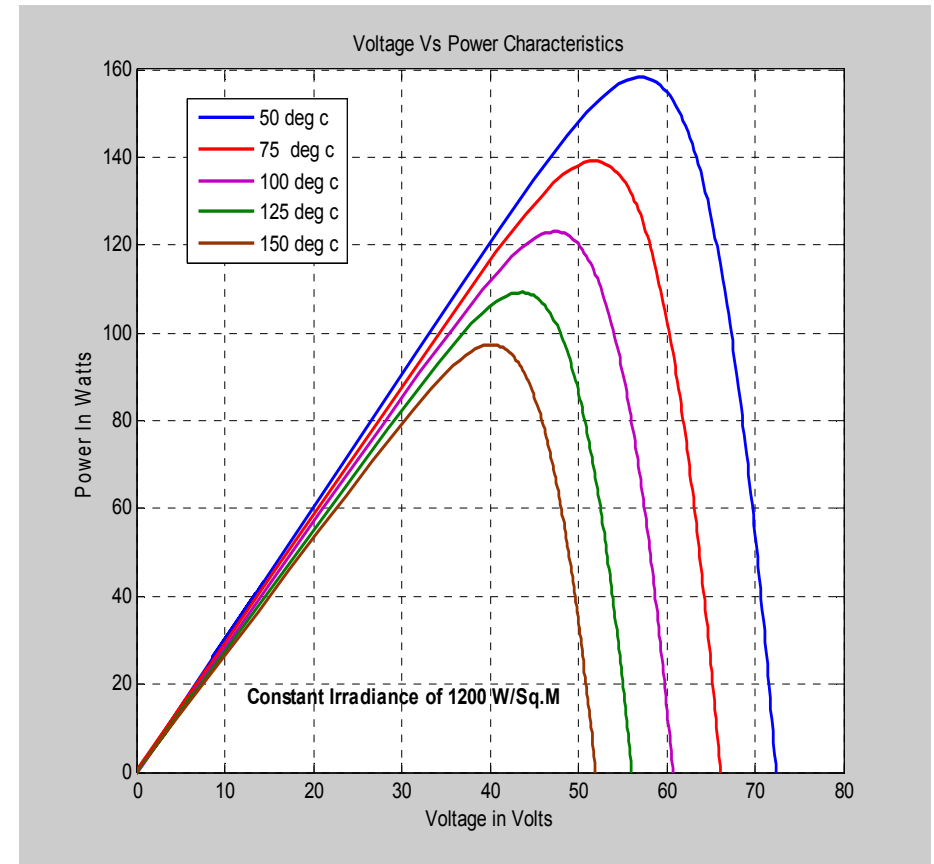
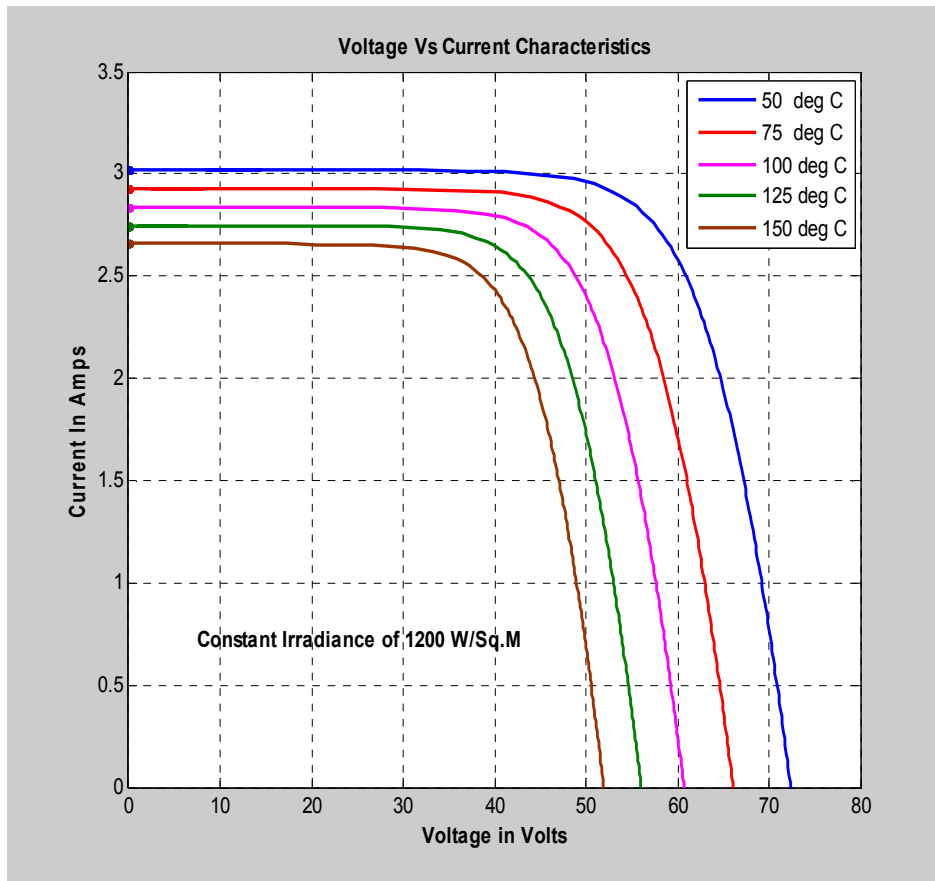
Distance lends enchantment to the view –CRO- Karl Ferdinand Braun- 1897





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CHARACTERISTICS OF PV CELL AT CONSTANT IRRADIANCE



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

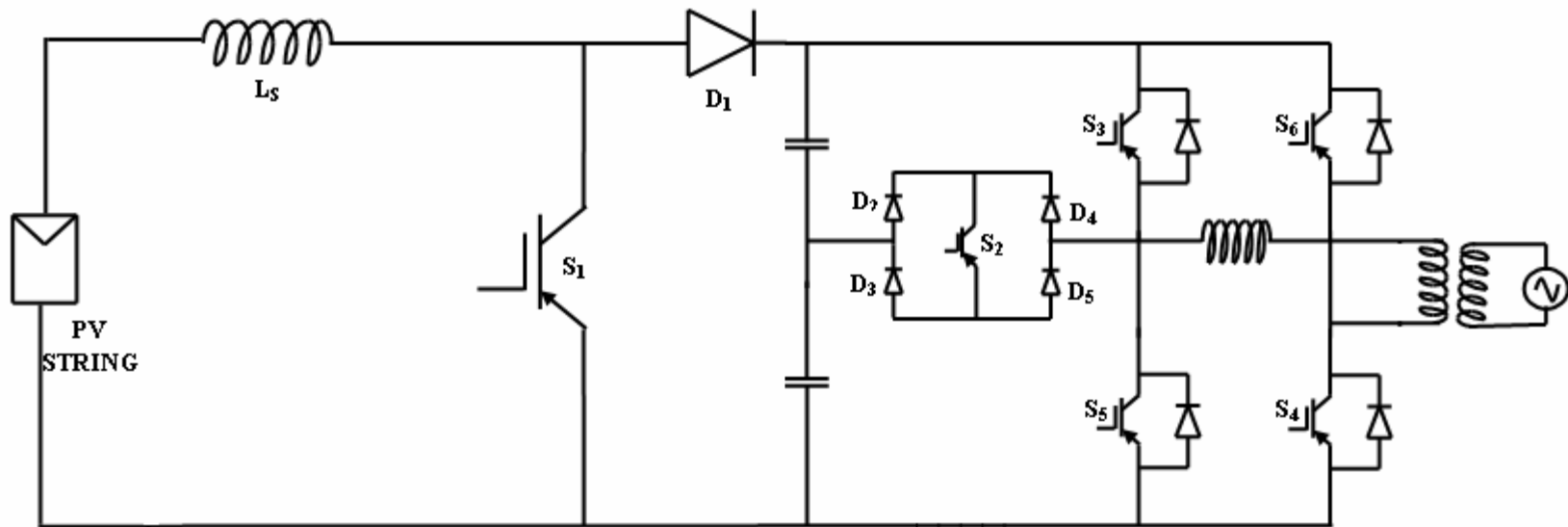




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New PV fed Multilevel Inverter



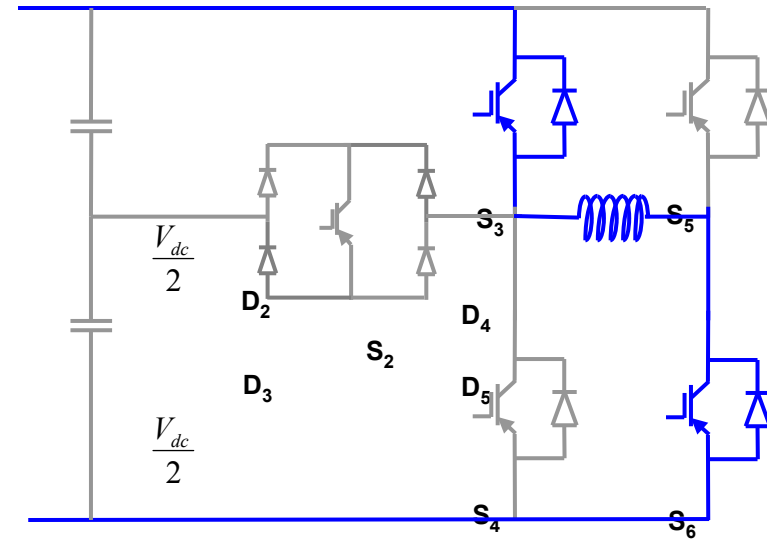
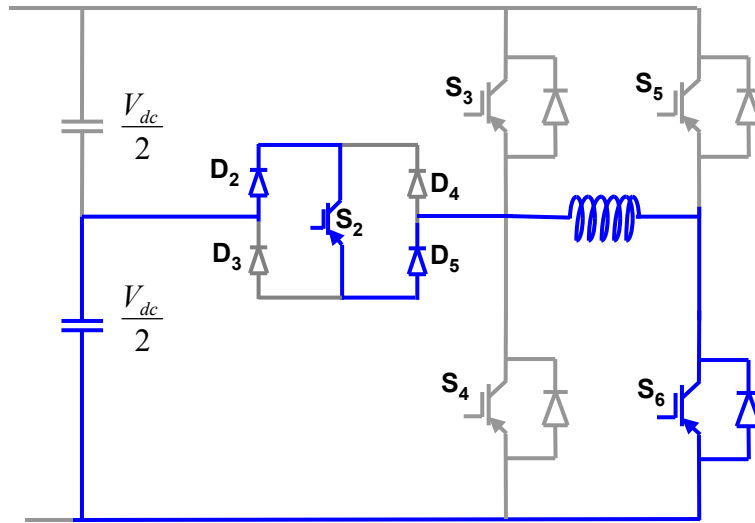
Everything comes to him who waits -Ammeter – Edward Weston -1886

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Operation of Five Level Inverter with Auxiliary Switch

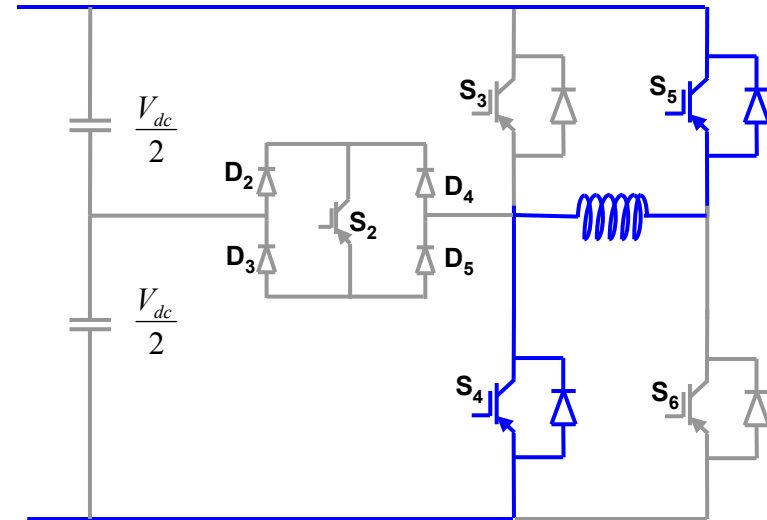
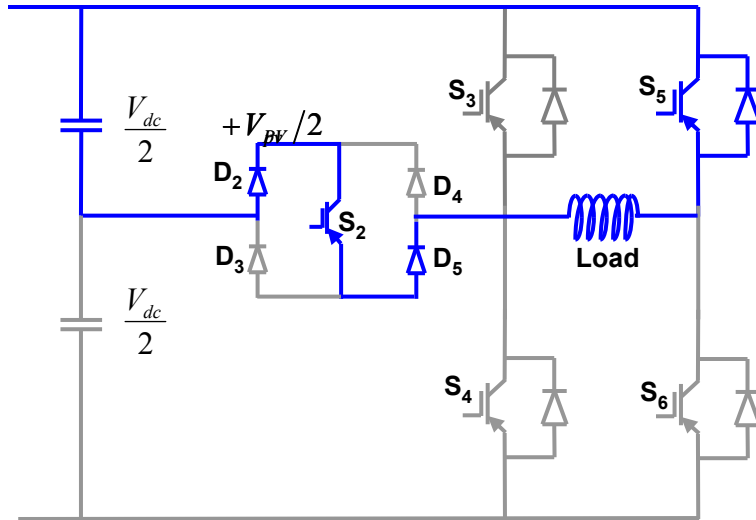




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Operation of Five Level Inverter with Auxiliary Switch



S_2	S_3	S_4	S_5	S_6	V_{inv}
ON	OFF	OFF	OFF	ON	$+V_{pv}/2$
OFF	ON	OFF	OFF	ON	$+V_{pv}$
OFF	OFF or (ON)	OFF or (ON)	ON or (OFF)	ON or (OFF)	0
ON	OFF	OFF	ON	OFF	$-V_{pv}/2$
OFF	OFF	ON	ON	OFF	$-V_{pv}$

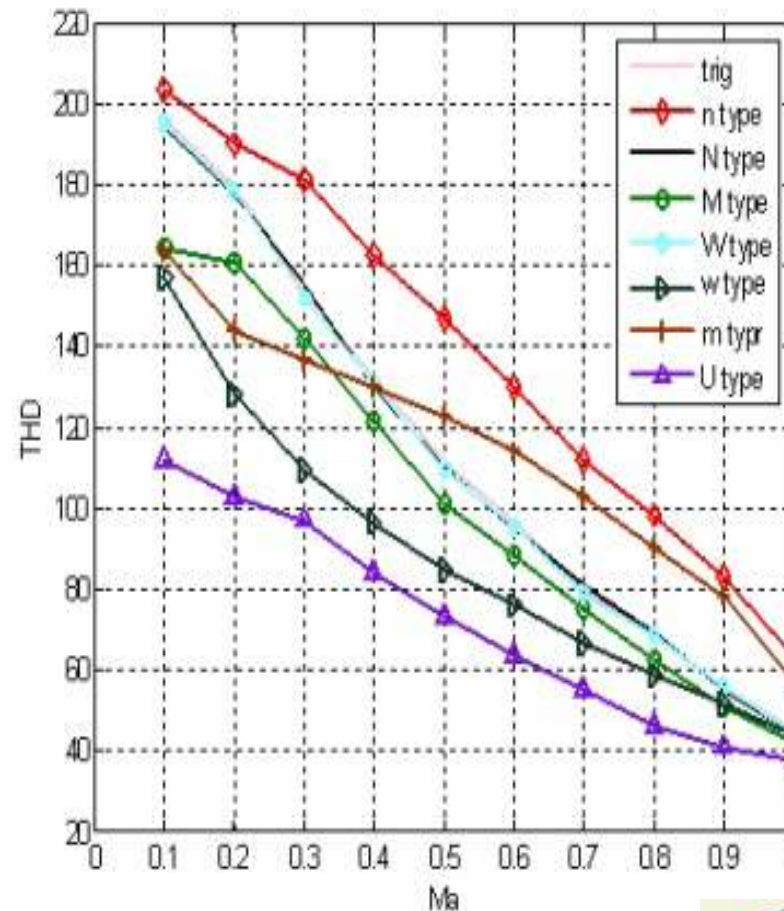
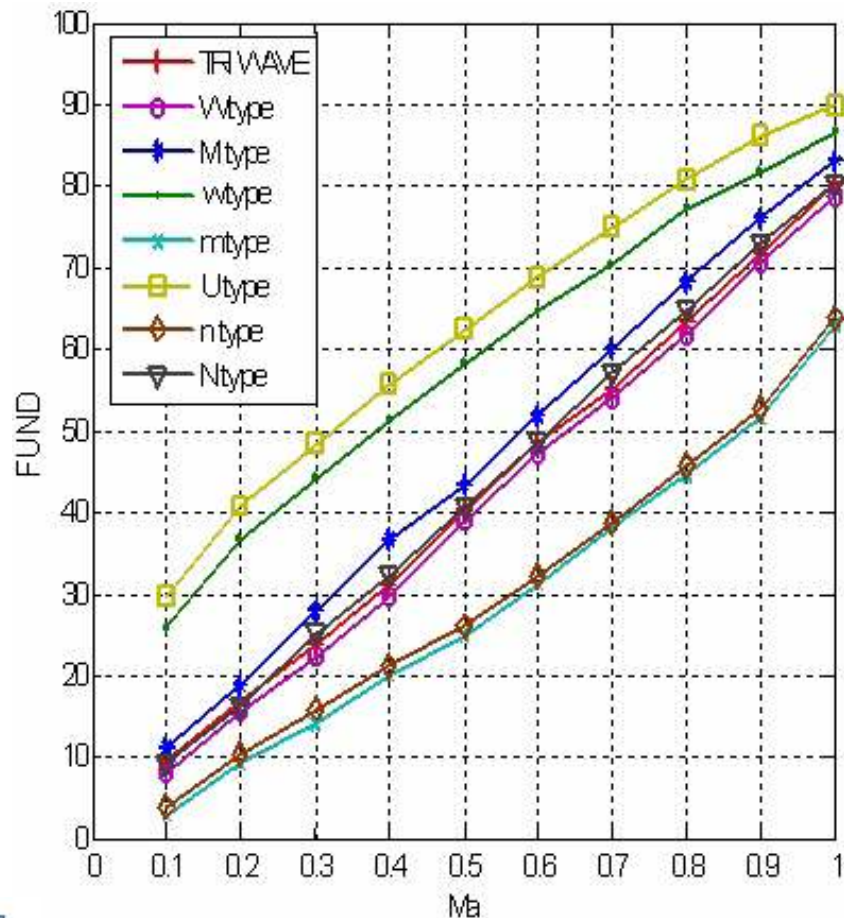


History repeats itself - Electrolytic capacitor- Julius Edgar-1928





Comparison of Different Carrier Waves



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

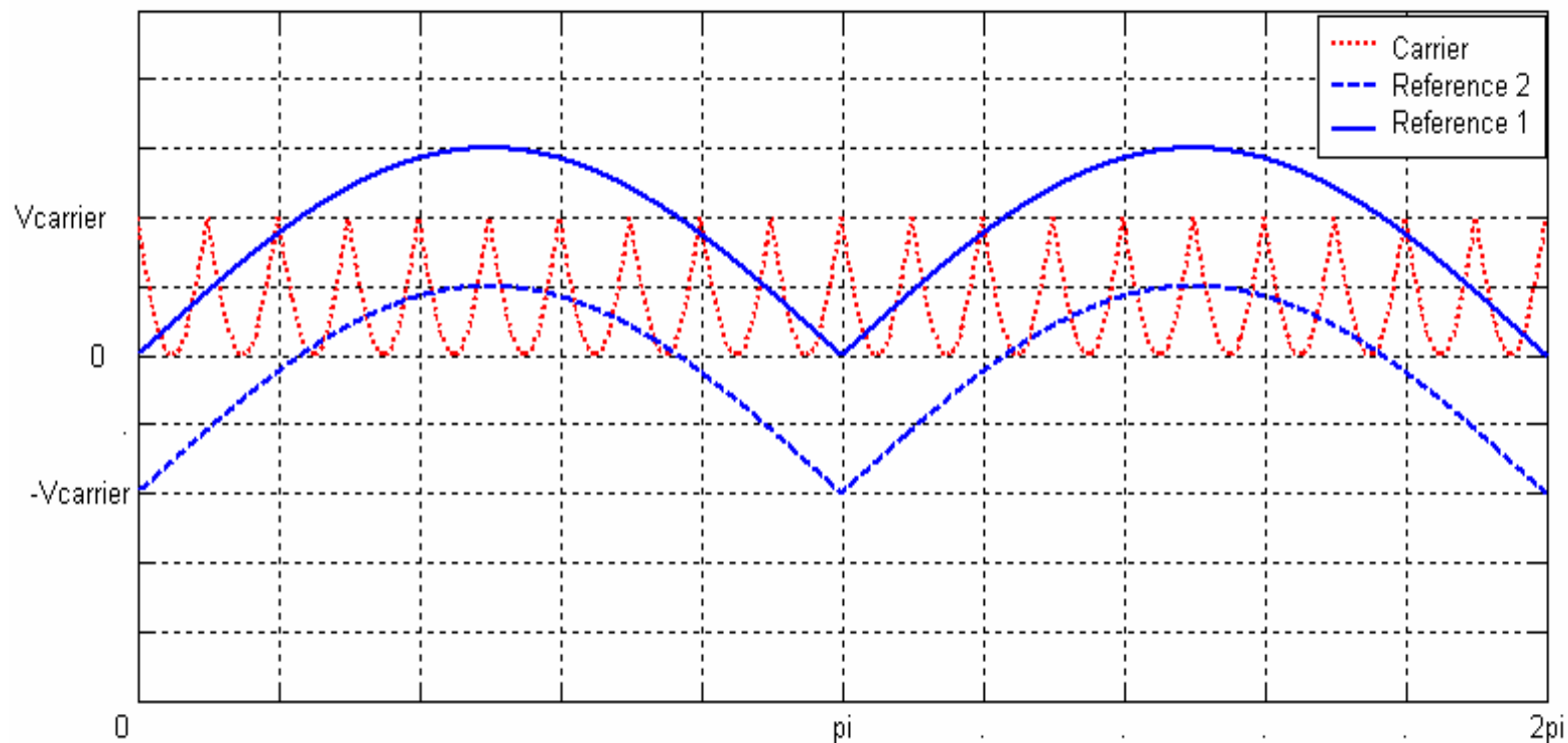




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New Five Level Inverter with Auxiliary Switch- A dual Reference Modulation Technique



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





PWM Strategy and Operating Principle

Modulation index M_a for five-level PWM inverter is given as

$$M_a = \frac{A_m}{2A_c}$$

Where A_c is the peak-to-peak value of carrier and A_m is the peak value of voltage reference V_{ref} . Since in this work two reference signals identical to each other are used, above equation can be expressed in terms of amplitude of carrier signal V_c by replacing A_c with V_c and $A_m = V_{ref1} = V_{ref2} = V_{ref}$

$$M = \frac{V_{ref}}{2V_c}$$



One today is worth than two tomorrows- Fuel Cell- Francis Thomas Bacon -1932

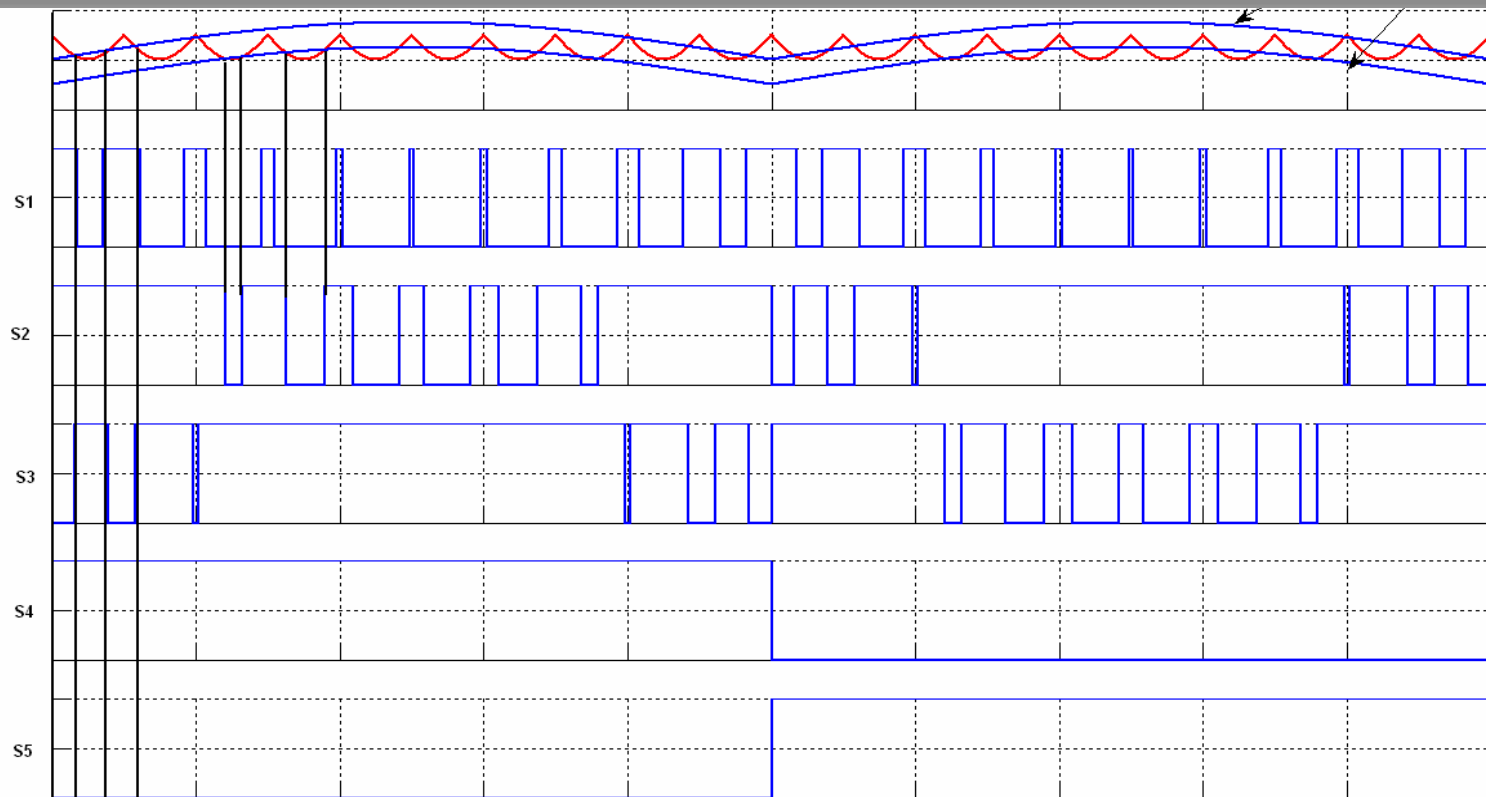




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PWM Strategy and Operating Principle



Switches S2–S4 will be switching at the rate of the carrier signal frequency, while S5 and S6 will operate at a frequency equivalent to the fundamental frequency.

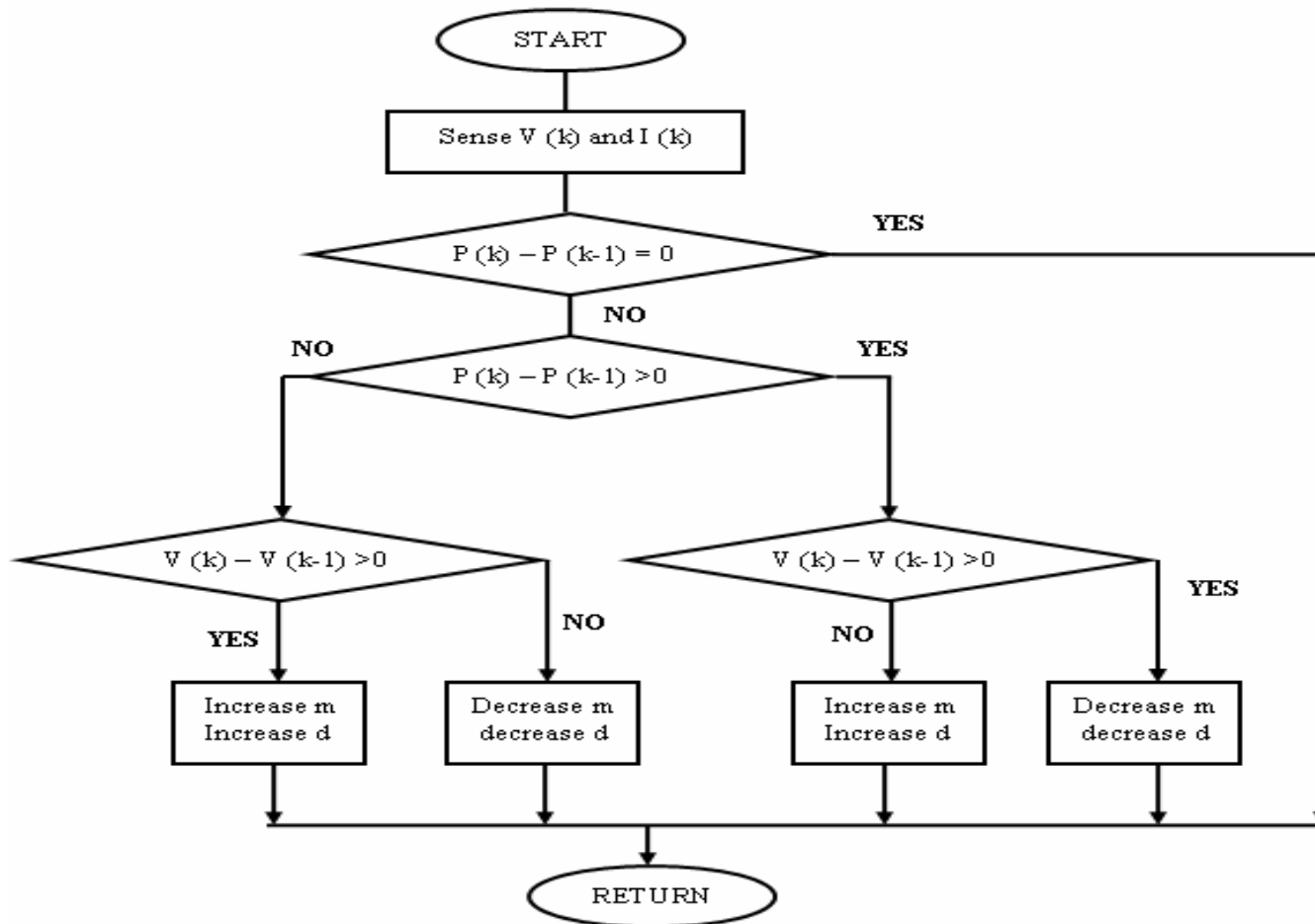


A great talker is a great liar - Hall Effect- Edwin Hall -1879





Maximum Power Point Algorithm

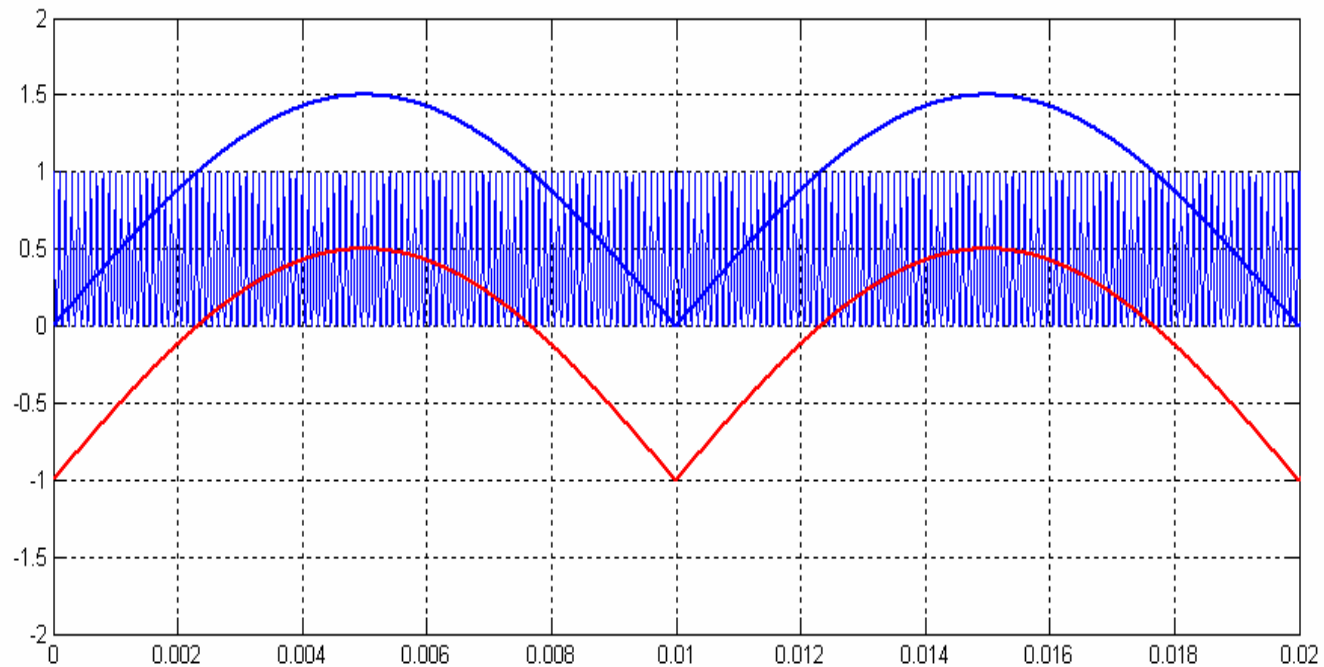




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SIMULATION RESULTS



Dual Reference and Carrier Comparison



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

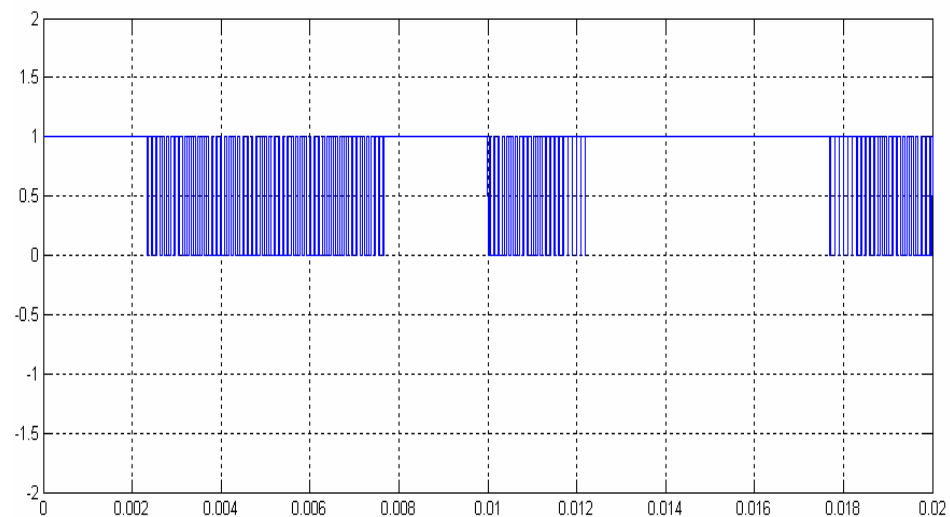
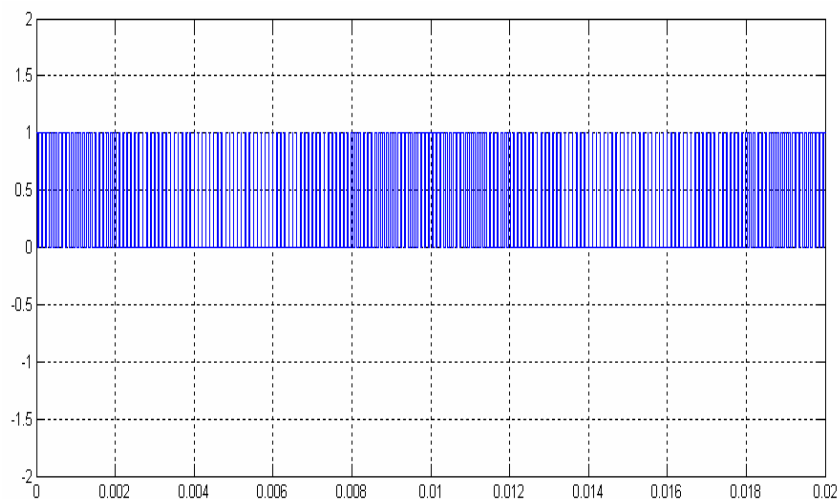




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SIMULATION RESULTS



Switching Signals to S2 and S3



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

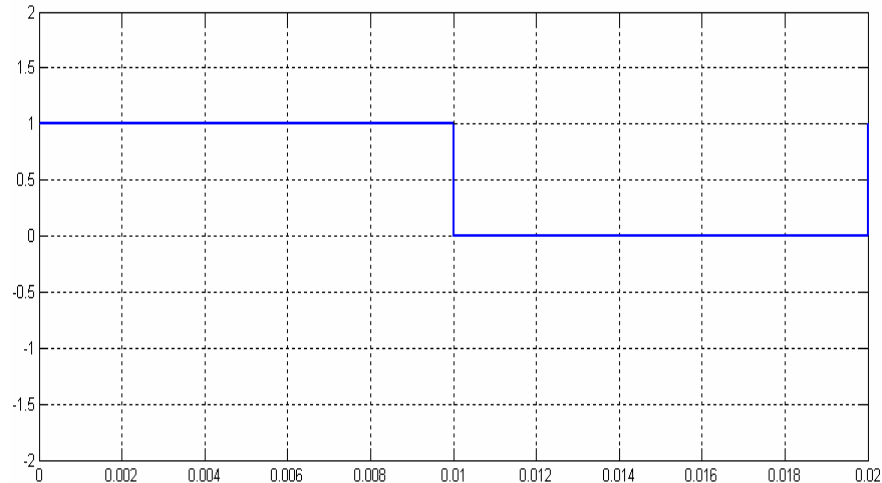
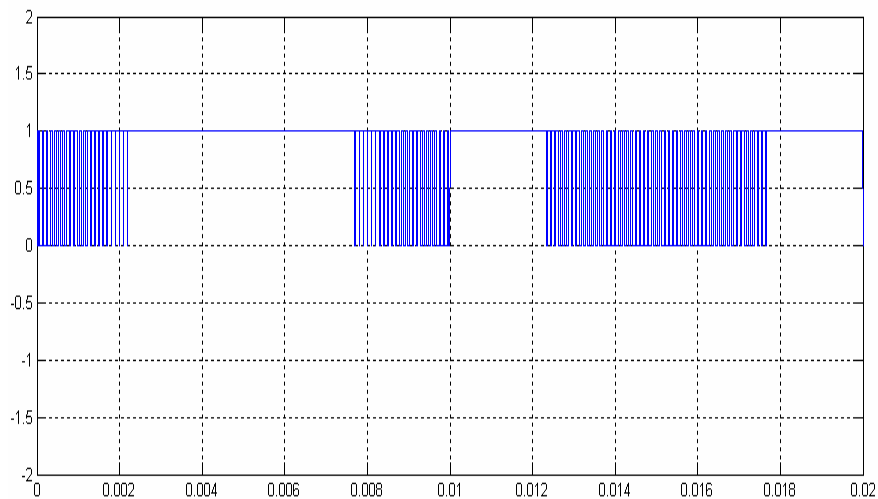




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SIMULATION RESULTS



Switching Signals to S4 and S5



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

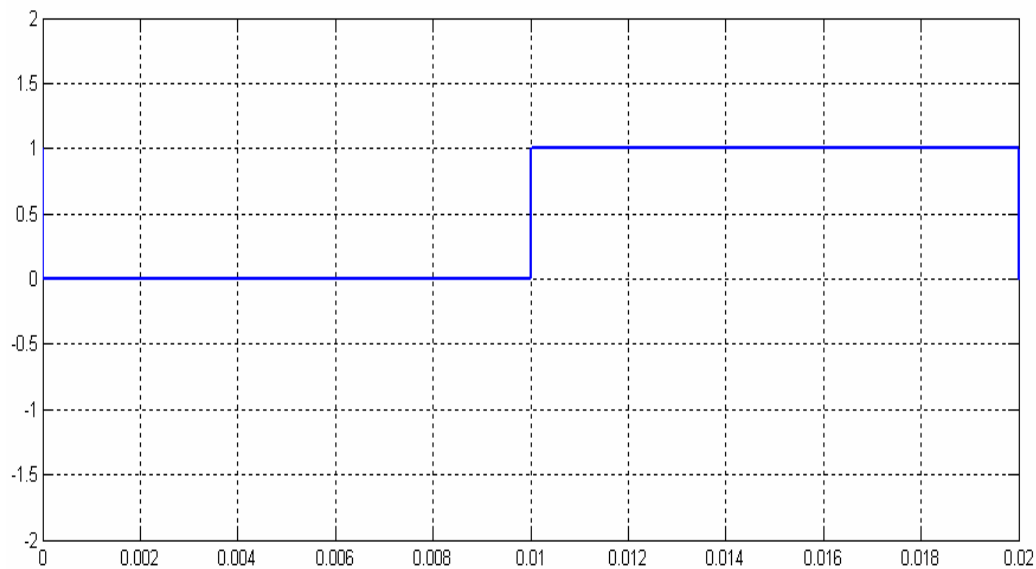




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SIMULATION RESULTS



Switching Signals to S6



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

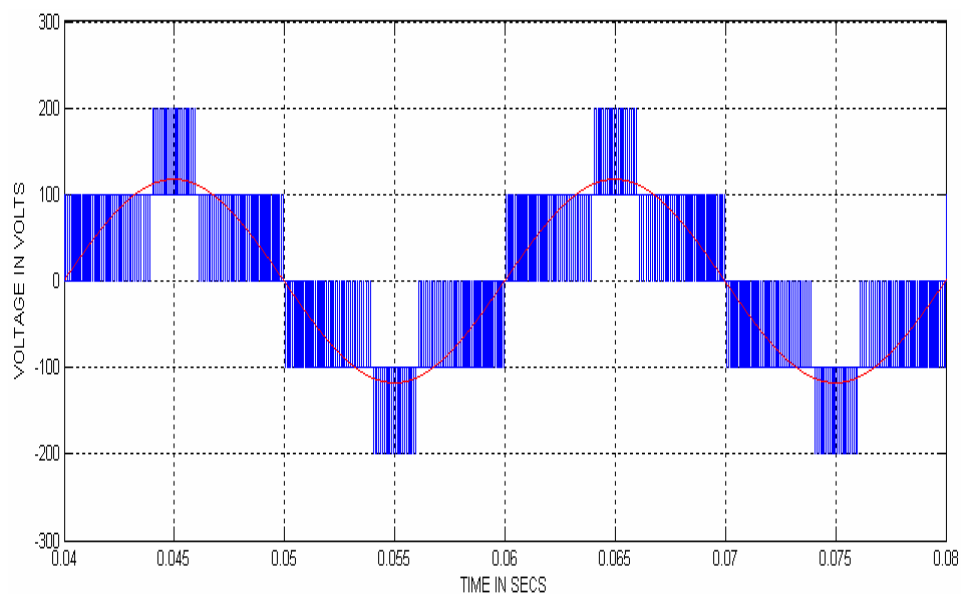




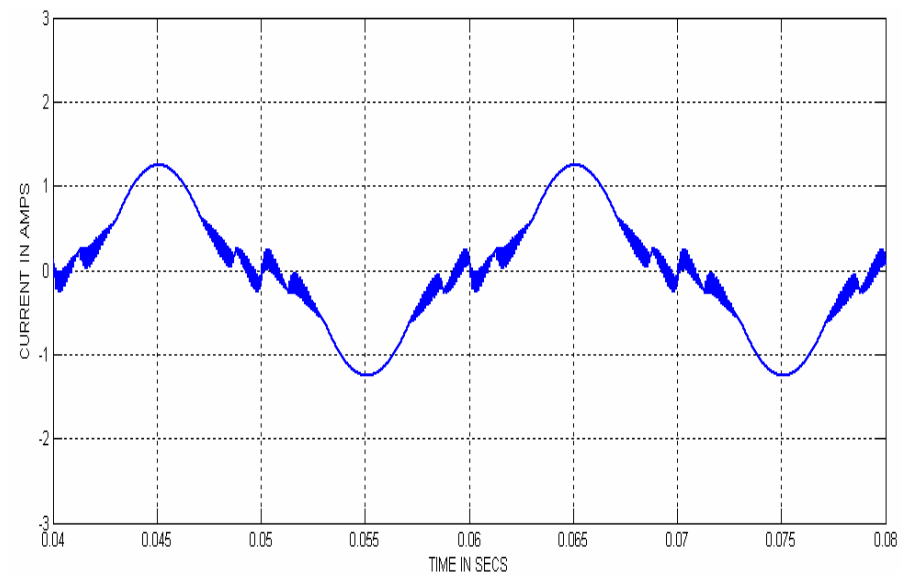
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SIMULATION RESULTS



OUTPUT VOLTAGE WITH $M, D < 0.5$



INVETER CURRENT WITH $M, D < 0.5$



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

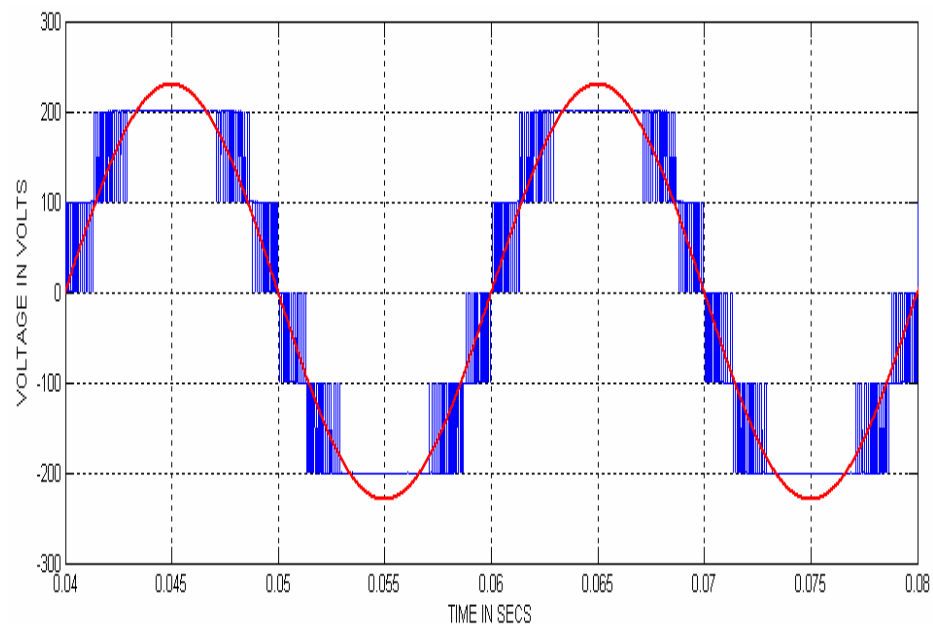




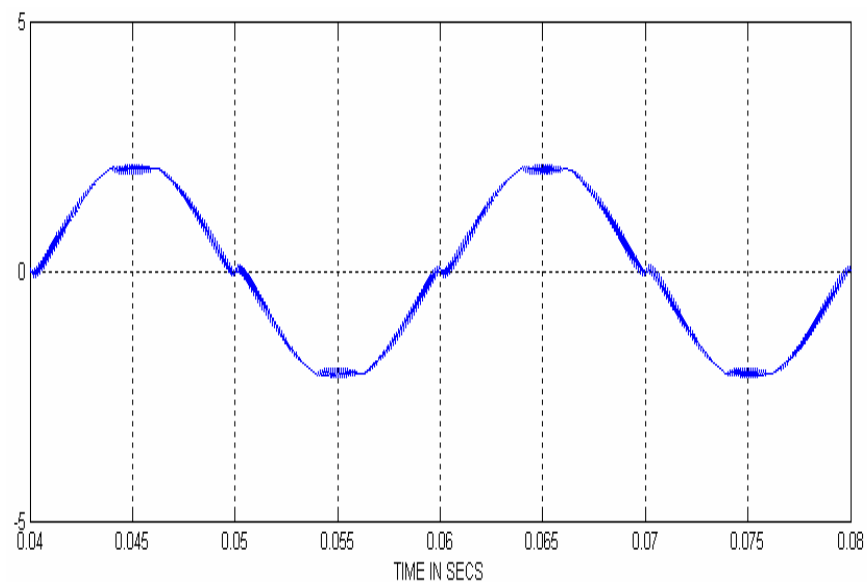
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SIMULATION RESULTS



**OUTPUT VOLTAGE AND ITS
FUNDAMENTAL WITH $M, D > 1.0$**



INVETER CURRENT WITH $M, D > 1.0$



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

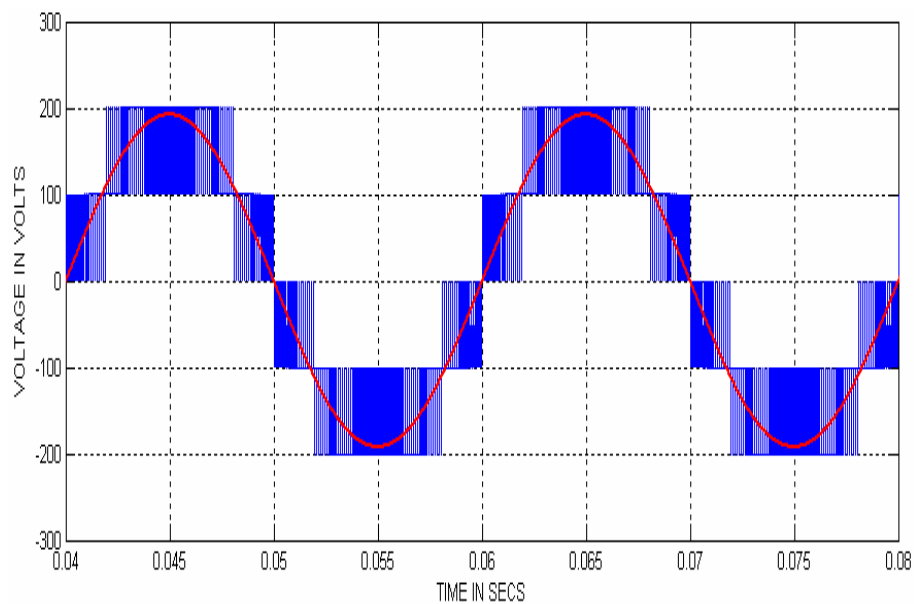




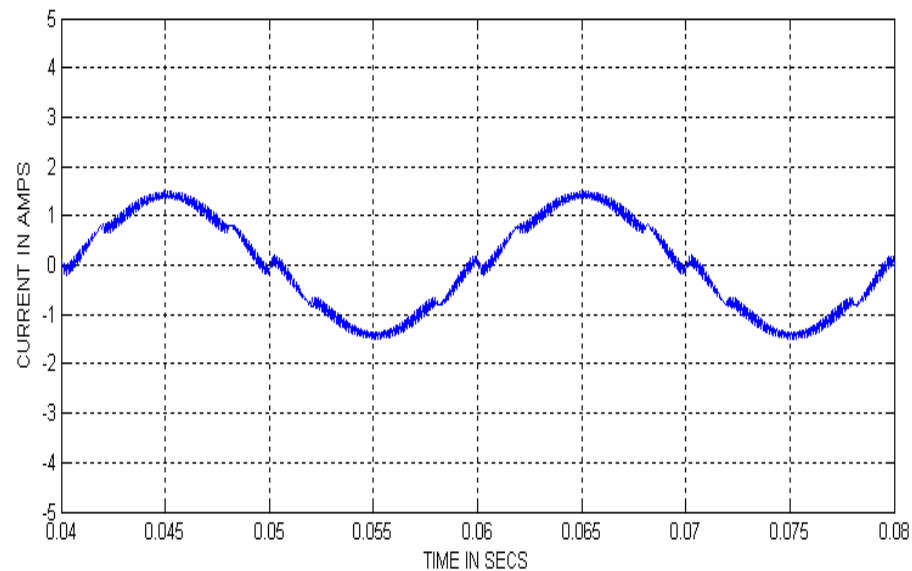
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SIMULATION RESULTS



**OUTPUT VOLTAGE AND ITS
FUNDAMENTAL WITH $0.5 < M, D > 1.0$**



INVETER CURRENT WITH $M, D > 1.0$



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

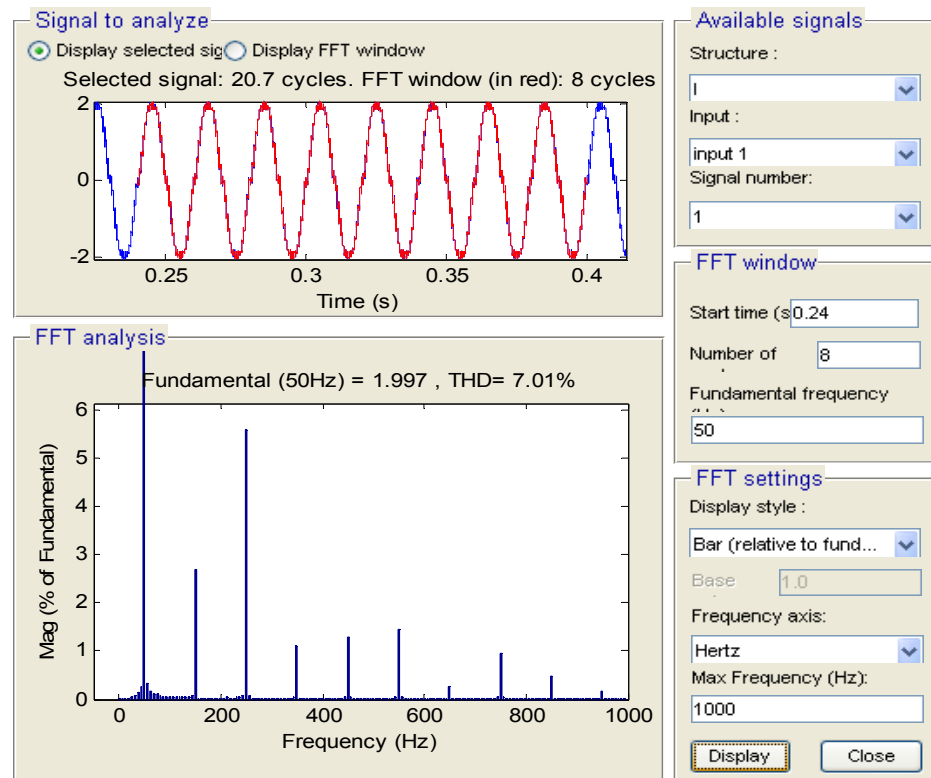
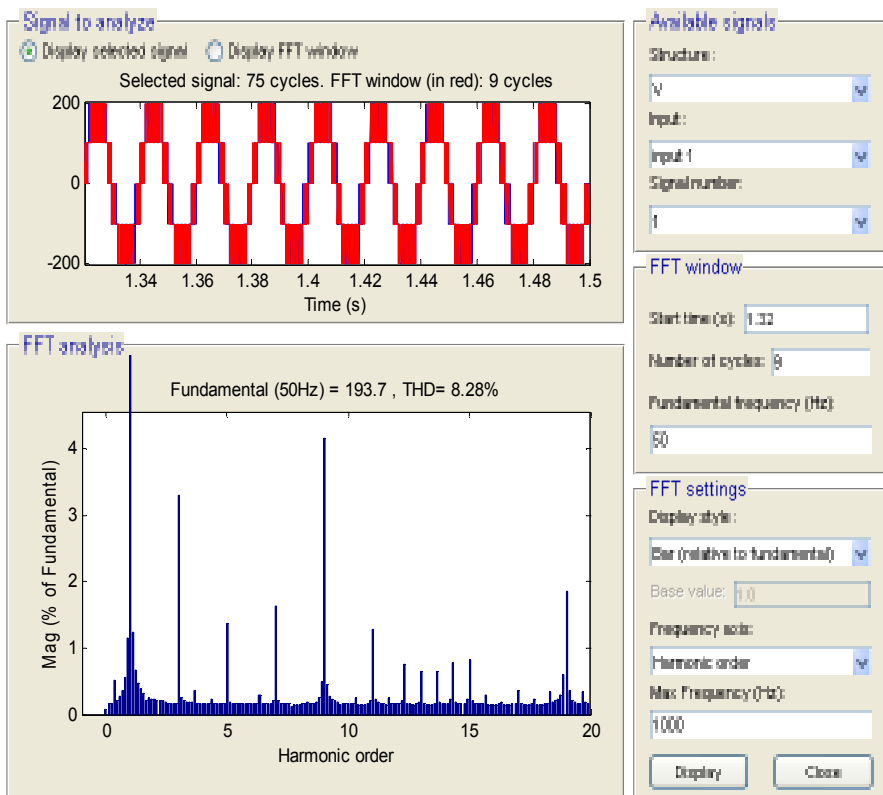




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SIMULATION RESULTS



Harmonic Spectrum of Voltage With $0.5 < M, D > 1.0$ With out filters

Harmonic Spectrum of Current With $0.5 < M, D > 1.0$ Without filters



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





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CONCLUSION



This paper presented a single-phase five-level inverter with a dual reference modulation technique for PV application. The dual reference modulation technique involves comparing two reference signals identical to each other except for an offset equivalent to its carrier signal, with a rectified inverted sine carrier signal to generate PWM switching signals for the switches. The circuit topology, control algorithm and operational principle of the proposed inverter were analyzed in detail. The results show that the THD of the five-level inverter is much less than that of the conventional three-level inverter. Furthermore, both the grid voltage and the grid current are in phase at near unity power factor.



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





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Thank
you



Success is a journey, Which has no Destination

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