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RESEARCH ARTICLE

ANALYSIS AND SIMULATION OF PV FED MULTI-LEVEL INVERTER.

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Abstract

Design and simulation of PV fed Multi-Level Inverter (MLI) through the DC-DC converter in Continuous Conduction Mode (CCM) have been carried out in this work. The voltage regulated PV fed DC-DC power converter is used as DC source for the MLI . Multicarrier PWM switching strategies are used for the selected seven level asymmetric MLI. The mathematical model of PV system and DC-DC converter have been presented and verified under varying climatic and load conditions. To improve the performance of the PV system, PI controller PWM control scheme and on-line INC MPPT algorithm with fixed and variable step size has been developed. Simulations are carried out using MATLAB/SIMULINK Simpower System block set .In variable step size MPPT method the PI controller modifies the step size enabling faster tracking of the maximum input power and shows the improvement in the efficiency of energy utilization. The developed setup is fed to the two H-Bridge cascaded asymmetric MLI to generate 7-level sinusoidal AC output .

Introduction:-

Applications of PV sources are mostly in battery charging, water pumping, house appliances and satellite power system etc. Photovoltaic (PV) modules are formed by series connections of cells to obtain the desired high voltage. The mathematical model of the PV source is developed . The simulation results of the modeled PV under variable climatic conditions such as temperature and irradiation are also analyzed. PV system exhibits nonlinear characteristics I-V and P-V. They vary with irradiation and cell temperature. The output current varies linearly with the solar irradiance. PV model under varying input parameters say irradiation and temperature lead to change in load voltage of the buck converter .Increased cell's temperature variation decreases the open circuit voltage and increased solar irradiation variation increases the open circuit voltage thus improving the power generation during the midday than the early morning & evening. To improve the efficiency, the PV module has to be operated at maximum power even under varying temperature and irradiation conditions. This can be achieved by matching PV source with the load for all varying atmospheric conditions. by using the MPPT technique.

Mathematical Model Of Pv System:-

The general PV cell model can be modelled as a current source and a diode connected in parallel, shunt resistor and a series resistor describes the leakage current, and internal resistance to the current flow, is shown in Fig. 1.

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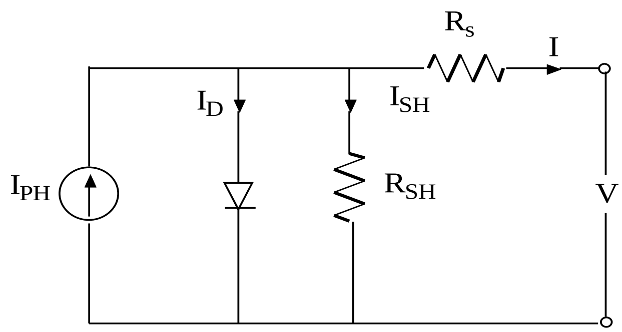


Fig. 1:- PV Cell General Model.

Applying the Kirchhoff current law the output current of the PV cell is given by the following equation.

$$I = I_{PH} - I_D - I_{SH} \quad (1)$$

$$I_D = I_S \left[\exp\left(\frac{q(V + IR_s)}{kAT_C} \right) - 1 \right] \quad (2)$$

$$I_{SH} = \frac{V + IR_s}{R_{SH}} \quad (3)$$

Substitute equation (3.2) and (3.3) in (3.1) we get

$$I = I_{PH} - I_S \left[\exp\left(\frac{q * (V + IR_s)}{kAT_C} \right) - 1 \right] - \frac{V + IR_s}{R_{SH}} \quad (4)$$

PV cell produces less than 2W at 0.58 V approximately. To meet the sufficient power, the series/parallel connection of the PV cell to form the modules is necessary.

$$I = N_P I_{PH} - N_P I_S \left[\exp\left(\frac{q(V + IR_s)}{N_S kAT_C} \right) - 1 \right] - \frac{V + IR_s}{R_{SH}} \quad (5)$$

where I_{PH} is a light generated current or photo current, I_D is the diode current, I_{SH} is the shunt current, I_S is the cell saturation of dark current, T_C is the cell's working temperature, N_S is the number of series cells, N_P is the number of parallel cells, R_{SH} is a shunt resistance, R_s is a series resistance, q (= 1.6 $\times 10^{-19}$ C) is an electron charge, k (= 1.3805×10^{-23}J/K) is a Boltzmann's constant and A (=1.3 Si-poly) is an ideal factor. The I_{PH} depends on the PV cell's temperature and solar irradiation is represented as.

$$I_{PH} = \left[I_{SC} + K_I (T_C - T_{Ref}) \right] G / 1000 \quad (6)$$

$$I_S = I_{RS} \left(\frac{T_C}{T_{Ref}} \right)^3 \left[\exp\left[\left(\frac{qE_G}{kA} \right) \left(\frac{1}{T_{Ref}} - \frac{1}{T_C} \right) \right] \right] \quad (7)$$

$$I_{RS} = \frac{I_{SC}}{\left[\exp\left(\frac{qV_{OC}}{N_S kAT_C} \right) - 1 \right]} \quad (8)$$

where I_{SC} is the cell's short-circuit current under standard test conditions (STCs) using 25°C and 1000 W/m^2, K_I is the cell's short-circuit current temperature coefficient, T_{Ref} is the cell's reference temperature and G is the solar irradiation in W/m^2, E_G (=1.12eV) is the semiconductor band-gap energy of the cell, I_{RS} is the cell's reverse saturation current and V_{OC} is the open-circuit voltage under STC.

$$I = N_{PM} N_P I_{PH} - N_{PM} N_P I_S \left[\exp\left(\frac{q\left(V + IR_s \times \frac{N_{SM}}{N_{PM\ s}} \right)}{N_S kAT_C N_{SM}} \right) - 1 \right] - \frac{V + IR_s \times \frac{N_{SM}}{N_{PM}}}{R_{SH} \times \frac{N_{SM}}{N_{PM}}} \quad (9)$$

N_{PM} and N_{SM} represents the parallel and series modules. R_s and R_{SH} is varied by iterative process until the experimental data fits with I-V curve as shown in the flow chart.

$$P_{\max,m} = P_{\max,e} = V_{mp} \left\{ I_{PH} - I_S \left[\exp\left(\frac{q(V_{mp} + R_s I_{mp})}{N_s AkT_C} \right) - 1 \right] - \frac{V_{mp} + R_s I_{mp}}{R_{SH}} \right\} \quad (10)$$

$$R_{SH} = \frac{V_{mp}(V_{mp} + I_{mp} R_s)}{\left\{ V_{mp} I_{PH} - V_{mp} I_S \left[\exp\left(\frac{q(V_{mp} + I_{mp} R_s)}{N_s kAT_C} \right) \right] + V_{mp} I_S - P_{\max,e} \right\}} \quad (11)$$

$$I_{SC} = \frac{R_{SH} + R_s}{R_{SH}} I_{SC} \quad (12)$$

$$R_{SH\min} = \frac{V_{mp}}{I_{SC} - I_{mp}} - \frac{V_{OC} - V_{mp}}{I_{mp}} \quad (13)$$

The values of R_s and R_{SH} are initially unknown but as the solution of the algorithm is refined along successive iterations the values of R_s and R_{SH} tend to the best solution. The iterative method gives the solution $R_s = 0.25\Omega$ and $R_{SH} = 56.72\ \Omega$ and other parameters are identified from the manufacture's data specification of a KCP 12060 solar module under standard test conditions (STCs) of solar irradiation and temperature at 1000W/m^2 and 25°C respectively as shown in Table 1. The PV module is modeled by simulation using Matlab/SIMULINK.

Table 1:- Data Specification of KCP 12060 Module

Parameters	Values
Open circuit voltage V_{OC}	21.20 V
Short circuit current I_{SC}	4.03 A
Voltage at maximum power V_{mp}	17 V
Current at maximum power I_{mp}	3.50 A
Maximum power P_{max}	59.5 W
Current temperature coefficient K_I	2.80mA/ºC
Number of cell's in series N_s	36
Number of cell's in parallel N_p	1

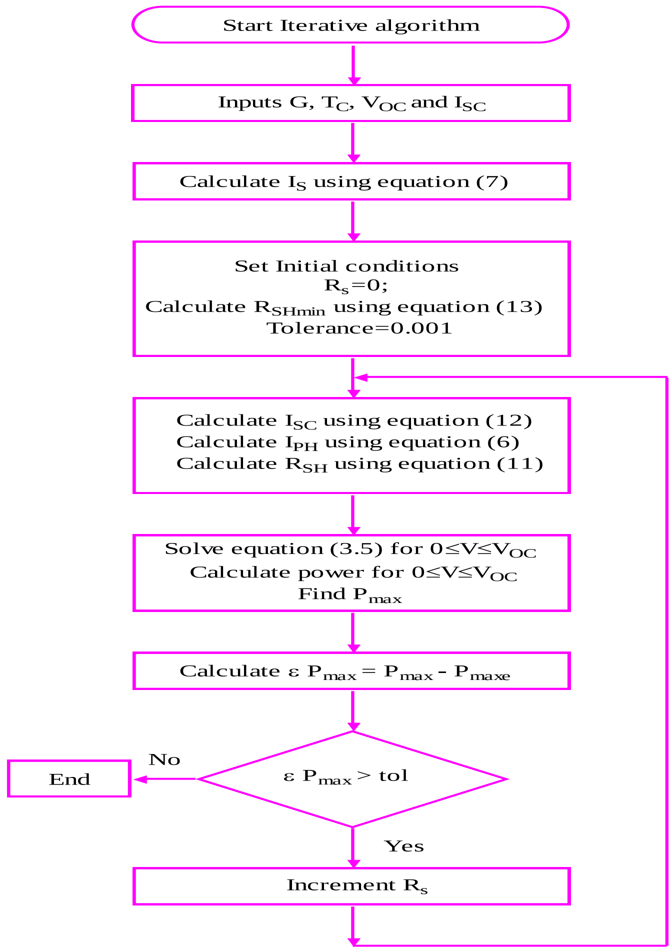


Fig. 2:- Iterative Algorithm to Adjust I-V Characteristics of PV Model

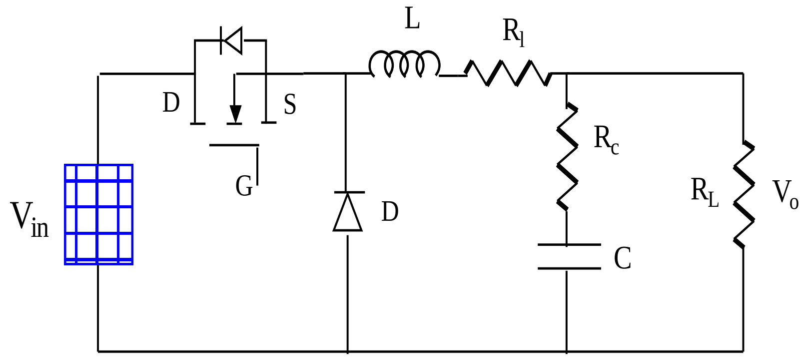


Fig. 3 Buck Converter

Table 2:- Specification of Buck Converter for Simulation Studies

Data specifications of buck DC-DC converter		
Parameters	1st-H bridges	2nd-H bridges
Switching frequency (f)	20Khz	20Khz
PV Input voltage (V_{in})	21V	42V
Output voltage (V_o)	12 V	24 V
Inductance (L)	1.8 mH	3.6 mH
Capacitance (C)	107 µF	97µF

Inductor series resistance (R_i)	1 mΩ	1 mΩ
Capacitor series resistance (R_c)	0.6 Ω	0.6 Ω

The basic circuit of a buck converter is shown in Fig.3 and its parameters chosen for simulation studies are shown in Table 2.The average output voltage V_o is given by

$$V_o = V_{in} \frac{T_{on}}{T_{on} + T_{off}} \tag{14}$$

where, T_{on} on time period, T_{off} off time period of the semi conductor switch and V_{in} is the input supply voltage .The simplified transfer function by the small signal model of the duty
cycle d to output V_o is as

$$\frac{\hat{V}_o}{\hat{d}} = \frac{V_{in} R_L d}{(R_L + R_i)} \left[\frac{1 + sCR_c}{s^2 LC\left[\frac{R_L + R_c}{R_L + R_i}\right] + s\left[\left[\frac{L}{(R_L + R_i)}\right] + C\left[R_c + \left(\frac{R_L R_i}{R_L + R_i}\right)\right]\right] + 1} \right] \tag{15}$$

Pwm Control Techniques:-
The PI controller is tuned by applying Zeigler Nicholas method applied to the approximately linearized buck model. The purpose of the controller is to influence the behavior of a system towards the desired set point under deviation due to the load or set point change. Fig. 4 show the open loop step response of the buck DC-DC converter for a constant temperature and irradiation in PV .

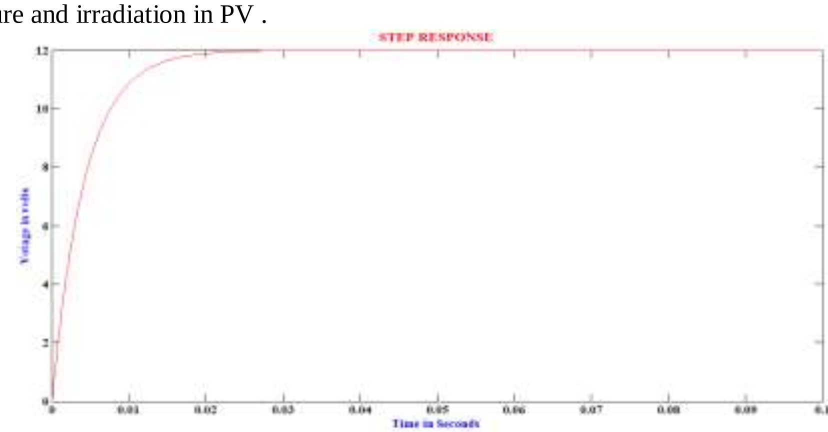


Figure 4:- Open Loop Step Response of Buck DC-DC Converter

On-Line Incremental & Conductance (I&C) Mppt Algorithm:-
Two on-line MPPT methods are available say perturb & observation (P&O) method and Incremental and conductance (I&C) method. The INC tracks the maximum power more than the P&O method even under fast varying weather conditions (Go et al 2011).In this work direct duty ratio INC method is used. The duty cycle of the converter is adjusted directly and control loop is simplified in this algorithm. It is based on the slope of the PV module power curve and are zero at the MPP, positive on the left side and negative on the right hand side of MPP .The flow chart of the incremental conductance algorithm is shown in Fig. 5. The principle of the INC algorithm is to increase or decrease the voltage by adjusting the duty cycle based on the step size ΔD. The step size can be adjusted automatically by means of a feedback PI controller and can achieve more power and efficiency. The perturbation step size ΔD is varied and depends upon the difference between feedback PI controller fD and last instant D from INC algorithm. The proposed method achieves reduced oscillation around the MPP and stable operation of the PV panel. .

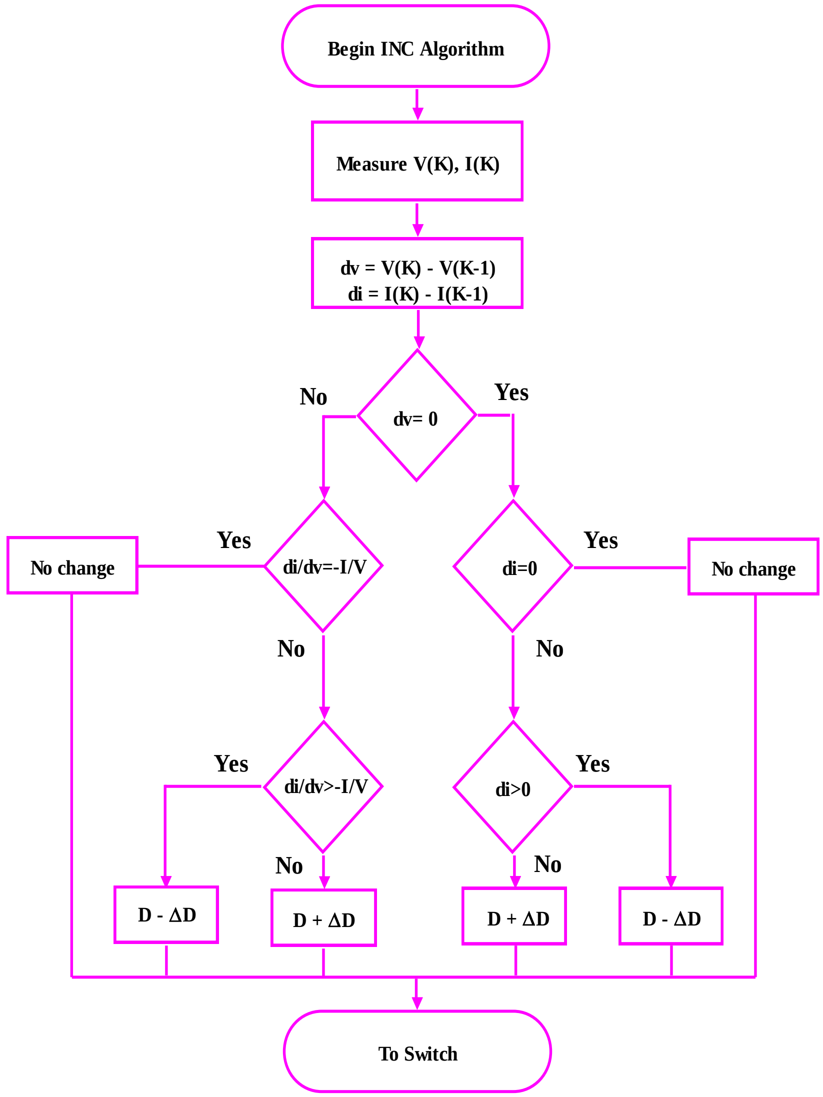


Fig 5:- Flow chart for Incremental & Conductance Method

Pv Fed Asymmetrical Binary Multilevel Inverter:-

The renewable energy is an increasingly important part of power generation. The block diagram of the solar fed inverter system is as shown in Fig.6.PV panel is fed as input to the MLI through the DC-DC converter. Binary H-bridge cascaded MLI consists of two H-bridges and its SIMULINK model is shown in the Fig.7. The H-bridges are fed from the PV panels of 21V and 42V each through a DC-DC converter. The 42V are obtained by connecting two PV modules in series. The multicarrier PWM switching strategy uses 6 triangular carriers and one sine wave reference signal is shown in Fig.8. Among the different multi-carrier based MLI PWM strategies PD, POD and APOD are developed and simulated in MATLAB-Simulink.

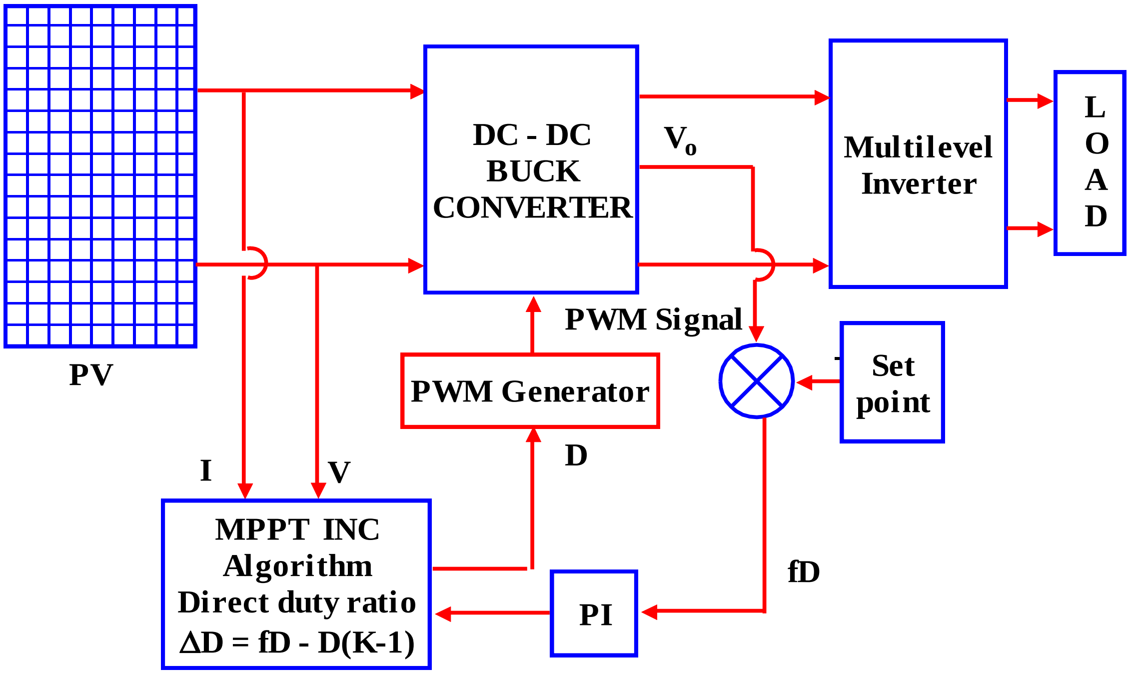


Fig. 6:- Block Diagram of PV Fed Multilevel Inverter

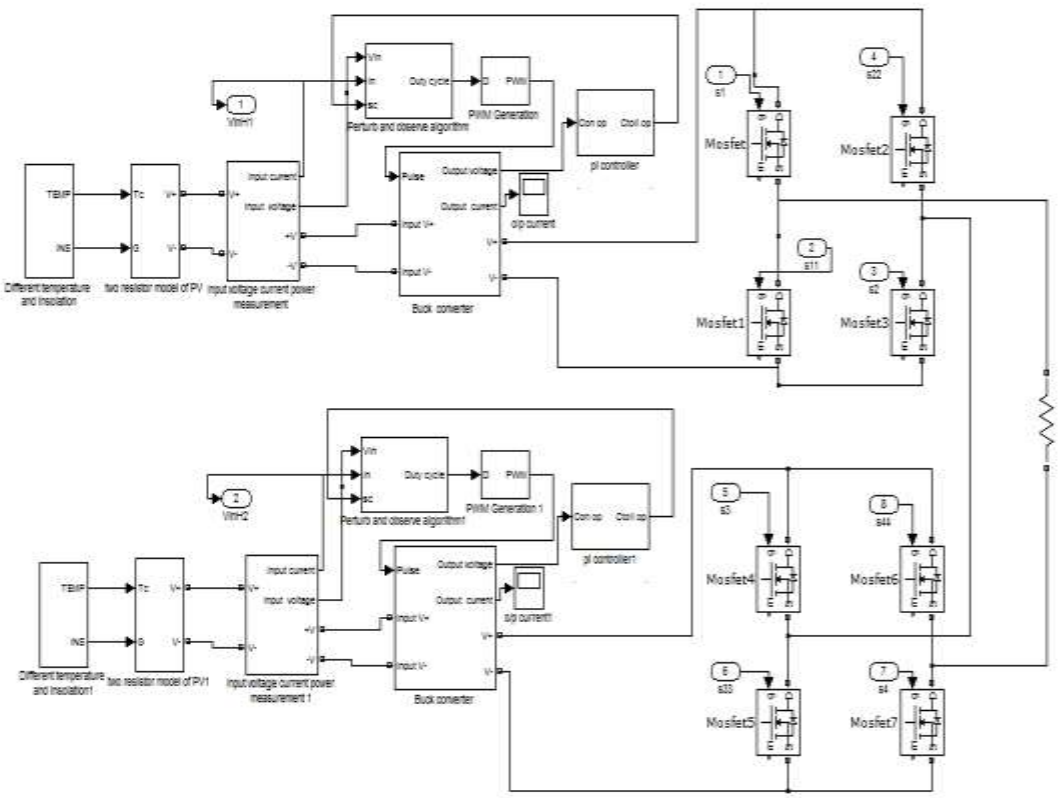


Fig. 7:- Simulink block diagram PV Fed Multilevel inverter

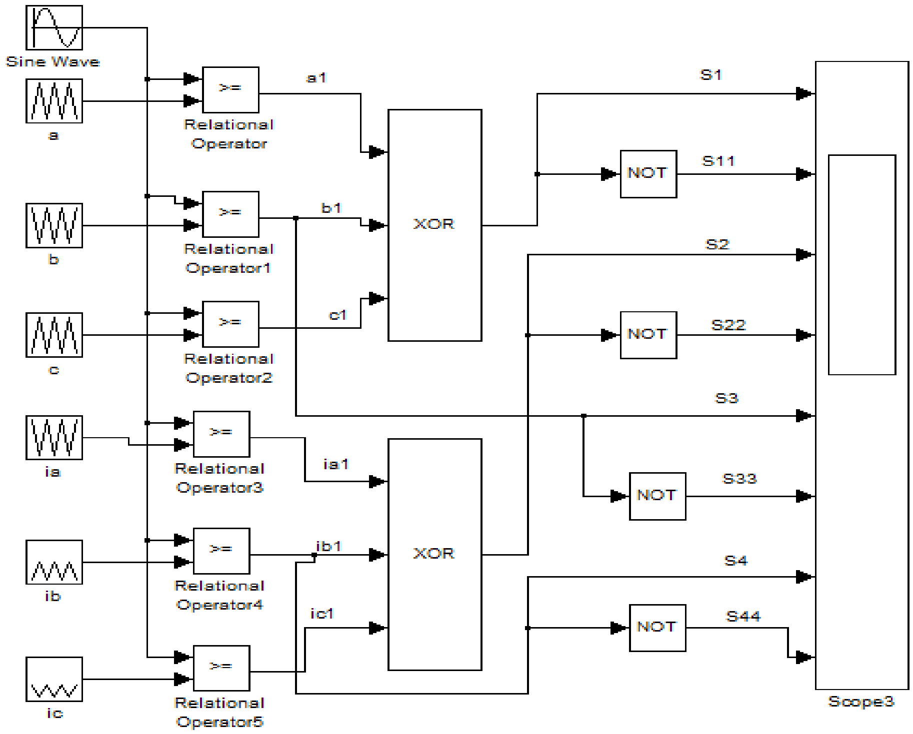


Fig. 8:- SIMULINK block diagram of APOD-PWM

Simulation Results:-

Fig.9 shows the continuously varying temperature and irradiation of PV module.Fig 10shows the PV output of converter 1 and converter2.Fig.11 shows the simulated sinusoidal reference and triangular multi-carrier used in the various PWM strategies.Fig.12 shows the 7 level AC output current and voltage responses and their corresponding FFT analysis using APOD PWM strategy. Total Harmonic Distortion is found to be 21.37% for the varying temperature and insolation in PV module. Table 3 shows performance evaluations of THD%,Vrms,Vpeak,Irms,Ipeak and crest factor for PD,POD,APOD PWM strategy.

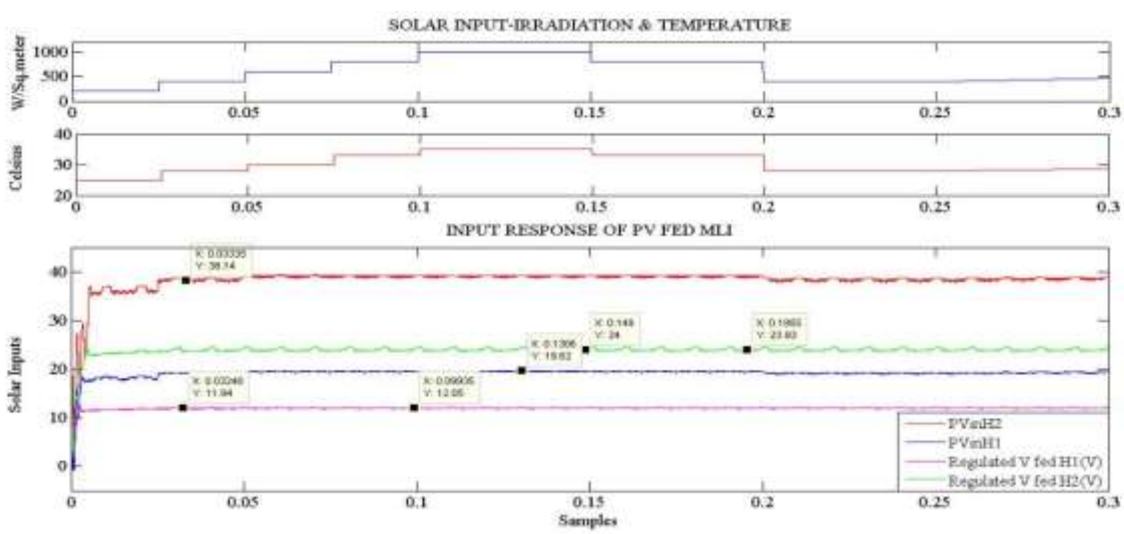


Fig 9:- Simulated solar input and input response of PV fed MLI

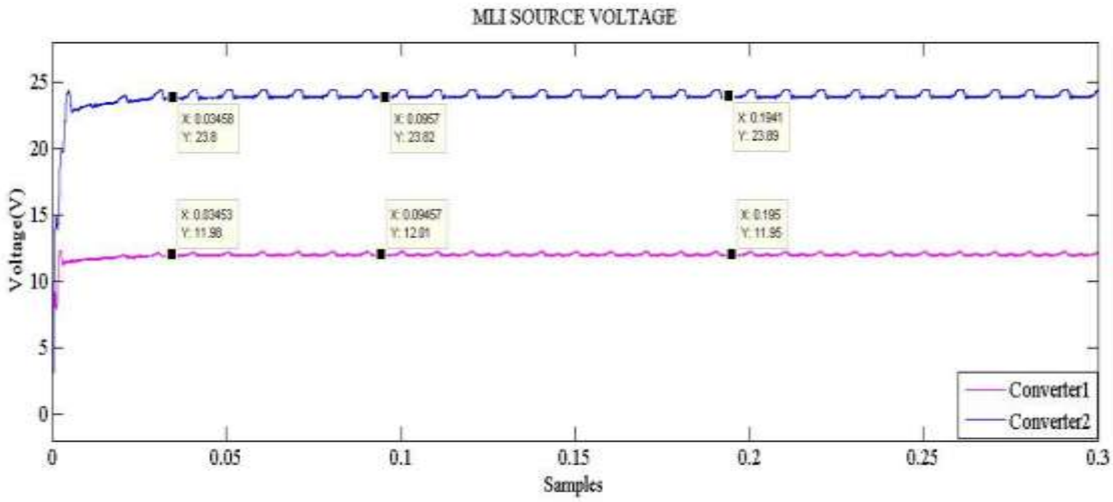


Fig10:- Simulated output response of MLI source voltage.

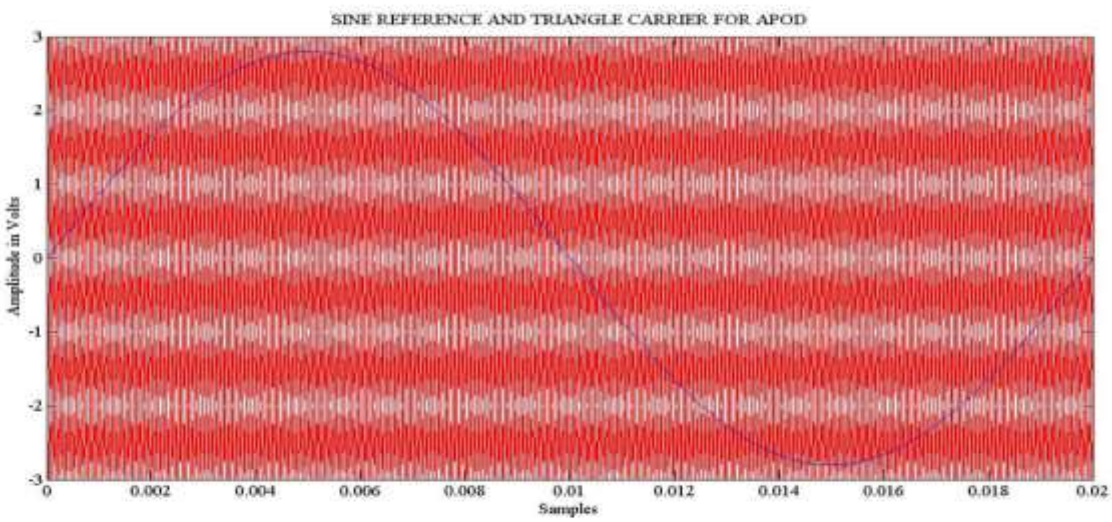
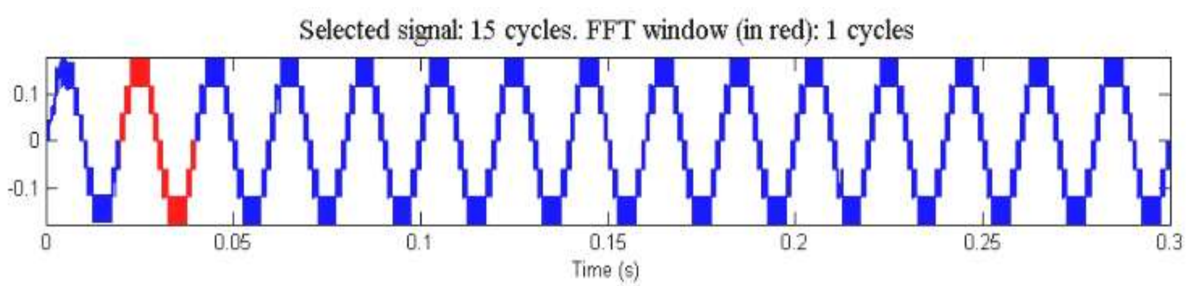


Fig. 11:- Simulated sine reference and triangular multi-carriers



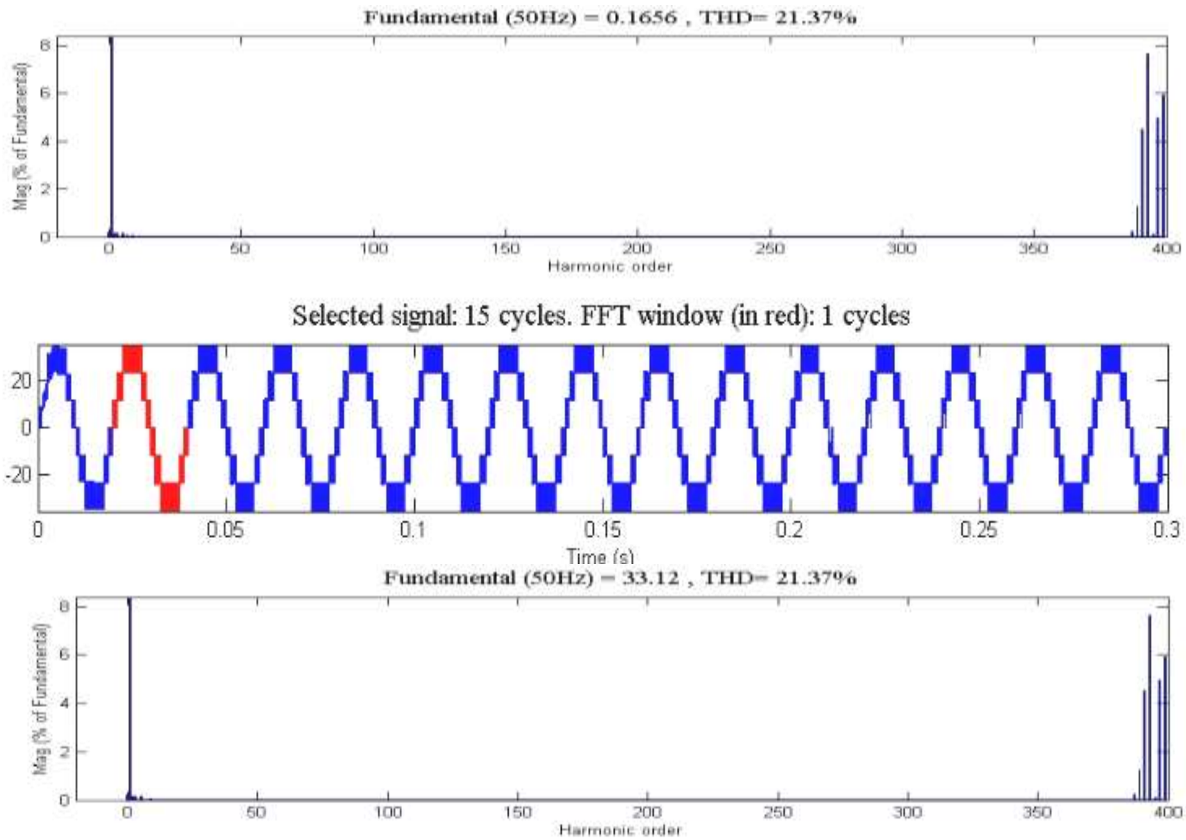


Fig 12:- MLI load current and voltage response and corresponding FFT analysis

Table 3:- Simulated Performance Evaluations of 7 Level BHCMLI

Parameters	PD	POD	APOD
THD%	21.35	21.28	21.37
Vpeak	33.5	33.49	33.1
Vrms	23.7	23.6	23.4
Ipeak	0.16	0.16	0.16
Irms	0.11	0.11	0.11
Crest factor	1.41	1.41	1.41

Conclusion:-

The simulation results show the possibility of AC power generation from the DC renewable PV source by using the asymmetrical MLI. The advantage of asymmetric MLI is the reduction in THD% of the responses by producing an output resembling the sine wave.

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