

THD ANALYSIS OF PV-FED PWM CONTROLLED MLI USING LEVEL SHIFTED MULTICARRIER MODULATION TECHNIQUE

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ABSTRACT

In India the demand of electric power is increasing rapidly, at present the maximum generation of electric power is based on non-renewable energy sources. In future there lies the use of renewable energy resources to satisfy increasing power demand and needs, among all renewable energy sources solar energy is most easily available and most comfortably used. For utilizing solar energy for generation of electric power solar cell or solar panel is mostly used. Available power from solar cell is DC in nature, but for utilization of this power for domestic purpose, it is needed to be converted in to AC. Inverter is the power electronic modulator that is used for this purpose. Multilevel cascade type inverter which intake multiple DC sources and gives combined AC output for desired voltage and frequency. In this project, single phase 5 level cascaded H-bridge multilevel inverter is implemented and investigation is carried out for multicarrier PWM technique at the end of the thesis. Report presents a bibliographical review of cascaded H-bridge MLI, control techniques, future scopes and some of applications. Simulation for 5 level cascaded H-bridge MLI has been carried out in MATLAB/Simulink and the investigation is made in terms of total harmonic distortion (THD). The computational results are demonstrated graphically for better understanding and to prove the effectiveness of the individual PWM technique.

Keyword : - Multicarrier modulation, THD Analysis, Multilevel Inverter, Level Shifted Technique, Partial Shading, Matlab Simulations

1. Introduction-1

The voltage source inverter produce an output voltage or a current with levels either 0 or $\pm V_{dc}$. They are known as two level inverters. To obtain a quality output voltage or current waveform with a minimum amount of ripple content, they require high switching frequency along with various pulse width modulation (PWM) strategies. In high power and high voltage application, these two level inverters, however, have some limitations in operating at high frequency mainly due to switching losses and device rating. The semiconductor switching devices should be used in such a manner as to avoid problems associated with their series-parallel combinations that are necessary to obtain capability of handling high voltage and current. The MLI concept has been introduced since 1970's. The term multilevel starts from 3 level converter [3]. MLI become an effective and practical solution for increasing power and reducing harmonics of ac waveforms. They are normally used to medium and high voltage for current applications. The output quality of the current and voltage of MLI can be determined by high frequency switching techniques. The semiconductor power (e.g. GTO or IGBT high caliber) usually operate at relatively low frequencies [2]. When the number of output levels increases, harmonics of the output voltage of the output voltage and current decreases.

The harmonics in the output voltage of power electronics inverters can be reduced using pulse width modulation switching techniques. The applications are diverse and affect a wide field of electrical engineering from few watts to several hundred megawatts.

1.1 Modulation Strategy

To synthesize multilevel output AC voltage using different levels of DC inputs, semiconductor devices must be switched ON and OFF in such a way that desired fundamental is obtained with minimum harmonic distortion [8]. The most common and popular technique of digital pure sinusoidal wave generation is Pulse Width Modulation. The output voltage waveform of the multilevel inverter can be controlled using different PWM techniques. Duty cycle is defined as the ratio of (t_{on}/T), where t_{on} is the on time for switching device and T is the total time duration in seconds. The simplest way of producing the PWM signal is through comparison of a low power reference sine wave with a triangular wave. Multicarrier PWM methods uses high switching frequency carrier waves in comparison to the reference waves to generate a sinusoidal output wave. The method PWM is the most common for comparing a modulating wave (generally sinusoidal). The PWM inverters are advancing to the square wave inverter in following points

- i. The ability of reducing total harmonic distortion
- ii. Capable of controlling the output voltage
- iii. Higher power quality factor

The phenomenon of rapid and repeated switching at high speed causes the frequency of appearance of lowest order harmonic in the output voltage [2].

Among the several modulation strategies proposed till now for switching of the multilevel inverters are **Modulating-Based PWM** signals, Sine wave Pulse Width Modulation (SPWM), Third Harmonic Injection PWM (THIPWM) and Space Vector Modulation (SVPWM) and, are the most popular ones. All **Carrier-Based PWM** algorithms operate based on the comparison of a reference signal with carrier signals. There are different types of approaches for the selection of switching techniques for the multilevel inverters. PWM strategies for MLI can be classified into two categories:

1. Modulating Signal Based
 - i. Sine PWM
 - ii. Third Harmonic Injection PWM
 - iii. Space Vector PWM
 - iv. Dead bend
 - v. Other technique
2. Carrier Signal Based
 - (i) Level Shifted
 - 1 . PD
 - 2 . POD3.APOD
 - (ii) Phase Shifted
 - (iii) Hybrid
 - (iv) Super Imposed Carrier

The different PWM techniques in terms of their switching frequencies are describe in given figure. The most common and simplest method for modulation is Sinusoidal PWM technique. The SPWM scheme with level shifting and phase shifting technology give better performance and give low THD at the output voltage waveform compare to the conventional SPWM method. Here, in this project Sine PWM method is implementing. The simulation for CHB MLI with SPWM switching technique is been established with the help of MATLAB Simulink.

1.2 Multicarrier PWM Strategy

To synthesize multilevel output AC voltage with minimum distortion of harmonic factor, using different levels of DC voltage value of input, semiconductor devices must be switched ON and OFF in a way that desired voltage

waveform is obtained. Multi-Carrier PWM strategies is mostly used technique because it is easy to implement for low voltage modules. This PWM technique can be classified as level shifted PWM (LS-PWM) and Phase shifted PWM (PS-PWM) techniques. The level shifted PWM (LS-PWM) are In Phase Disposition (PD), Phase Opposition Disposition (POD) and Alternative Phase Opposition Disposition (APOD). In general the amplitude modulation index (m.a.) for level shifted PWM technique is defined as the ratio of amplitude of the reference sine wave (Ar) to the amplitude of the carrier wave (Ac) and it is given by,

$$ma = 2 * Ar / (m-1) * Ac$$

Similarly, the amplitude modulation index (m.a.) for phase shifted PWM technique is obtained by,

$$ma = Ar / Ac / 2$$

The frequency modulation index (m.f.) for level shifted and phase shifted PWM methods are describe as the ratio of frequency of the carrier wave value (fc) to the frequency of the reference sine wave (fr) and it is given by,

$$mf = fc / fr.$$

- (A) In this technique all the carriers wave which are above and below the zero reference values are in same phase with each other. Carrier as well as reference waveform arrangements are as shown in given figure. The converter is switched to + Vdc/2 when the sinusoidal wave is greater than both carriers, the converter switches to +Vdc/4 when the sinusoidal wave has low value than the highest most carrier wave and greater than all other carriers, the converter is switched to zero when sinusoidal wave has low value than upper carrier but higher than the lower carrier, the converter switches to - Vdc / 4 when the sinusoidal wave is higher than the lowest most carrier wave and lesser than all other carriers and the converter is switched to - Vdc / 2, the sinusoidal wave is less than both carrier waveforms.[8]

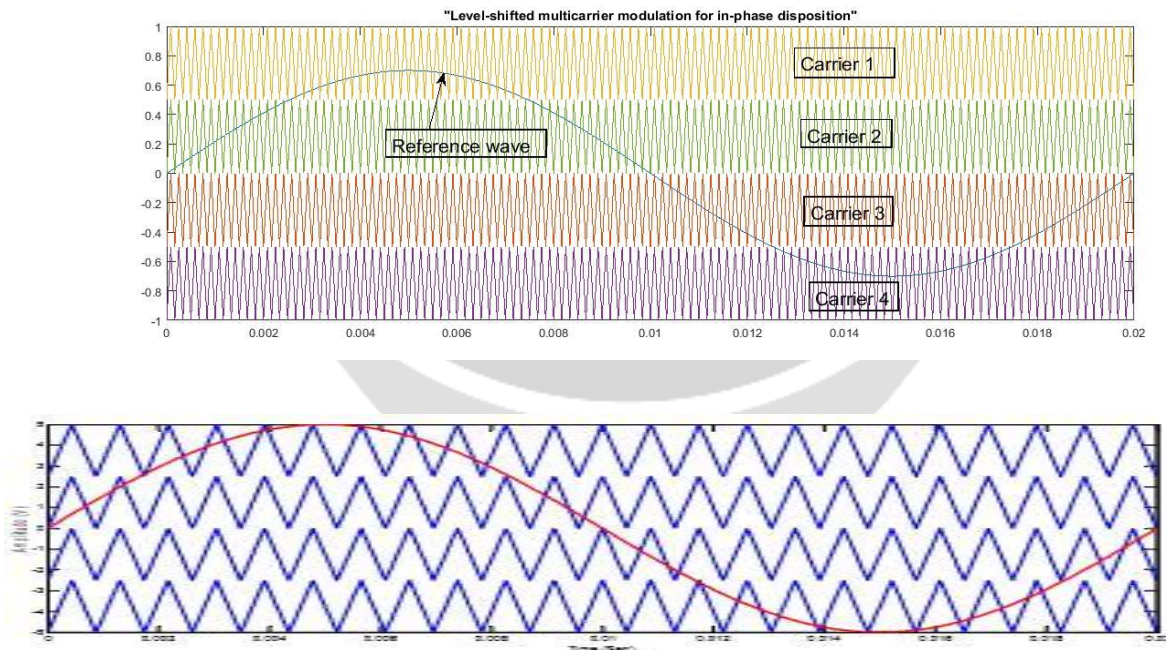


Figure1.1: IPD Method

- (B) In this method all the carriers have the same frequency and the adjustable amplitude. But all the carriers above the zero value references are in phase but in opposition (180 degrees phase shifted) with below

carrier phases. The converter is switched to $+V_{dc} / 2$ when the sinusoidal wave has high voltage value than both carrier waveform value, the converter switches to $+V_{dc} / 4$ when the sinusoidal wave has low voltage value than highest most carrier waveform and greater than all other carrier waveform, the converter is switched to zero when the sinusoidal wave is greater than the lower carrier waveform but less than the upper carrier waveform, the converter switches to $-V_{dc} / 4$ when the sine wave has highest voltage value than the lower most carrier waveform and lesser than all other carriers and the converter is switched to $-V_{dc}/2$ when the sinusoidal wave has less voltage values than both carrier waveforms, shown in below figure arrangement.

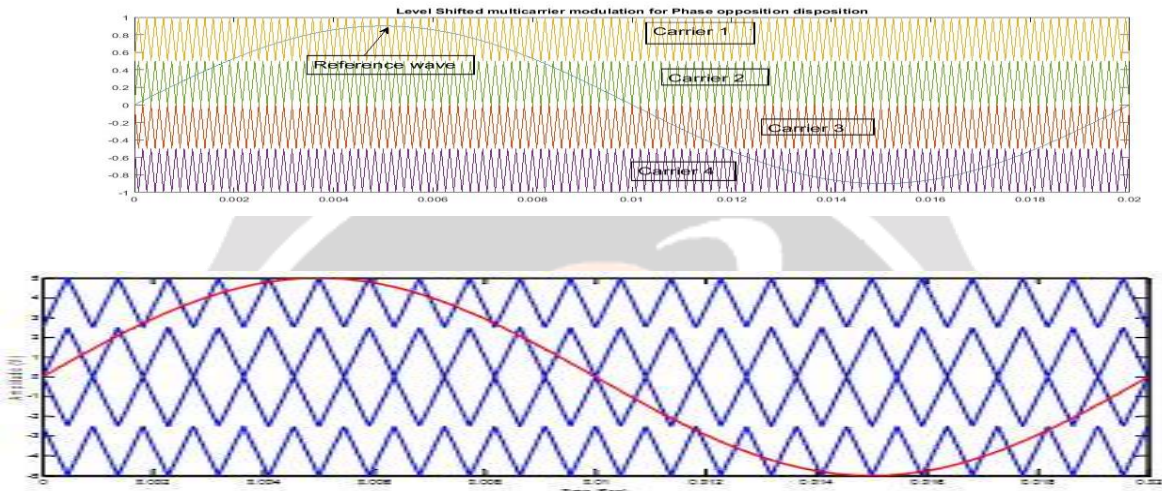


Figure 1.2: POD Method

(C) In this method all the carrier waveforms have the same frequencies and the adjustable amplitude. All carrier waves have phase shifted by Π from each other. The converter switches to $V_{dc}/2$ when the reference wave has highest voltage value than remaining carrier waveforms, the converter switches to $+V_{dc} / 4$ when the sinusoidal wave has lowest voltage value than the highest most carrier waveform and greater than all other carrier, the converter switches to zero when the sinusoidal wave has lowest voltage value than the two highest most carrier waveform and greater than two lowest most carrier waveform, the converter switches to $-V_{dc} / 4$ when the sinusoidal wave has highest voltage value than the lowest most carrier waveform value and lesser than all other carrier waveforms and the converter switches to $-V_{dc} / 2$ when the sinusoidal waveform value is lesser than all carrier.[8]

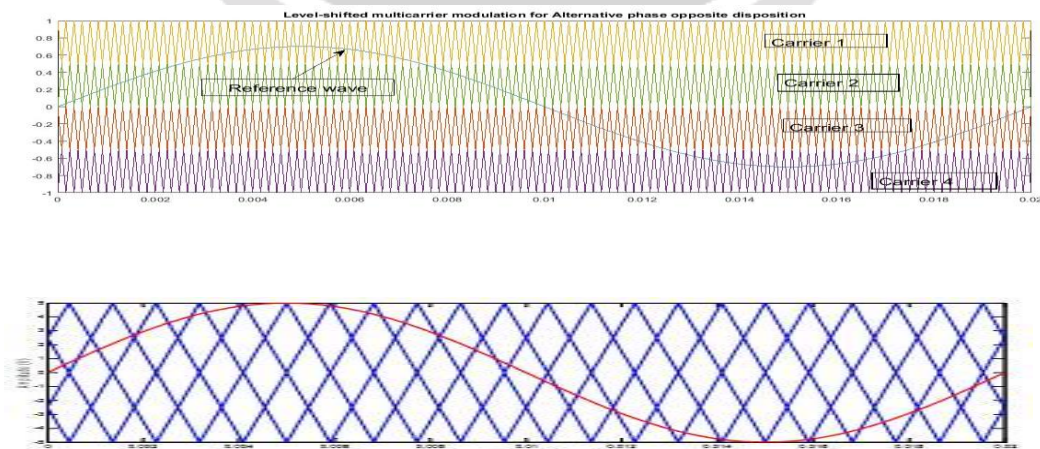


Figure 1.3: APOD method

2. Input Source

The details of Solar Energy (Renewable energy sources) is discussed as an input source.

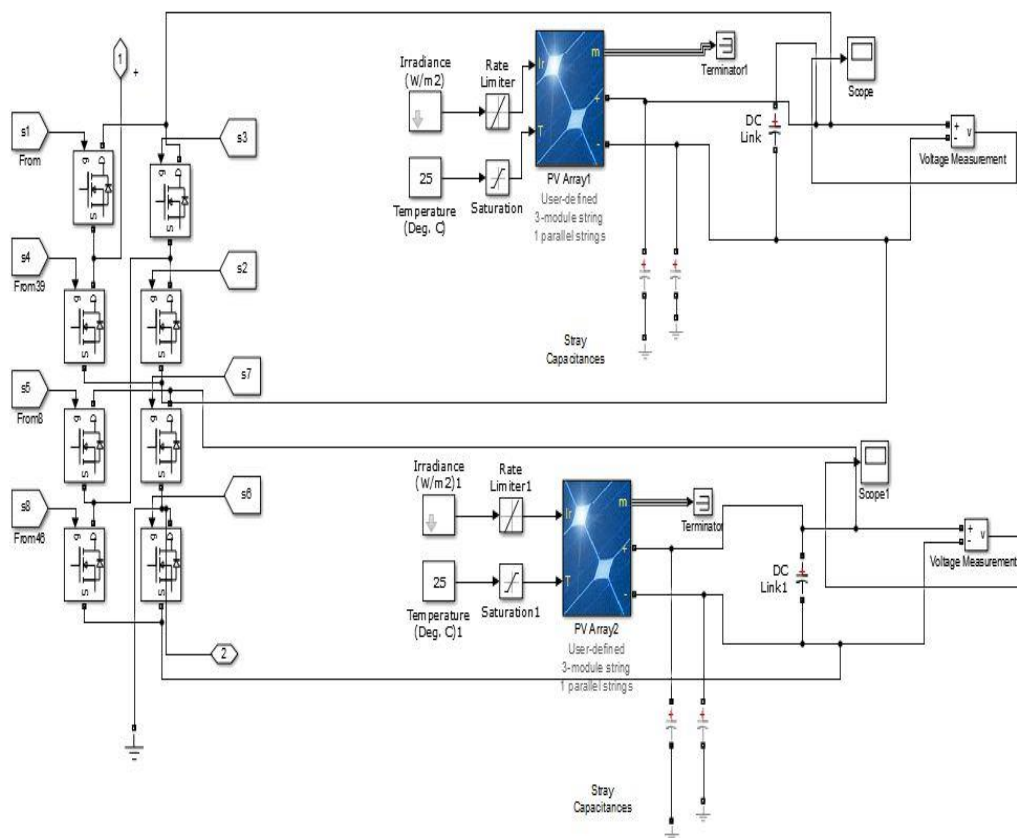
Solar panel refers either to a photovoltaic module, a solar hot water panel, or to a set of solar Photovoltaic (PV) modules electrically connected and mounted on a supporting structure. Solar panels can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. There are a few solar panels available that are exceeding 19% efficiency. A single solar module can produce only a limited amount of power; most installations contain multiple modules.

Merits of Solar Power

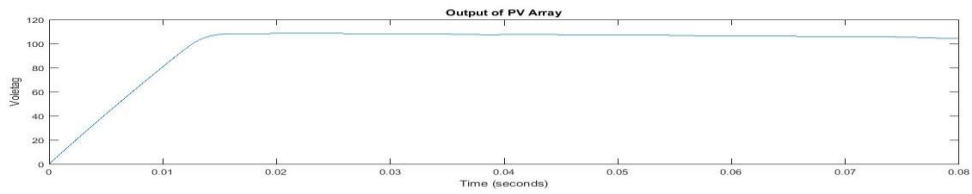
- A. Less maintenance compared to Conventional energy sources
- B. Produce little or no waste products such as carbon dioxide or other chemical pollutants.
- C. Minimal impact on the environment Sustainable and will never run out.
- D. Generated from natural sources and no fuel requirement.
- E. Reduces use of depleting fossil fuels

As discussed above input from DC source (i.e. DC Battery and PV array) is 100V.

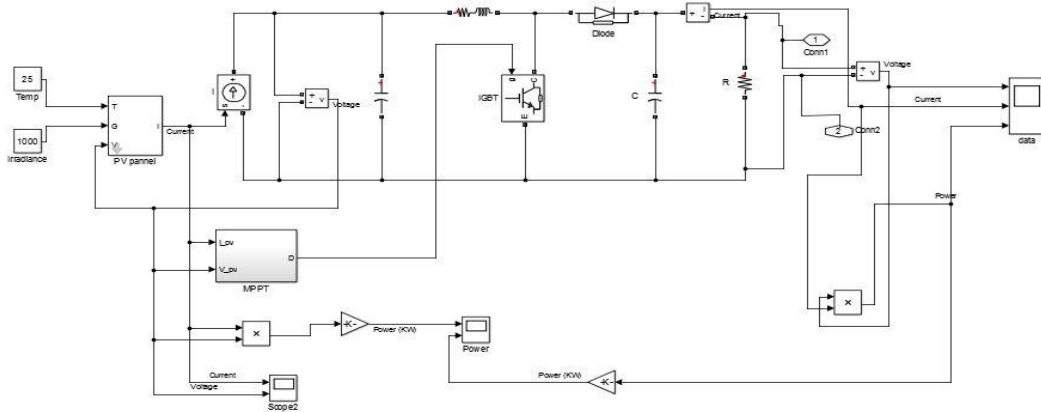
- (1) Here from MATLAB-Simulink, Solar panel Array is illustrated **Fig. 2.1**



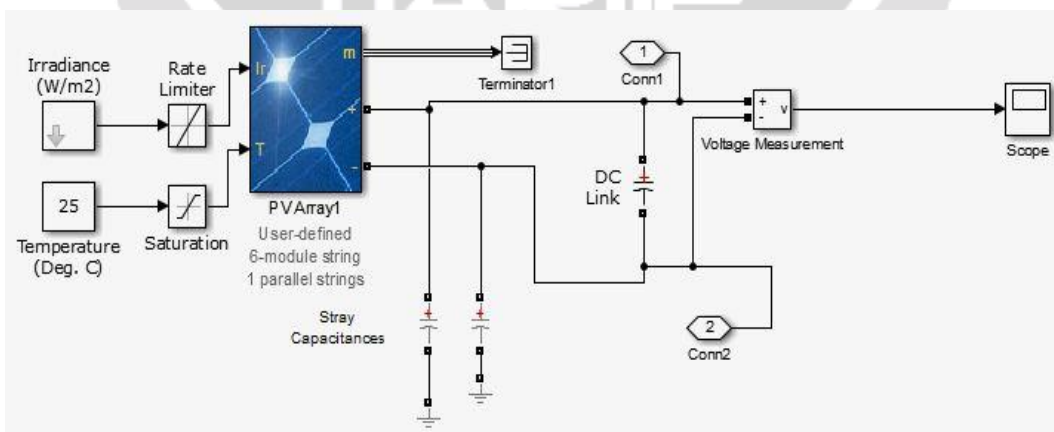
(2) Output from PV Array in MATLAB-Simulink **Fig.2.2**

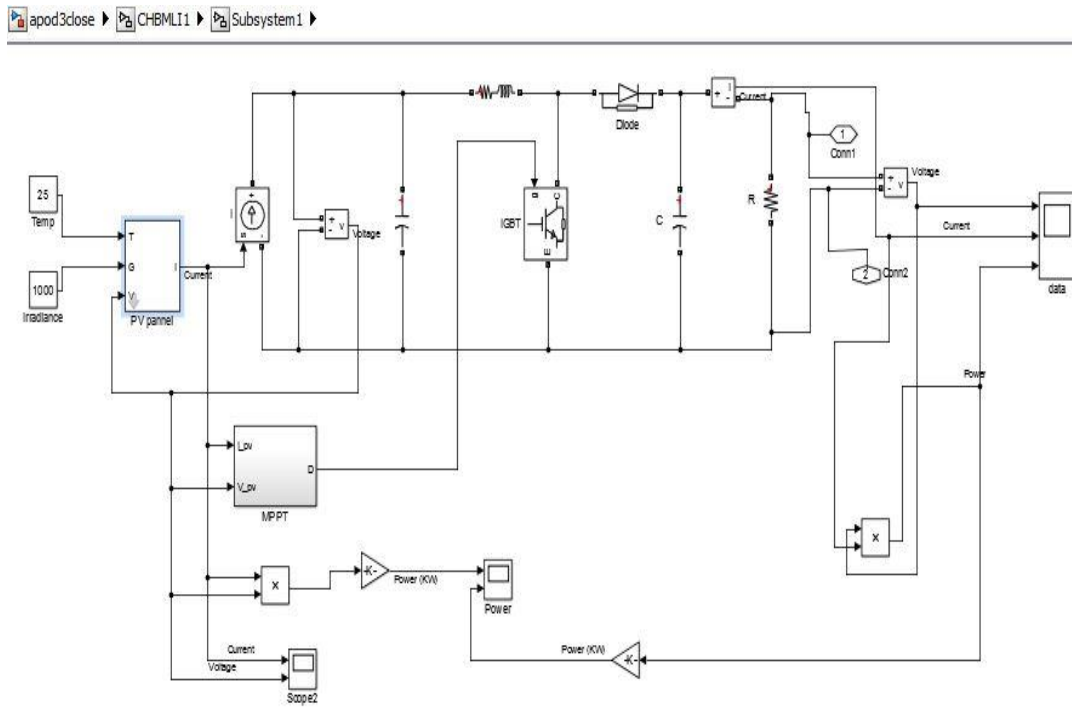


(3) Single phase Closed loop With MPPT Configuration **Fig.2.3**



(4) Three Phase Open Loop PV Input **Fig.2.4**



(5) Three Phase Closed Loop MPPT Configuration **Fig.2.5****2.1 MPPT and Insolation****MPPT**

A MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. To put it simply, they convert a higher voltage DC output from solar panel down to the lower voltage needed. Maximum Power Point Tracking is electronic tracking - usually digital. The charge controller looks at the output of the panels, and compares it to the battery voltage. It then figures out what is the best power that the panel can put out to charge the battery. It takes this and converts it to best voltage to get maximum into the battery. Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load. Engineers developing solar inverters implement MPPT algorithms to maximize the power generated by PV systems. The algorithms control the voltage to ensure that the system operates at "maximum power point" (or peak voltage) on the power voltage curve, as shown below. MPPT algorithms are typically used in the controller designs for PV systems. The algorithms account for factors such as variable irradiance (sunlight) and temperature to ensure that the PV system generates maximum power at all times. There are a number of maximum power point tracking (MPPT) algorithms which track the optimal current and voltage in a changing environment such as the model-based method, perturbation & observation (P&O) method, incremental conductance method and fuzzy logic method. Multilevel inverters put forward many benefits for higher power applications. In particular, these include ability to synthesis the voltage waveforms with lower harmonic content than 2-level inverters and operation at higher DC voltages using series connected semiconductor switches.

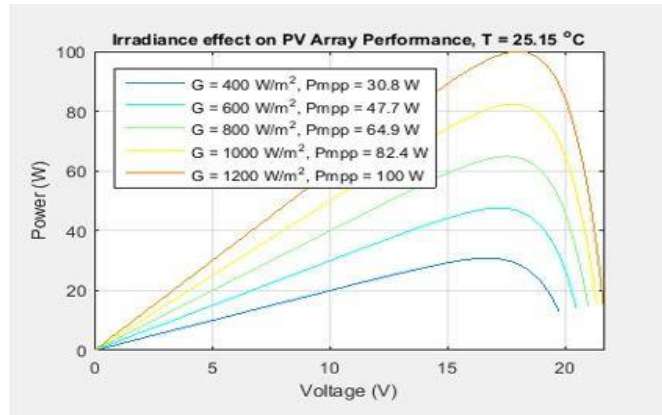


Fig. 2.6 Power voltage curve with I-V and P-V characteristics of a photovoltaic system.

Insolation

This refers to the amount of solar energy that is available at a given location, per unit of area and time. Typically, solar insolation is measured in **kilowatt-hours per square meter per day (kWh/m2/day)** and it is a very important factor to consider before installing a PV system, since it is the main variable that affects output:

$$\text{System output (kWh/day)} = \text{PV Array Area (m2)} \times \text{Efficiency (\%)} \times \text{Solar Insolation (kWh/m2/day)}$$

The array area and system efficiency are constant values, which means that the only variable factor is solar insolation. Two identical PV systems will have a different output if installed on locations with different solar insolation rates.

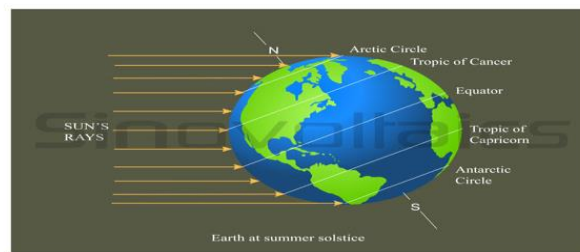
2.2 Solar Irradiance and Partial Shading

Solar Irradiance

Solar irradiance is the **instantaneous solar power per unit area**, and it is variable throughout the day. Solar irradiance is measured in **kilowatts per square meter**, and it directly affects the power generated by a solar PV system at a given moment.

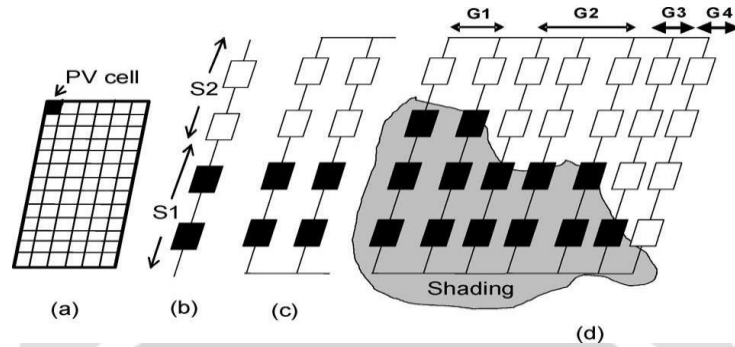
$$\text{Solar PV system instant power (kW)} = \text{PV array area (m2)} \times \text{Efficiency (\%)} \times \text{Solar Irradiance (kW/m2)}$$

It is important to note that the **nameplate power** of a solar PV module is the result of a laboratory test under an irradiance of **1 kilowatt per square meter**, at 25°C and using a light source with the same spectral characteristics as sunlight.



Partial Shading

In a solar photovoltaic array, it is possible that shadow may fall over some of its cells. Under partial shading conditions the PV characteristic gets more complex with multiple peaks. The purpose of this paper is to illustrate the effects that partial shading can cause in a PV array. This is done by simulation using Matlab. The characteristics of PV array are compared under partial shading and uniform irradiation.



The PV module is connected to a variable DC voltage source for measuring its I-V and P-V characteristics. It is modeled as three strings of 20 series-connected cells in parallel with bypass diodes that allow current flow when cells are shaded or damaged. Standard irradiance of 1000 W/m² is applied on the first string of 20 cells while partial shading is applied on strings 2 (cells 21-40) and string 3 (cells 41-60), resulting in respective irradiances of 300 W/m² and 600 W/m². [4]

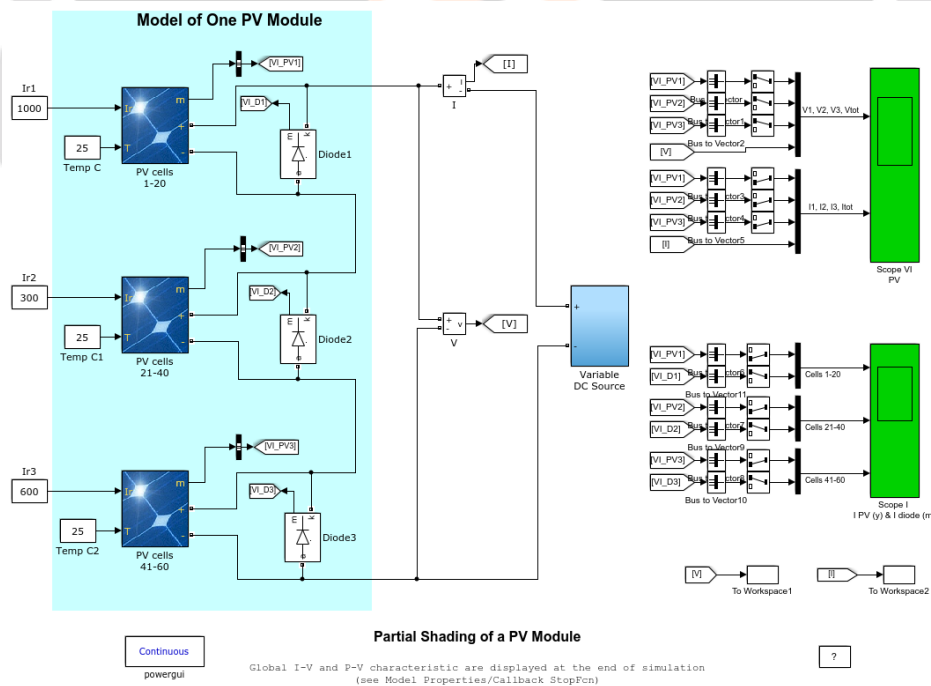
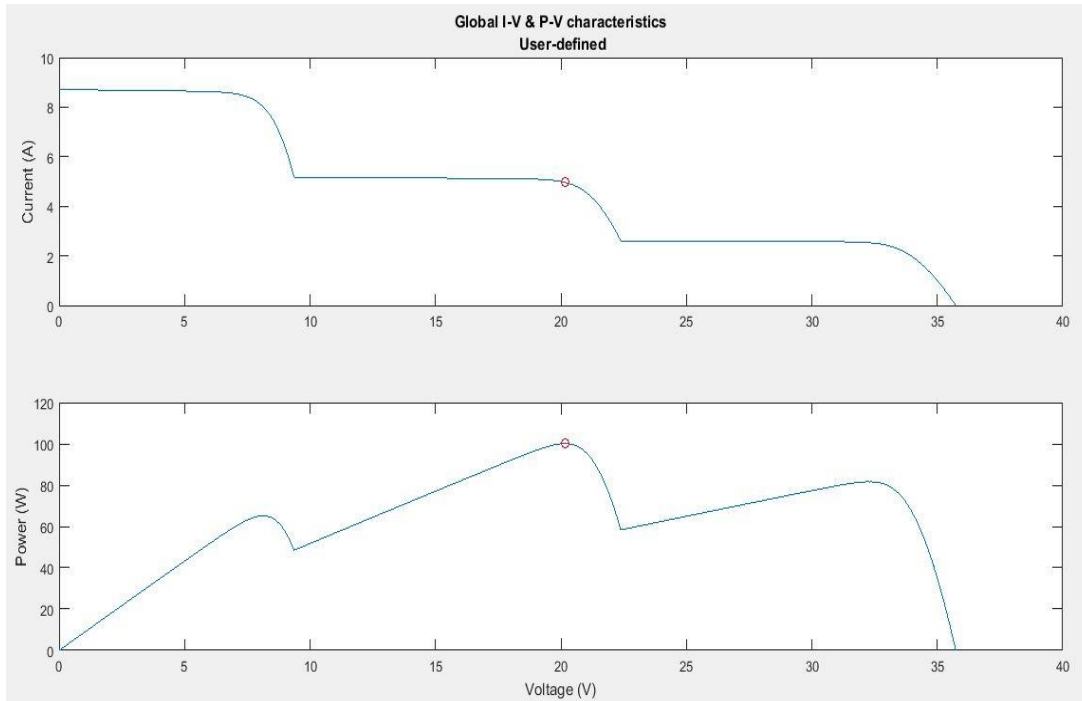


Fig. 2.7 The global I-V and P-V characteristics are plotted at the end of simulation.



Note that the P-V curve exhibits three maxima. When this PV module is connected to a voltage-sourced converter, this may be challenging for the Maximum Power Point Tracking (MPPT) algorithm to converge on the highest peak. The Global Maximum Power Point (GMPP) ($P_m = 104 \text{ W}$) indicated by a red circle on the figure is 34% lower than the expected maximum power ($250/3 \cdot (1 + 0.3 + 0.6) = 158 \text{ W}$).

3. Simulations and Results

The simulation is done using MATLAB Simulink. The name MATLAB stands for Matrix Laboratory. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research. MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide. It has powerful built-in routines that enable a very wide variety of computations. It also has easy to use graphics commands that make the visualization of results immediately available. Specific applications are collected in packages referred to as toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering. In addition to the MATLAB documentation which is mostly available on-line.

Single-phase CHB Inverter in MATLAB

Single phase five level Cascaded H-Bridge multilevel inverter with switching technique of multi carrier PWM techniques are employed. As suggested in previous chapters, there are three basic modulation methods for level shifted technique. We present here these methods in Simulink MATLAB model. The Simulink model and the internal circuit of five level single phase cascaded inverter for all three methods; IPD, PD and APOD became same. The modulation index for single phase can be varied from 0.1 to 0.9 and above 1.0 for over modulation, as an ideal condition; but we carried out our results with modulation index varies from 0.6 to 1.0 for all three methods.

The parameters employed for these models are as follow:

Sr. No.	Parameter	Value
1	DC voltage	200V
2	Reference Frequency	50Hz
3	Carrier frequency	6000Hz (Generally)
4	Modulation Index	0.8 (Generally)
5	MOSFET as a switch	8 nos.

Table 3.1: Parameter for IPD, PD, APOD methods for single phase

3.1 In Phase Disposition Method in MATLAB

The Simulink model, control circuit, CHB circuit, output voltage, output current as well as FFT analysis are implemented with the help of MATLAB Simulink Software. Here, we present the very first method IN PHASE DISPOSITION method as a PWM technique. The block diagram of single phase five level cascaded H- bridge multilevel inverter with In Phase Disposition method with R-L load is presented in figure. The value of resistor 20 Ω is and the value for inductor is 1mH.

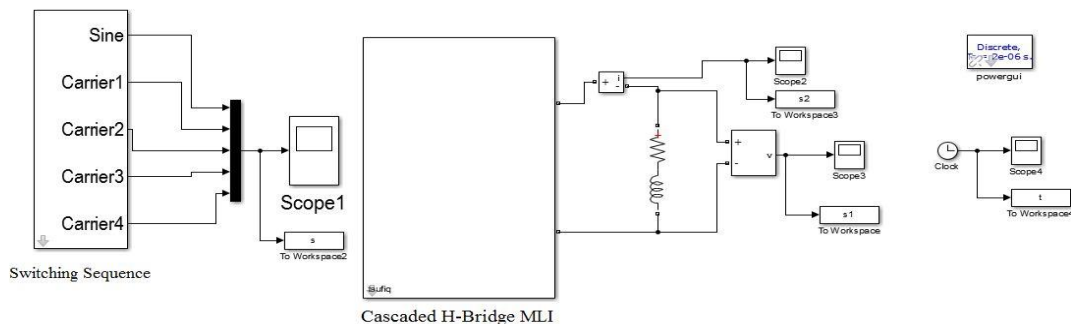


Figure 3.1: Simulink Model for single phase open loop IPD, PD, APOD in MATLAB

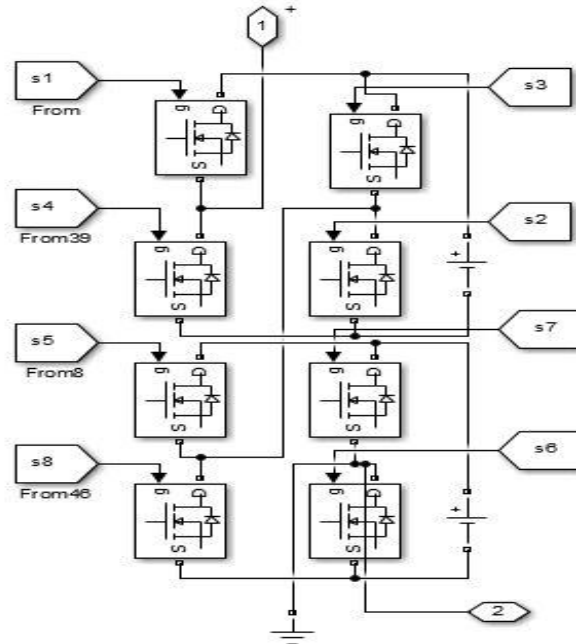


Figure3.2: Single phase open loop CHB inverter for IPD, PD, APOD in MATLAB

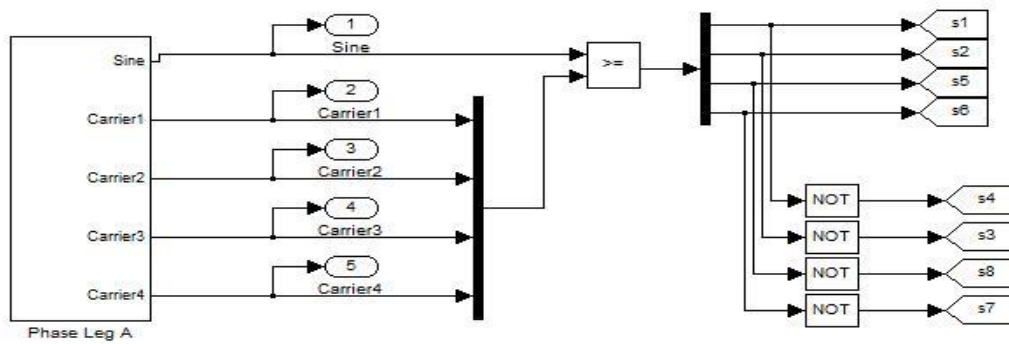


Figure 3.3: Switching diagram of Phase A of IPD in MATLAB

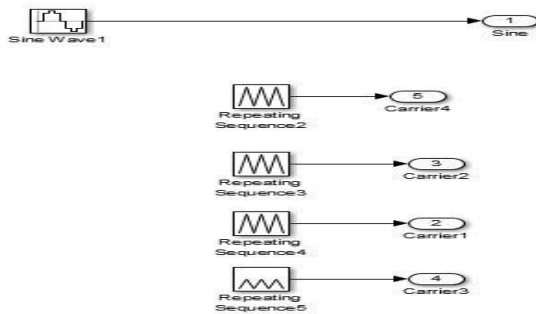


Figure 3.4: Switching technique for IPD in MATLAB

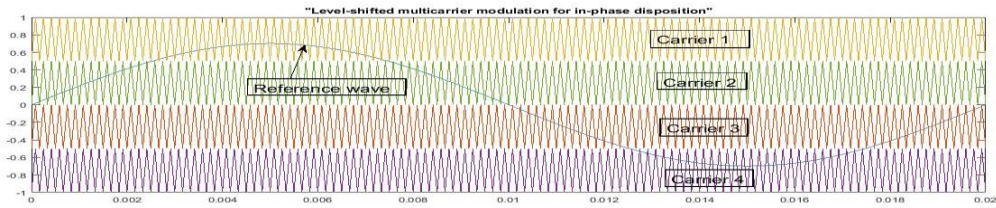


Figure 3.5: Comparison of signals in IPD technique in MATLAB

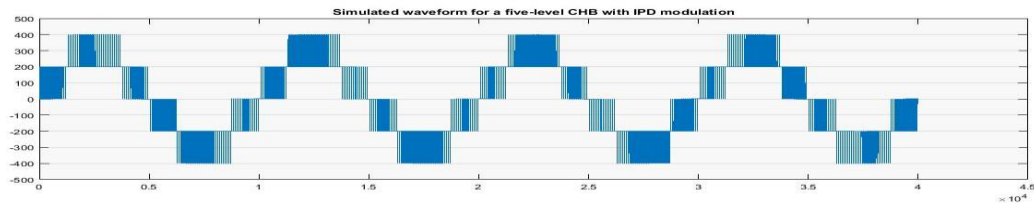


Figure 3.6: Output line to neutral voltage for IPD in MATLAB

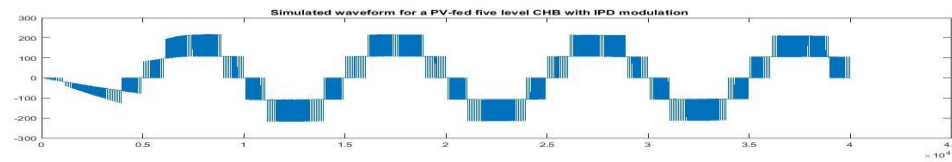


Figure 3.7: PV fed output voltage for IPD in MATLAB

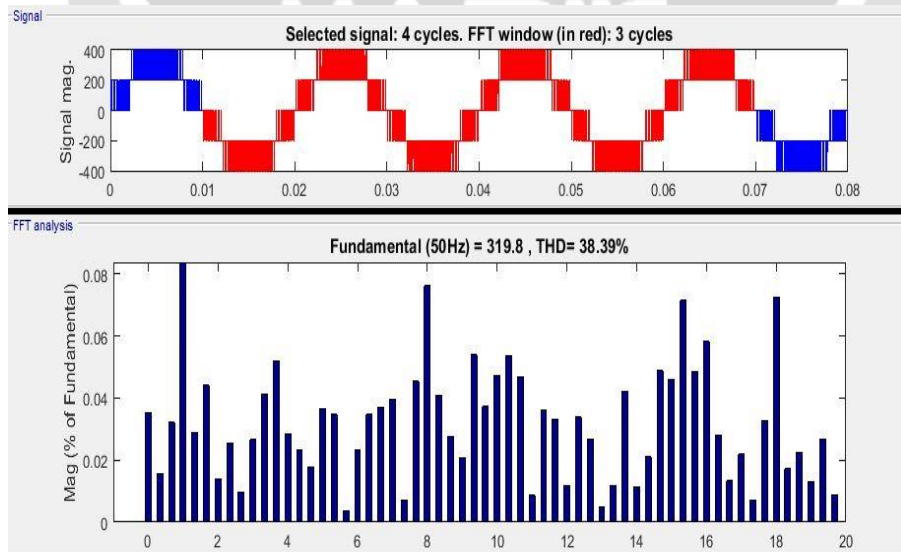


Figure 3.8: %THD voltage for IPD in MATLAB

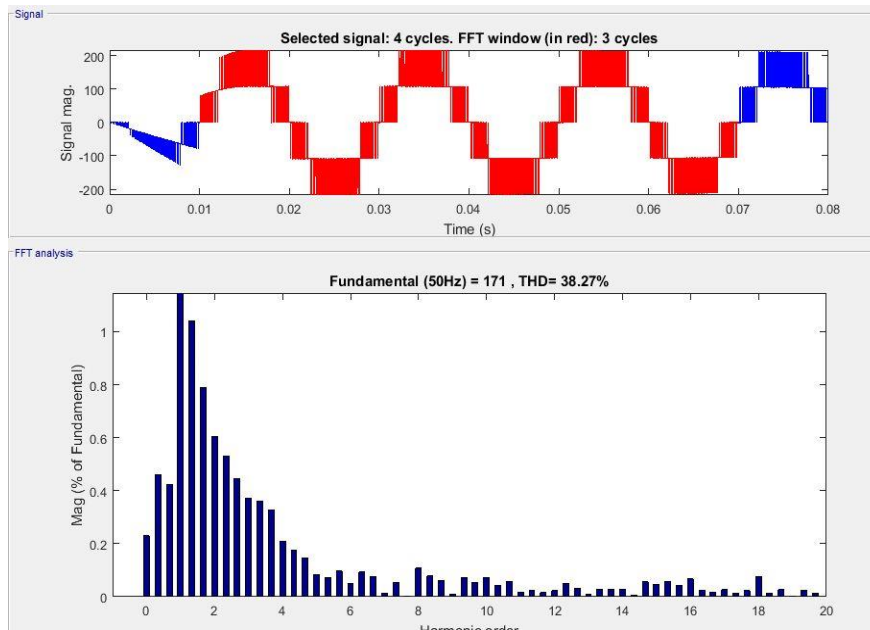


Figure 3.9: %THD voltage for PV fed IPD in MATLAB

Phase Opposition Disposition Method in MATLAB

The Simulink model, control circuit, CHB circuit, output voltage, output current as well as FFT analysis are implemented with the help of MATLAB Simulink Software. Here, we present the method PHASE OPPOSITION DISPOSITION method as a PWM technique. The block diagram of single phase five level cascaded H- bridge multilevel inverter with Phase Opposition Disposition method with R-L load is presented in figure. The value of resistor 20 Ω is and the value for inductor is 1mH..

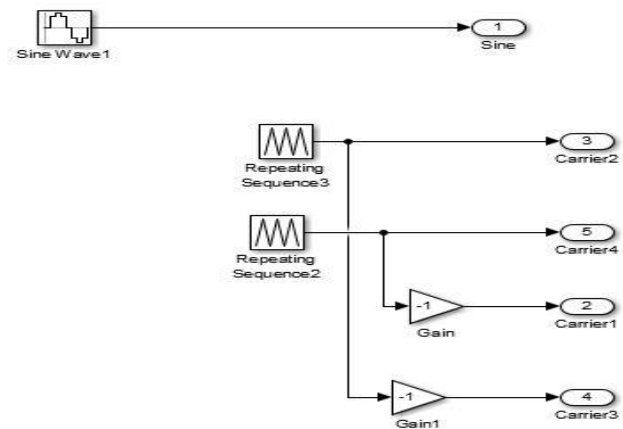


Figure 3.10: Switching technique for POD in MATLAB

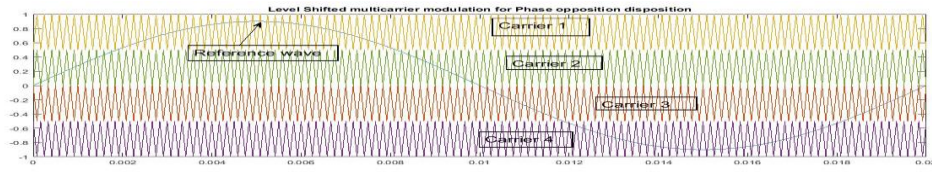


Figure 3.11: Comparison of signals in POD technique in MATLAB

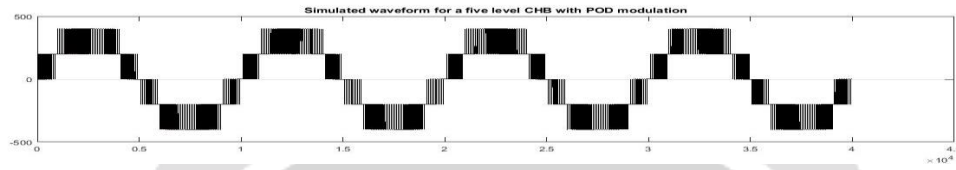


Figure 3.12: Output line to neutral voltage for POD in MATLAB

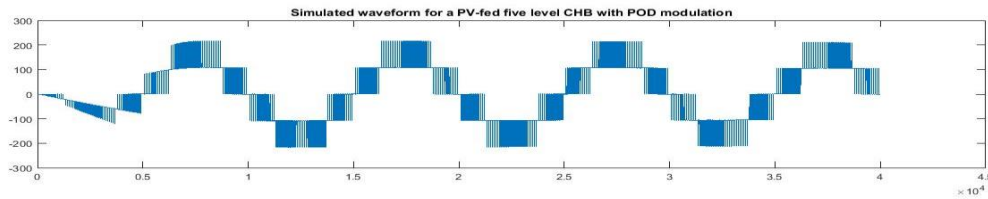


Figure 3.13: Output voltage for PV fed POD in MATLAB

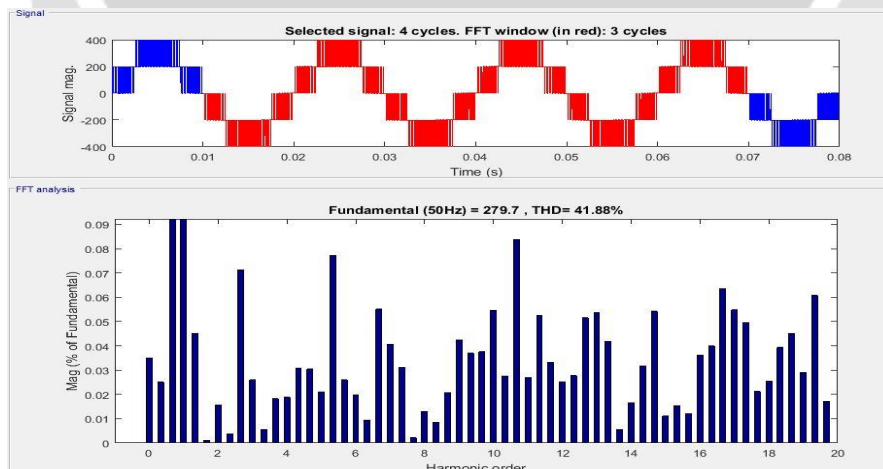


Figure 3.14: %THD voltage for POD in MATLAB

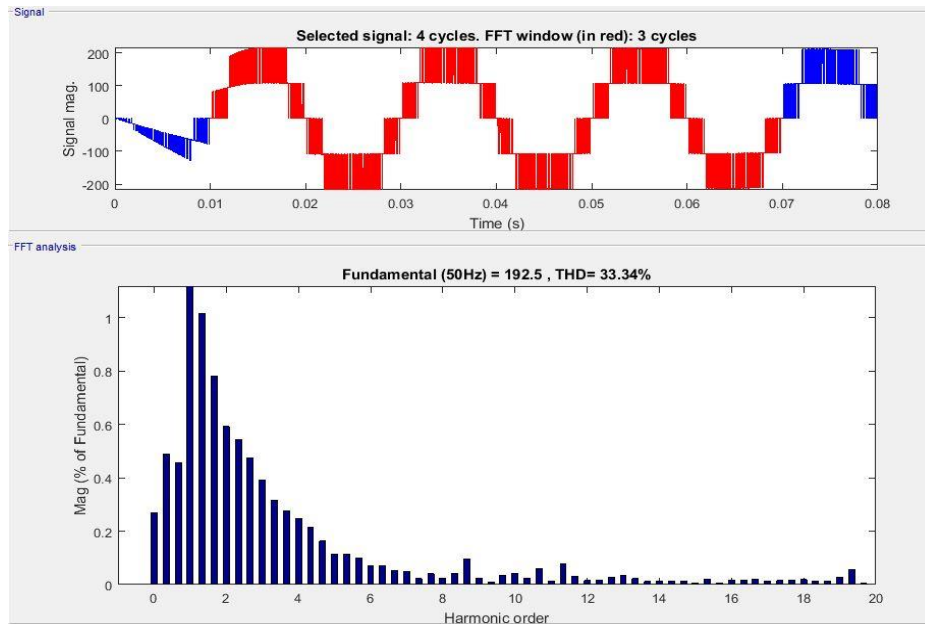


Figure 3.15: %THD voltage for PV fed POD in MATLAB

Alternate Phase Opposition Disposition

The Simulink model, control circuit, CHB circuit, output voltage, output current as well as FFT analysis are implemented with the help of MATLAB Simulink Software. Here, we present third method, ALTERNATE PHASE OPPOSITION DISPOSITION method as a PWM technique. The block diagram of single phase five level cascaded H- bridge multilevel inverter with Alternate Phase Opposition Disposition method with R-L load is presented in figure. The value of resistor 20Ω is and the value for inductor is 1mH. Switching diagram for APOD PWM is same as figure5.3.

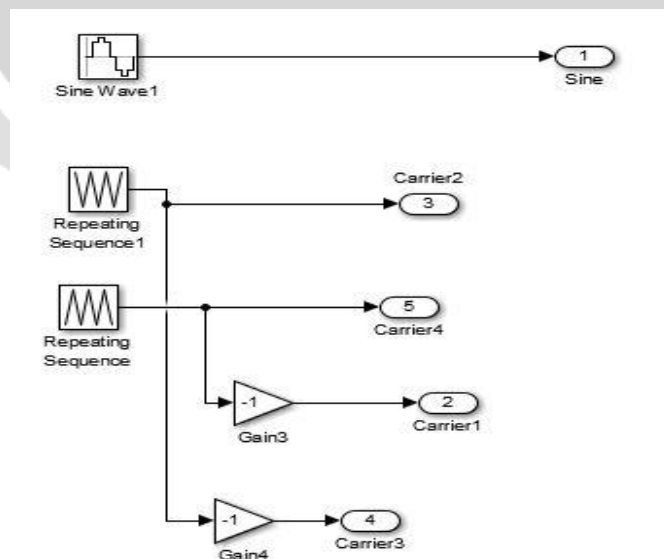


Figure 3.16: Switching technique for APOD in MATLAB

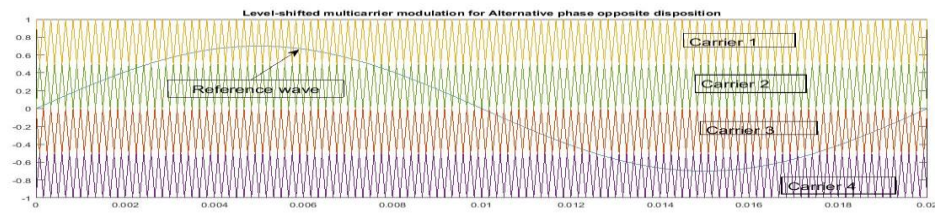


Figure 3.17: Comparison of signals in APOD technique in MATLAB

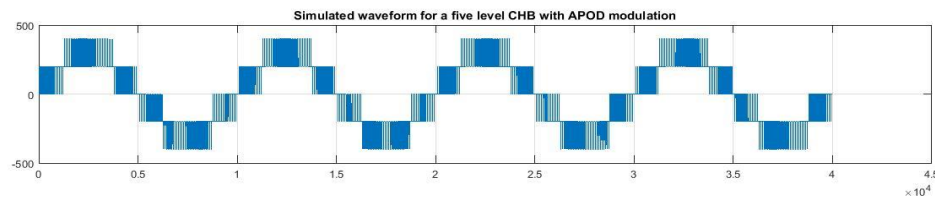


Figure 3.18: Output line to neutral voltage for APOD in MATLAB

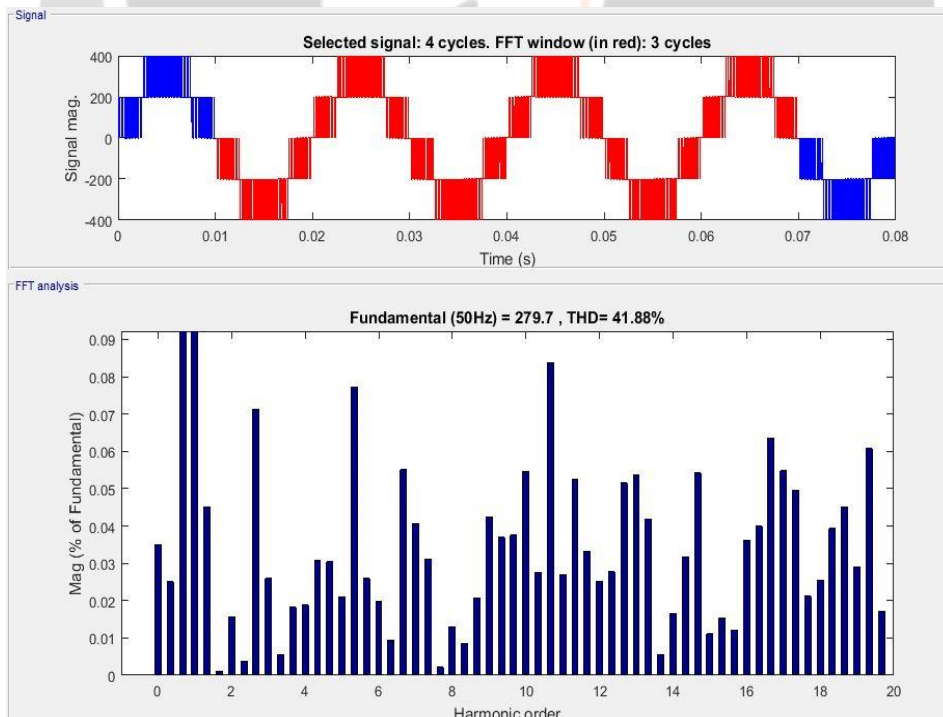


Figure 3.19: %THD voltage for APOD in MATLAB

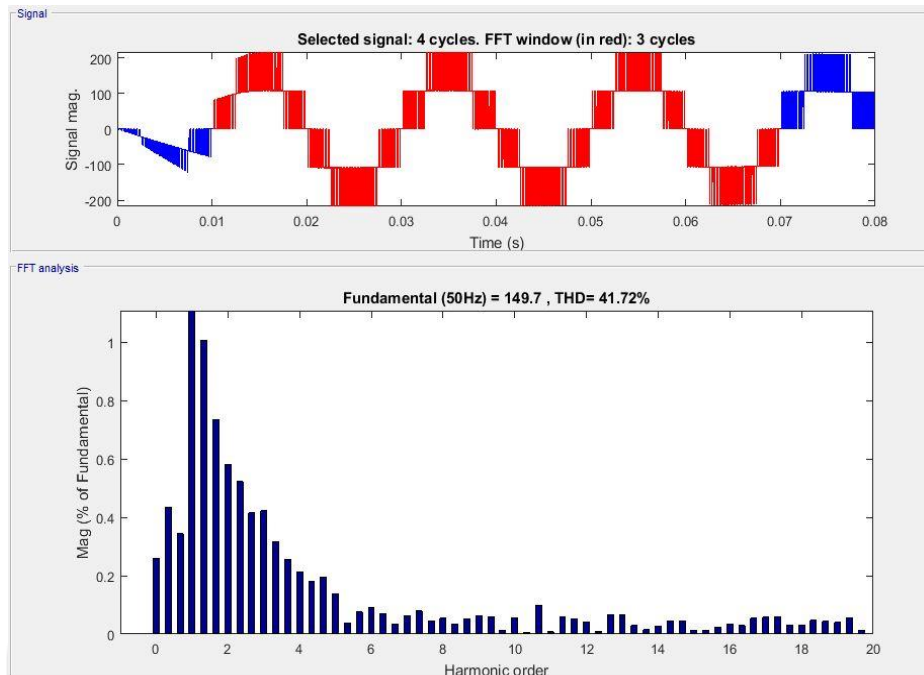


Figure 3.20: %THD voltage for PV fed APOD in MATLAB

From the above discussion, here we present a chart for single phase system in terms of Modulation Index with Carrier frequency, %THD for output voltage.

M.I.	IPD		POD		APOD	
	Cf	%THD Vol	Cf	%THD Vol	Cf	%THD Vol
0.7	4000	41.87	4000	41.72	4000	41.89
0.8	4000	38.38	4000	38.27	4000	38.34
0.9	4000	33.42	4000	33.32	4000	33.31

Table 3.1: Readings for single phase system with IPD, POD, and APOD method

M.I.	IPD		POD		APOD	
	Cf	5000	5000	5000	5000	5000
	%THD	%THD	%THD	%THD	%THD	%THD
	Vol	Vol	Vol	Vol	Vol	Vol
		With PV		With PV		With PV
0.7	41.93	41.76	41.86	41.68	41.84	41.65
0.8	38.41	38.30	38.42	38.30	38.41	38.28
0.9	33.51	33.40	33.52	33.40	33.41	33.29

Table 3.2: Readings for single phase system with IPD, POD, and APOD method

M.I.	IPD		POD		APOD	
	Cf	6000	6000	6000	6000	6000
	%THD	%THD	%THD	%THD	%THD	%THD
	Vol	Vol	Vol	Vol	Vol	Vol
		With PV		With PV		With PV
0.7	41.88	41.75	41.86	41.72	41.88	41.72
0.8	38.39	38.27	38.37	38.25	38.39	38.25
0.9	33.46	33.36	33.46	33.34	33.43	33.31

Table 3.3: Readings for single phase system with IPD, POD, and APOD method

4. CONCLUSIONS



The five level inverter using Multi-carrier based level shift PWM method consist high %THD in reference of the IEEE standard. %THD for voltage and using In Phase Disposition, Phase Opposition Disposition and Alternate Phase Opposition Disposition method can be decrease to a desire value is obtained. From the above discussion it is clear that the %THD value is also depends on the modulation index. There is a change in THD with respect to

Carrier Frequency and Modulation Index. In my case THD in close loop simulation is comparatively higher. Through Different irradiance we can different output and concept of partial shading can be understood.

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