International Journal of Engineering & Technology, 7 (3.31) (2017) 30-35

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Investigation of PV Connected Multilevel Cascaded H-Bridge Inverter Using Disposition Techniques

Muzeeb Khan Patan*, P. Udaya Bhanu, M.D. Azahar Ahmed

Department of Electrical and Electronics Engineering, S R K R Engineering College, Andhra Pradesh, India.-534204.
**Corresponding author E-mail:muzeebthegreat@gmail.com;Tel:+91-9030592248.*

Abstract

Inverters have many Technological improvements in their maximum power handling capabilities by using renewable energy sources. Multilevel inverters give effective and efficient interface for renewable energy sources and perform Transformer-less operation and increase the power quantity and quality of voltage of the PV system. In this paper, the benefits of H-bridge inverters including the total harmonic distortions are discussed. This paper has primarily focused on Sinusoidal PWM and worked on the carrier based phase disposition techniques. The performances of modulation schemes are compared. Simulations were done using MATLAB Simulink for the given PWM techniques.

Keywords: *Cascaded H-bridge multilevel inverters; Total harmonic distortions; phase disposition techniques; PV cell;, MPPT;*

1. Introduction

The structure of multilevel inverter should follows that have minimum number of switching devices, frequency and capable of receiving high input voltage power applications for HVDC transmission. Neutral point e clamped multilevel inverters, Imbricated cell multilevel inverters, Modular structured multilevel inverters are the three types of Multilevel Inverters.

For a desired AC voltage from different levels of DC voltages, a cascade MLI is used. From several years the research work is started, where the DC levels which are identical are considered from either batteries, solar cells or any renewable energy sources etc. A MLI have two separate DC sources instead of two transformers. Here one DC source for CHB MLI and other DC source for capacitors. In cascaded multilevel inverter for getting 2n+1 levels require ‘n’ number of DC sources. The difference between single stage invertor and cascaded invertor is shown in **Figure 1**. The cascaded H-bridge inverter structure have easy packaging and storage, the voltage levels are double the DC sources which are used and FC type MLI are having the disadvantages like number of DC sources or capacitors are required and controller is required due to complexity of structure.

In MLI types of carrier signals for high frequency schemes are Phase Disposition (PD) technique, Phase Opposition Disposition technique (POD), and Alternative Phase Opposition Disposition (APOD) technique, Phase Shift (PS), Variable Frequency Carrier Bands (VFCB) and Carrier Overlapping (CO). In Phase Disposition (PD) technique, all carrier waveforms are in phase with same frequency and amplitude and are shown in **Figure 2**. In Phase Opposition Disposition (POD) technique, the carrier waveforms above or below the zero reference value is in phase. However, they are phase shifted by 180° between the carrier waveforms above and below zero and it is shown in **Figure 3**. In Alternative

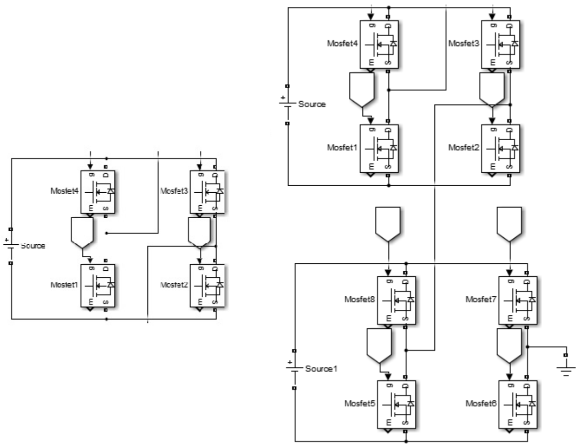


Fig. 1: Single Stage, 5 level Cascaded Inverter

Phase Opposition Disposition (APOD) technique, all carrier waveforms in this APOD technique are phase-displaced by 180° alternatively and it is shown in **Figure 4**.

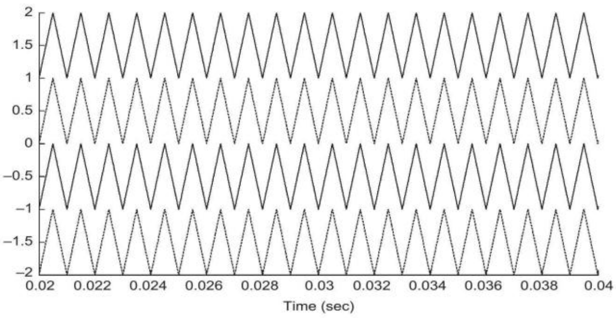


Fig. 2: Phase Disposition technique

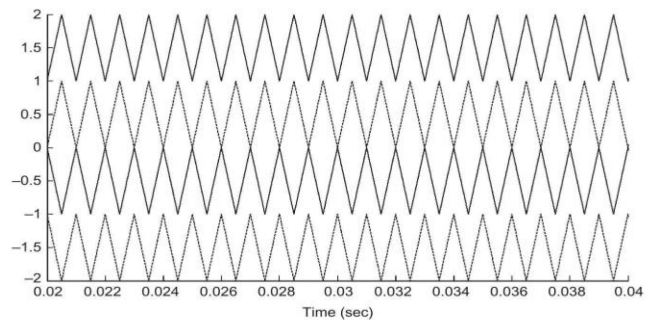


Fig. 3: Phase Opposition Disposition technique

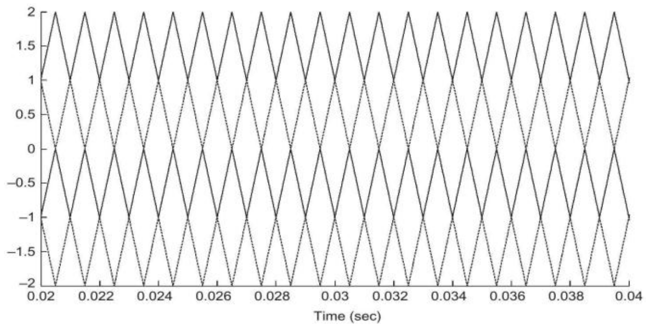


Fig. 4: Alternative Phase Opposition Disposition technique

In PS technique carriers are phase shifted depends on angle between the carriers which is shown in **Figure 5**.

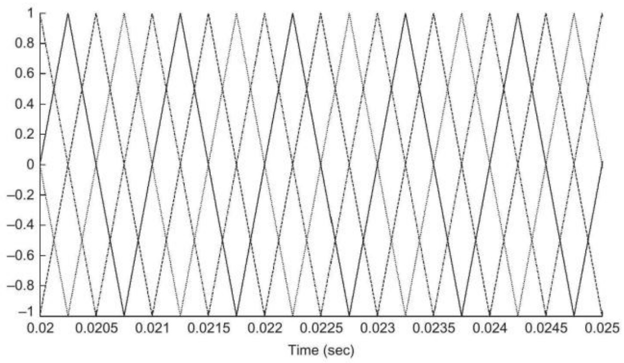


Fig. 5: Phase Shift technique

In Variable Frequency Carrier Bands (VFCB) technique, the frequency of the carriers is different which are shown in **Figure 6**.

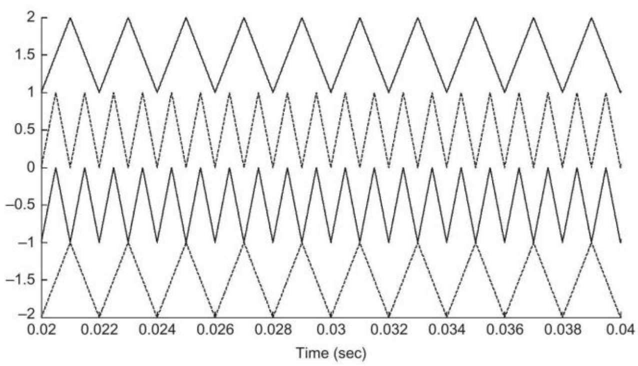


Fig. 6. Variable Frequency Carrier Bands technique

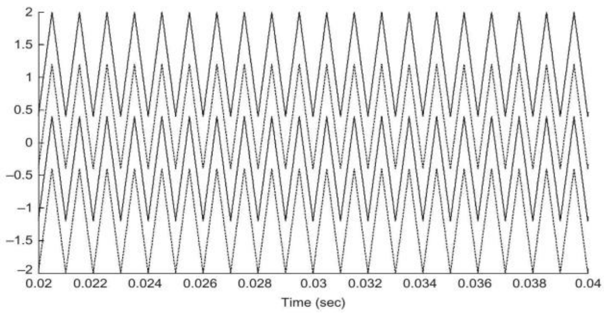


Fig. 7: Carrier overlapping technique

In CO technique, the carriers are overlap each other and it is depends on quality of output waveform. The waveforms for Carrier Overlapping technique are shown in **Figure 7**.

Mohan M. Renge, et al. explained by using a phase opposition disposed (POD) sinusoidal pulse width modulation (SPWM) technique how the common-mode voltage (CMV) at the output of multilevel inverters is reduced [1]. Abdelhalim Zekry explained a system which is used to give the optimum results [2]. Krishna Kumar Gupta, et al. reviewed and analyzed some of the recently proposed multilevel inverter topologies with reduced power switch count [3]. Walter A. Hill Salem, Cyrus D. Harbourt, presented the ways to build Medium Voltage Inverters and mainly focused on the characteristics of two types of non-regenerative Medium Voltage Source Inverters that are in the market place today [4]. Kapil Jain, Pradyumn Chaturvedi are proposed the multilevel began with the three level converters. The elementary concept of a multilevel converter to achieve higher power to use a series of power semiconductor switches with several lower voltage dc source to perform the power conversion by synthesizing a staircase voltage waveform [10].

All the previous work having the disadvantage of diode clamped multilevel inverters that are have the extra clamping diodes which are required when the number of voltage levels are increased. It is difficult to control the real power flow of individual converter and in Flying capacitor multilevel have the drawback i.e., When the number of voltage levels are increased, a bulk amount of storage capacitor is required. Hence the high level systems are more difficult to package due to bulky capacitors and expensive and converter control is very complicated.

2. Proposed PV Connected RES

Micro-grid connected PV power based on modular MLI topology is shown in **Figure 8**.

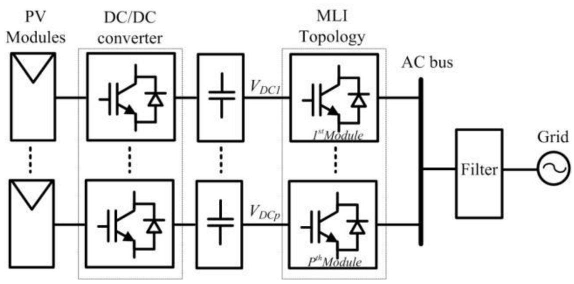


Fig. 8: Micro grid connected PV power based on modular MLI topology.

The single DC source MLI topologies reduce the extra DC sources requirement for high levels. The issue of capacitor voltage balancing problem needs the solution. The multiple DC source MLI topologies are best for new power generations based on renewable energy sources (RES) such as photo-voltaic due to its modular and simple structure. Cascaded H-bridge MLI topology is shown in **Figure 9**.

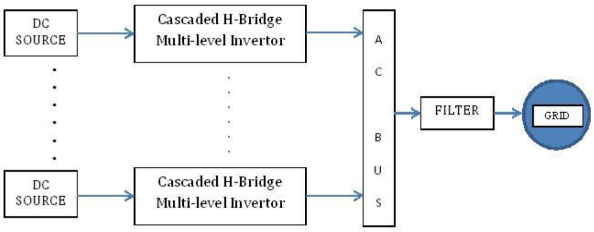


Fig. 9. Cascaded H-Bridge MLI topology

2.1 PV Module

PV module contains Solar cells which converts directly solar power into DC. The quality of delivered DC depends on the intensity of Solar and also atmosphere conditions. It provides two non-linear characteristics; they are P-*V* curve and *I*-*V* curve. For getting maximum power from Solar, MPPT controller is required. The Solar cell output voltage is not satisfying the desired value because its output voltage depends upon the atmospheric conditions. So a step-up DC/DC converter is used for getting better results as required. By changing the parameters like irradiance, temperature etc. observe the behavior of the PV panel get simulation results in software. For Maximum power from PV panel developed an algorithm by sensing the PV panel voltage *VPV* and current *IPV*. To simulate the PV panel, the specifications are taken from the SOLAREX MSX 60 datasheet.

The PV panel model having photo current, *Iph*, series resistor Rs and shunt resistor *Rsh* are given in **Figure 10**. The equation for *V-I* characteristic is from single diode model:

$$I_{PV} = I_{ph} - \underbrace{I_o\left[\exp\left(\frac{V_{PV}+I_{PV}R_s}{V_t a}-1\right)\right]}_{I_d} - \frac{V_{PV}+I_{PV}R_s}{R_{sh}} ------(1)$$

Here I_d - diode current, I_o - saturation current, and V_t - junction voltage. It is formed as

$$V_t = \frac{kATn_s}{q} --------(2)$$

Here q- charge of electron (1.6x10^{-19} C), *k*- Boltzmann's constant (1.38x10^{-23} J/K), *A* - Ideal factor, *T* - running temperature, *ns* – no.of series connected cells of PV module. For Simulation results using SOLAREX MSX-60 PV panel.

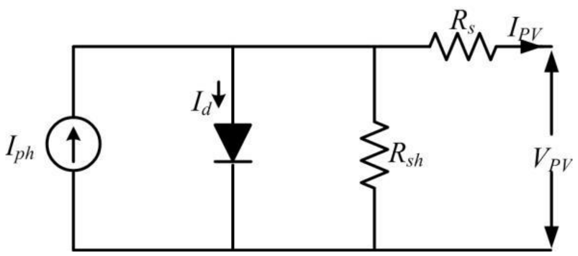


Fig. 10: Model of single diode PV cell.

By observing SOLAREX MSX 60 Datasheet Specifications, Maximum power(P_{MAX}) drawn by the system is given 60W, Voltage at P_{MAX}(V_{MP}) is given 17.1V, Current at P_{MAX}(I_{MP})is given by 3.5A, Short circuit current, I_{SC} is given by 3.8A, Open circuit voltage, V_{OC} is given as 21.1V, Temperature co-efficient of V_{OC} is given as -80mV/^{0}**C,** Temperature co-efficient of I_{SC} is given by 0.065%/^{0}**C,** Temperature co-efficient of P_{MAX} is given by -0.5%/^{0}**C,** Number of series cells are given 36, Number of Parallel cells are given as value 1.

2.2 Maximum Power Point Tracking (MPPT)

The Photo Voltaic system is the main source of renewable energy system. For getting the maximum power from the SUN use Maximum Power Point controller at generation side [11]. Voltage from PV panel is irregular so for getting constant voltage from PV panel use DC/DC boost converter and use perturbation & observation technique algorithm shown in **Figure 11**. Input voltage taken up to 200v in this paper.

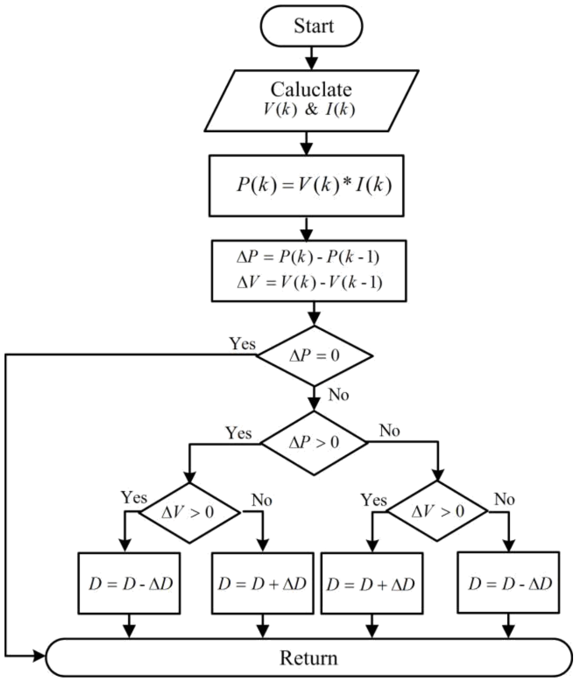


Fig. 11: Conventional Perturb & Observe MPPT Algorithm.

3. Simulation Results

Simulation results for voltages and currents of output for MPPT model are shown in **Figure 12**. THD analysis for MPPT at Power factor 1 is shown on **Table 1** and in this THD is less in APOD technique as compared with PD & POD. THD analysis for MPPT at Power factor 0.5 is shown on **Table 2**. Bar graph for THD analysis of voltage using different disposition techniques is shown in **Figure 13**.

Table 1. THD analysis for MPPT at Power factor 1

	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
PD	26.97	156.6	26.97	1.305	17.34	270.9
POD	26.96	156.9	26.96	1.307	23.08	270.8
APOD	26.03	156.4	26.03	1.303	22.90	270.3

Table 2. THD analysis for MPPT at Power factor 0.5

	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
PD	26.51	153	1.49	3.423	17.07	264.5
POD	26.51	153.4	1.37	3.433	22.72	264.9
APOD	25.62	152.9	1.41	3.421	22.52	264.4

(a) (b) (c)

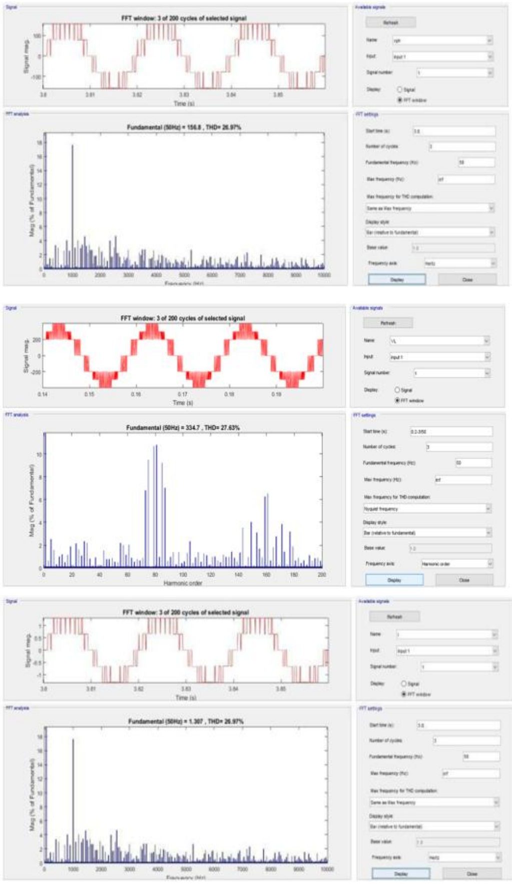


Fig. 12: THD analysis for MPPT model (a) Output Current waveform; (b) Output line voltage; (c) Output Phase voltage.

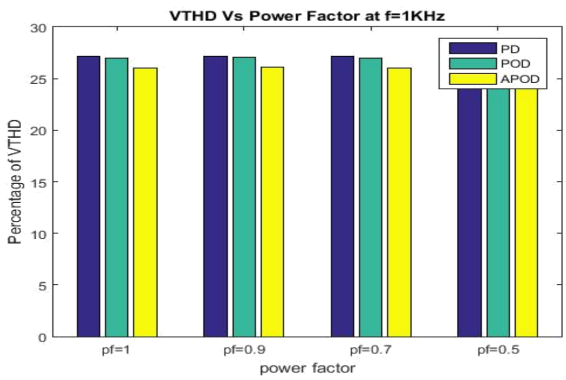


Fig. 13: Bar graph for THD analysis of voltage using disposition techniques.

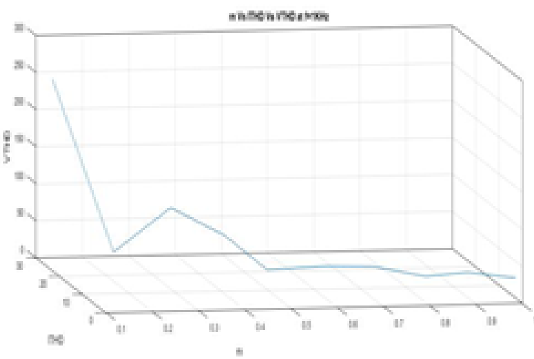


Fig. 14: m Vs ITHD Vs VTHD for MPPT model at f=1KHz

And a graph between m Vs ITHD Vs VTHD at f=1KHz is shown in **Figure 14**. Different values of current and voltage at different values of m for PD is shown in **Table 3**. And in this, VTHD & ITHD are better in APOD technique. Different values of current and voltage at different values of m for PD is shown in **Table 4**. And in this, VTHD & ITHD are better in APOD technique.

Simulation results for voltages and currents of output for DC model at PF=1, are shown in **Figure 15**. Bar graph for THD analysis of voltage using different disposition techniques for DC model is shown in **Figure 16**. Simulation results for voltages and currents of output for DC model at PF=0.5, are shown in **Figure 17**.

Table 3. Voltages and Currents for DC at Freq=1 KHz, for PD

m	VTHD	VFND	ITHD	IFN	VLTH	VLFN
1	27.19	199.7	3.00	2.14	17.32	344.7
0.9	34.07	178.3	3.74	1.91	17.55	309
0.8	35.23	181.3	1.61	1.95	16.22	312.6
0.7	42087	138.1	4.50	1.48	23.82	239
0.6	44.88	118.3	4.46	1.27	26.43	206
0.5	27.02	200.2	10.28	1.99	23.15	345.1
0.4	78.80	79.17	8.50	0.85	63.88	136.3
0.3	109.36	58.75	11.90	0.63	86.95	101.3
0.2	39.27	153.83	16.62	0.42	130.23	66.55
0.1	258.35	17.68	23.00	0.19	230.40	30.09

Table 4. Voltages and Currents for MPPT at Freq=1 KHz, for PD

m	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	26.92	155.6	3.04	1.673	17.32	269.1
0.9	33.79	141.4	3.76	1.521	17.45	245.4
0.8	38.96	126.9	4.50	1.364	21.33	220.6
0.7	42.55	112.3	4.54	1.207	23.86	194.6
0.6	44.51	97.21	4.48	1.045	26.59	169.4
0.5	54.28	81.64	5.35	0.878	36.14	141.6
0.4	66.14	78.75	8.59	0.711	41.99	114
0.3	109.34	48.9	11.73	0.525	52.88	85.02
0.2	154.95	31.73	15.85	0.341	97.78	55.21
0.1	258.35	14.46	21.53	0.155	185.34	25.26

(a) (b) (c)

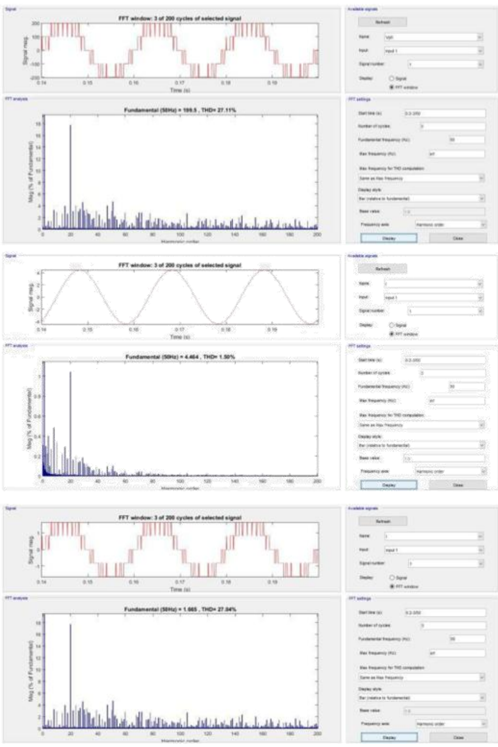


Fig. 15. THD analysis for DC model at PF =1, (a) Output line voltage; (b)Output current waveform; (c) Output Phase voltage.

A graph between m Vs. ITHD vs. VTHD at f=1 KHz is shown in **Figure 18**. And simulation results for voltages and currents of output for MPPT model at PF=0.5, are shown in **Figure 19**. THD analysis for Voltages and Currents at Frequency=1KHZ, m=1, PF=1 for PD, POD, APOD are shown in **Table 5**. THD analysis for Voltages and Currents at Frequency=1KHZ, m=1, PF=0.5 for PD, POD, APOD are shown in **Table 6**.

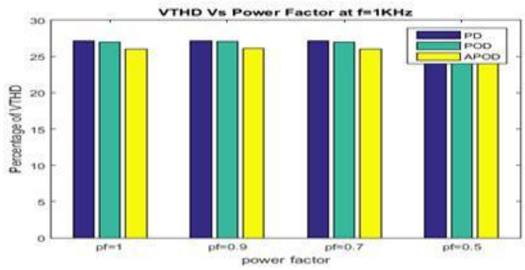
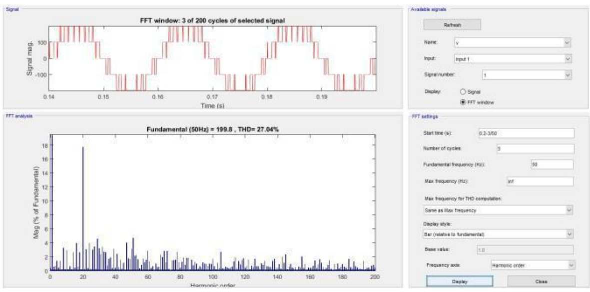
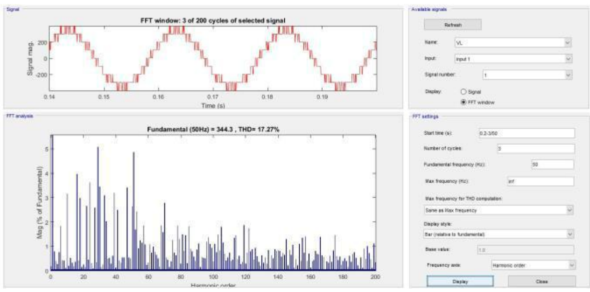


Fig. 16: For DC model, VTHD Vs Power factor at f=1KHz

(a)



(b)



(c)

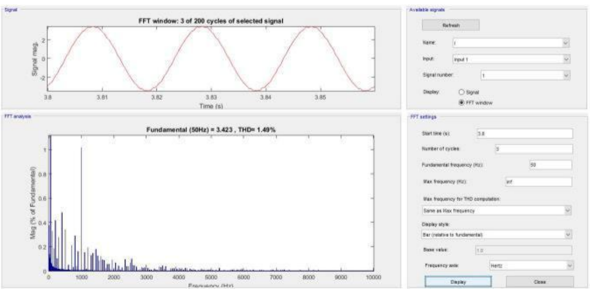


Fig. 17: THD analysis for DC model at PF=0.5, (a) Output line voltage; (b)Output current waveform; (c) Output Phase voltage.

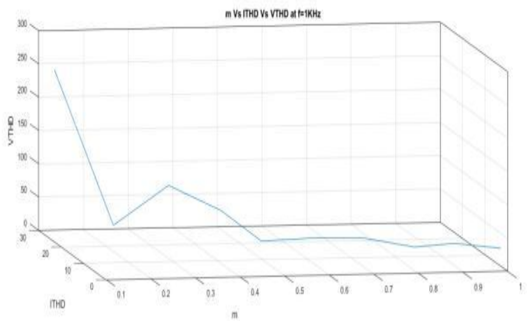
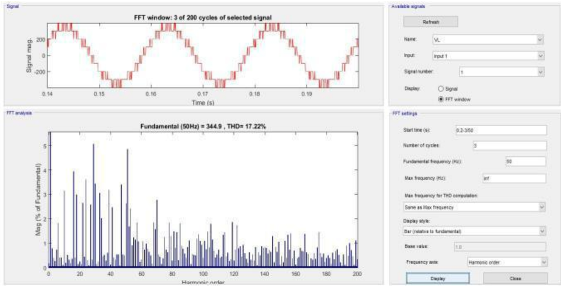
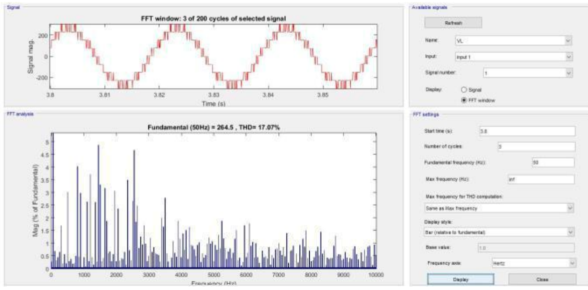


Fig. 18: mVs ITHD Vs VTHD at f=1KHz

(a)



(b)



(c)

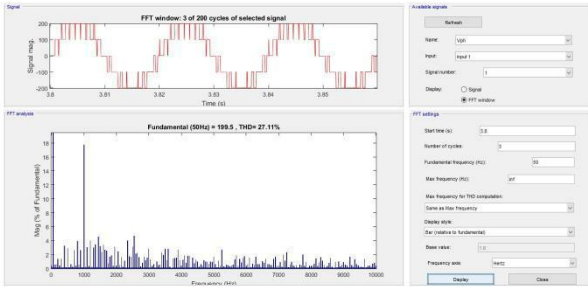


Fig. 19: THD analysis for MPPT model at PF 0.5 (a) Output line voltage; (b) Output current waveform; (c) Output Phase voltage.

Table 5. THD analysis for Voltages and Currents atFrequency=1KHZ, m=1, PF=1 for PD, POD, APOD.

	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
PD	27.12	199.8	27.12	1.665	17.27	344.9
POD	26.95	200.3	26.95	1.669	22.11	343.1
APOD	26.03	344.2	26.03	1.661	22.80	29.94

Table 6. THD analysis for Voltages and Currents at Frequency=1KHZ, m=1, PF=0.5 for PD, POD, APOD.

	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
PD	27.19	199.5	1.48	4.464	17.32	344.3
POD	27.02	199.9	1.42	4.474	22.11	342.7
APOD	26.10	199	1.39	4.453	22.86	343.6

THD analysis for Voltages and Currents at Frequency=1KHZ, m=1 for Phase Shift Pulse Width Modulation (PS-PWM) technique for different PF values are shown in **Table 7**. THD analysis for Voltages and Currents at Frequency=1KHZ, PF=1 for Phase Shift Pulse Width Modulation (PS-PWM) technique for different modulation values are shown in **Table 8**.

Table 7. THD analysis for Voltages and Currents at Frequency=1KHZ, m=1 for PS PWM technique.

PF	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	37.70	47.87	37.70	0.399	41.17	78.85
0.9	37.68	47.84	23.50	0.5133	41.14	78.82
0.7	37.37	46.6	28.56	0.8349	40.73	76.85
0.5	37.36	46.58	32.73	1.043	40.78	76.81

Table 8. THD analysis for Voltages and Currents at Frequency=1KHZ, PF=1 for PS PWM technique

m	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	37.70	47.87	37.70	0.399	41.17	78.85
0.9	40.24	45.36	40.24	0.378	41.23	74.49
0.8	47.79	38.25	47.79	0.3188	45.17	63.3
0.7	48.94	36.22	48.94	0.3018	38.38	59.42

0.6	47.46	28.97	47.46	0.2414	42.45	47.31
0.5	58.05	26.36	58.05	0.2197	48.12	43.5
0.4	104.46	18.26	104.46	0.1521	104.05	29.76
0.3	112.79	16.44	112.79	0.137	104.76	27.01
0.2	242.01	6.752	242.01	0.056	231.68	10.77
0.1	242.01	6.756	242.01	0.056	231.68	10.77

THD analysis for Voltages and Currents at Frequency=1KHZ, m=1 for Variable Frequency Carrier Band (VFCB) for different PF values are shown in **Table 9**. THD analysis for Voltages and Currents at Frequency=1KHZ, PF=1 for Variable Frequency Carrier Band (VFCB) for different modulation values are shown in **Table 10**.

Table 9. THD analysis for Voltages and Currents at Frequency=1KHZ, m=1 for VFCB technique.

PF	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	113.17	19.69	113.17	0.1641	77.55	36.14
0.9	113.94	19.76	54.07	0.213	77.97	36.31
0.7	114.52	19.59	45.41	0.3516	78.39	36.02
0.5	113.31	19.74	42.63	0.423	77.87	36.26

Table 10. THD analysis for Voltages and Currents at Frequency=1KHZ, PF=1 for VFCB technique.

m	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	113.17	19.69	113.17	0.1641	77.55	36.14
0.9	156.67	14.52	156.67	0.121	98.69	27.89
0.8	224.36	10.04	224.36	0.083	152.09	19.97
0.7	367.01	6.015	367.01	0.0501	263.09	12.37
0.6	953.82	2.162	953.82	0.018	523.54	6.005
0.5	1732.34	1.14	1732.34	0.0094	1627.20	1.791
0.4	1159.39	1.76	1159.39	0.01467	2015.75	1.62
0.3	805.41	2.47	805.41	0.0205	2196.50	1.476
0.2	573.17	3.141	573.17	0.0262	2477.65	1.064
0.1	323.24	4.35	323.24	0.036	4008.76	0.4484

THD analysis for Voltages and Currents at Frequency=1KHZ, m=1 for Carrier Overlapping (CO) technique for different PF values are shown in **Table 11**. THD analysis for Voltages and Currents at Frequency=1KHZ, PF=1 for Carrier Overlapping (CO) technique for different modulation values are shown in **Table 12**.

Table 11. THD analysis for Voltages and Currents at Frequency=1KHZ, m=1 for CO technique

PF	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	43.33	51.86	43.33	0.432	35.43	83.06
0.9	43.22	51.91	24.83	0.5572	37.24	86.43
0.7	42.63	50.21	34.77	80.69	34.77	80.69
0.5	42.39	50.14	31.29	1.122	36.46	83.61

Table 12. THD analysis for Voltages and Currents at Frequency=1KHZ, PF=1 for CO technique.

m	VTHD	VFND	ITHD	IFND	VLTHD	VLFND
1	43.33	51.86	43.33	0.432	35.43	83.06
0.9	48.23	49.13	48.23	0.4094	37.74	82.3
0.8	54.23	45.89	54.23	0.3824	39.50	76.64
0.7	64.93	41.41	64.93	0.3451	41.20	70.1
0.6	76.94	36.77	76.94	0.3064	43.93	62.09
0.5	99.29	29.69	99.29	0.2474	53.17	51.08
0.4	126.68	22.47	126.68	0.1873	69.07	40.14
0.3	164.31	16.44	164.31	0.137	98.14	29.64
0.2	276.18	9.581	276.18	0.07984	148.73	19.2
0.1	1086.48	2.528	1086.48	0.021	260.19	7.716

4. Conclusions

The proposed PV RES is being controlled using maximum power point tracking (MPPT) at the generation side using Carrier Disposition techniques are compared with different modulations and power factors. The total harmonic distortions are analysed by using MATLAB software facilities. By comparing six high frequency carrier signal disposition techniques PD, POD, APOD, PS, CO, VFCB and observe the line THD's. In three phase system prefer PD for line voltages and phase voltages and current THD's are equal in CO, VFCB & PS. It concludes that in future effective usage of RES using MLI's.

References

[1] Mohan M Renge, Hiralal M Suryavanshi "Multi level inverter to reduce common mode voltage in AC motor drives using SPWM technique", *Journal of Power Electronics (JPE)*, 11, (2011), 21-27.

[2] Abdelhalim Zakri, "Computer aided analysis of stepped sine wave invertors", *Solar cells*, 31 (1991), 559-579.

[3] Krishna Kumar Gupta, Alekh Ranjan, Pallavi Bhatnagar, Lalit kumar sahu, Sailendra Jain "Multilevel inverter topologies with reduced count", *IEEE transaction on Power Electronics*, 31, (2016), 135-151 .

[4] W. A. Hill and C. D. Harbourt, "Performance of Medium Voltage Multilevel Inverters", *IEEE Industry Applications Society (IAS) Conference*, Vol. 2, pp. (1999) 1186–1192.

[5] P. W. Hammond, "A New Approach to Enhance Power Quality for Medium Voltage AC Drives", *IEEE Transactions on Industry Applications*, 33, 1 (1997) 202–208.

[6] P.S. Bhimbra, "*Power Electronics*", 2 ed., New Delhi, Khanna Publications, (2004).

[7] G. Narayanan, IISc(Bangalore), Lectures on "*Pulse width Modulation for Power Electronic converters*'" NTPEL.

[8] Muhammad H. Rashid, "*Power Electronics Circuits, devices, and Applications*", Prentice-Hall of India Private Limited, Third Edition, (2004).

[9] N. Mohan, T. M. Undeland, et al, "*Power Electronics - Converters, Applications and Design*", 3rd edition, John Wiley & Sons, New York, (2003).

[10] Kapil Jain, Pradyumn Chaturvedi, "MATlab -based Simulation & Analysis of Three-level SPWM Inverter", *International Journal of Soft Computing and Engineering (IJSCE)*, 2, (2012).

[11] Raghavendra Reddy Karasani, Vijay Bhanuji Borghate, Prafullachandra M. Meshram, Hiralal Murlidhar Suryawanshi, and Sidharth Sabyasachi, "A Three-Phase Hybrid Cascaded Modular Multilevel Inverter for Renewable Energy Environment", *IEEE transactions on power electronics*, 32, 2, (2017), 1070-1087.

[12] https://www.academia.edu/6742849/Multilevel_Inverter_3level_topologies_Diode_and_capacitor_clamped_and_controlscheme

[13] Hind Djeghloud and Hocine Benalla, "Space Vector Pulse Width Modulation Applied to Three- Level Voltage Inverter", *5th International Conference on Technology and Automation ICTA'05*, Thessaloniki, Greece, (2010).