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Novel Hybrid Pulse Width Modulation Technique for Solar Fed Cascaded Multilevel DC-Link Inverter

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Abstract

Multilevel inverter plays an important role especially in solar based renewable energy sources due to its modularity in structure and medium or high power applications. It is well known that there are three types of inverters which are Diode clamped multilevel inverter, flying capacitor multilevel inverter and cascaded multilevel inverter. One of the drawback of these inverters are, more switching losses due to which quality of power get decreases. The main intention of this work is to improve the quality of power, thereby increasing the life and performance of the overall system at consumer side. One of the reduced switched multilevel inverters have been used to perform so called multilevel DC link inverter. In earlier days, Sinusoidal Pulse Width Modulation (SPWM) technique is used to reduce the switching losses of the inverter. Present work proposes a new Hybrid Pulse Width Modulation (HPWM) technique to control the switching losses in the system. In this HPWM technique, multi level DC link inverter having combination of SPWM (at level generation), and Fuzzy controller(at polarity generation) are used to reduce the losses, and the results are compared with conventional SPWM technique considering R and R-L load.

Keywords

Cascaded Full-Bridge Inverter, THD, PD-SPWM, Techniques and Fuzzy Logic Controller.

Introduction

The conversion efficiency of power electronic devices has been in increasing trend recently and has playing a major role in Renewable Energy Sources (RES). The usage of reduced components in hybrid multilevel inverter with APOD technique has been used in [1-3]. Hybrid modulation, optimal time-domain PWM and SVPWM techniques used for Inverter topology to overcome the capacitor voltage balancing issues in MPPT Tracking have been proposed in [4-6]. Multilevel inverters with SVPWM [7] and Particle Swarm Optimization [8] have been adopted. The survey on multilevel inverter has been discussed in [9]. The comparison of different topologies has been proposed in [10]. Hybrid modulation technique for reduction of switched multilevel inverter has been used in [11]. Some of the drawbacks of the above techniques are difficulty in switching strategy and high harmonic distortion. To overcome these drawbacks Artificial Intelligent based PWM control technique was recommended in [12]. This paper proposes a technique for application of PV based inverter which can eliminate the THD significantly and also improves the conversion efficiency of the system using HPWM.

Solar fed Eleven Level Cascaded Inverter

The block diagram for the proposed system is shown in figure 1. Photo Voltaic generation (chemical energy to electricity) system having different irradiants and temperatures, to control these, boost converter with Perturb and Observeb (P&O) MPP Tracking method is used to convert variable DC voltage to stable DC voltage and is given to cascaded multilevel inverter to fed resistive and Inductive load. Table 1 gives the parameters and their ratings for PV based cascaded multi level DC link inverter system.

Table 1: Parameters and Rating for PV Based Inverter

Parameter	Rating
Solar panel	N_s=54, N_p=1 V_{oc}=37.6V, I_{sc}=8.2Ams, P_{max}=235.8W
MPPT Boost converter	V_{in}=113V, V_{out}=100V
Inverter output voltage for eleven level (using proposed new Hybrid PWM)	R load R=100 Ohms, MI=0.888, Vin=V1+V2+V3+V4+V5=500V RL Load R=100 Ohms, L=30mH MI=0888, Vin= V1+V2+V3+V4+V5=500V

It gives the details of proposed method for eleven level. Where N_s is series N_p is parallel panels, V_{oc} is open circuit voltage, I_{sc} is short circuit current, P_{max} is maximum power, V_{in} is input voltage, V_{out} is output voltage, RL is resistive & inductive load and MI is modulation index. The equations from [1] to [5] give solar modeling from reference [6]

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$$I_{ph} = [I_{sc} + k_i(\mathrm{T} - 298)]\frac{G}{1000} \quad (1)$$

$$I_o = I_{rs}\left(\frac{T}{T_s}\right)^3 * \exp[\frac{qE_{go}\left(\frac{1}{T_s}-\frac{1}{\mathrm{T}}\right)}{nk}] \quad (2)$$

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{qV_{oc}}{nN_s kT}\right)}-1} \quad (3)$$

$$I_{sh} = \left(\frac{V+IR_S}{R_{sh}}\right) \quad (4)$$

$$I = I_{ph} = I_o\left[\exp\left[\frac{q(V+IR_S)}{nkN_S T}\right]-1\right] - I_{sh} \quad (5)$$

Where, I_{ph} is Photo-current(A), I_{sh} is short-circuit current(A), K_i=0.0032, T is operating temperature(K), T_n is nominal temperature (K), G is solar Irradiation(W/m2), q is electron charge(C), V_{oc} open circuit voltage(V), n=1.3, K=1.38*10^(-23)(J/K), E_{go}=1.1(eV), R_s is series resistance, R_{sh} is parallel resistance, V(or)V_{pv} is PV panel output voltage(V), I(or) I_{pv} is panel output current(A). The boost converter output voltage V_o is given by

$$V_o = \left(\frac{1}{1-D}\right)V_{pv} \quad (6)$$

Where, Vo is output voltage of boost converter, D is duty cycle.

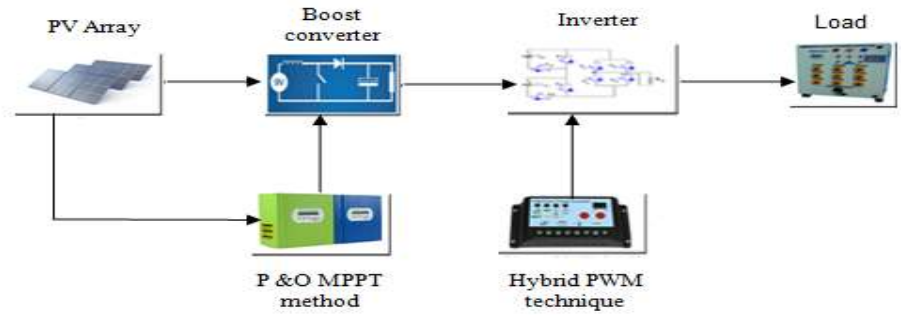
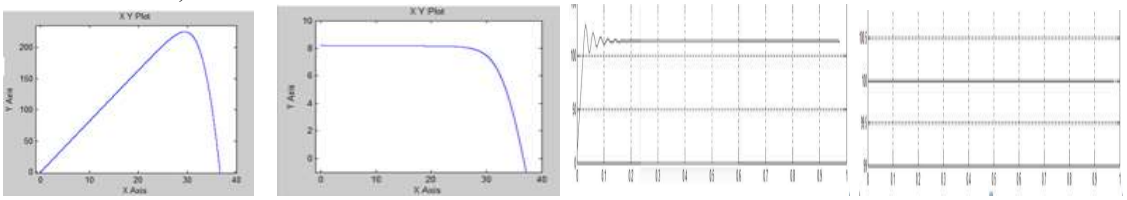


Figure 1: Block Diagram for PV Based Reduced Switched Cascaded Multilevel DC-link Inverter using Existing PD-SPWM and Proposed Hybrid Pulse Width Modulation Technique

The simulation of I-V and P-V curves of P&O method for 25˚C, 400 Irradiance per second are shown in figures 2.(a),(b) respectively. The output voltage of solar after MPPT tracking is 89.38volts and is boost up to 100 volts threw boost converter. The simulation results of boost converter input and output are shown in figures 2(c),(d) respectively. The output voltage of boost converter is given to source of each cell in the CMLDC-link inverter and is fed to the R, RL load.



(a) (b) (c) (d)

Figure 2: (a) (b) PV Curve and IV Curves for Solar (c) (d) Boost Converter Input and Output Voltages

Existing PD-SPWM:

Diagram of the eleven-level cascaded inverter, the number of cells contains (m-1)/2 =5, where m indicates the number of output voltage levels. Each cell contains one MOSFET, one diode/IGBT and one DC source. The source voltage is equal in magnitude taking 100V each. The switching frequency of MOSFET is 10 KHz, Modulation Index(MI) of 0.8888 and a resistive load of 100 ohms is considered. Switching pulses are generated by sinusoidal pulse width modulation technique. The generalized output voltage for inverter is in equation (7), where V_l is line voltage, V_{dc} is cell voltage, θ is switching angle.

$$V_l(wt) = \sum_{l=1,5,7\ldots}^{\infty} \frac{4V_{dc}}{n\pi}(\cos(n\theta_1) + \cos(n\theta_2) + - - - + \cos(n\theta_m))\sin(nwt)) \quad (7)$$

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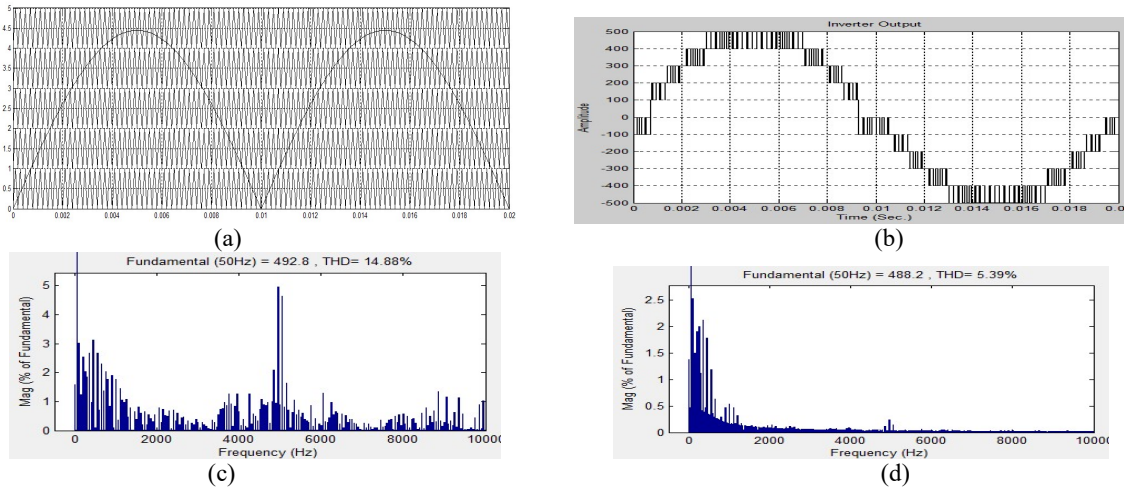
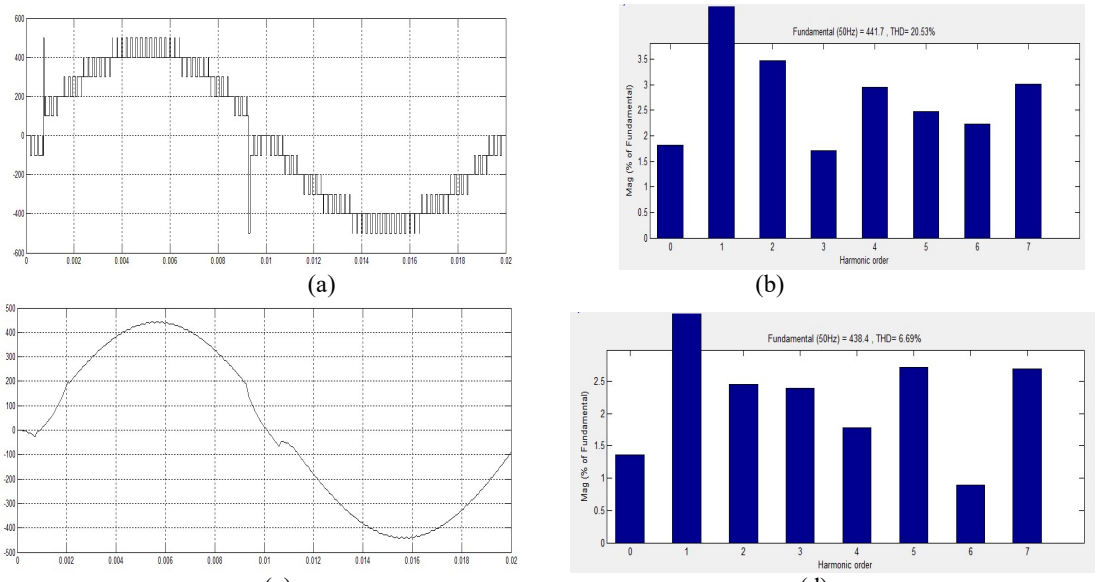


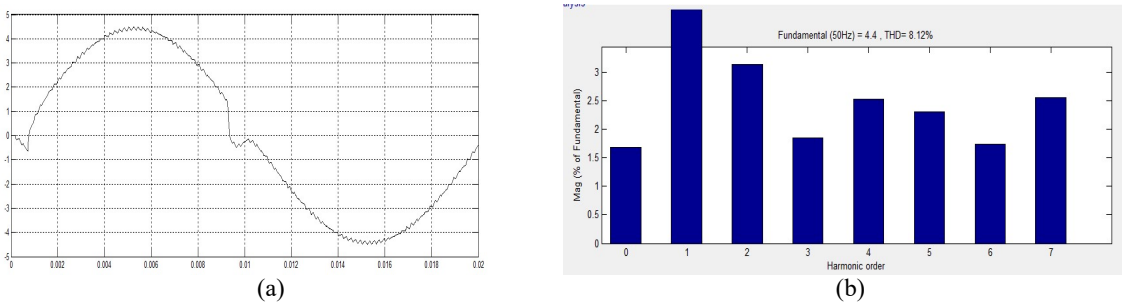
(a) (b) (c) (d)

Figure 3: (a) PD-SPWM Siganl Generation (b) Output Voltage Waveform, (c) & (d) Voltage FFT Analysis before Filter and after Filter Cascaded 11 Level DC Link Inverter with R Load using PD SPWM



(a) (b) (c) (d)

Figure 4: (a),(b) Voltage Waveform, FFT Analysis before Filter (c),(d)Voltage Waveform, FFT Analysis after Filter Cascaded 11 Level DC Link Inverter with RL Load using PD SPWM



(a) (b)

Figure 5: (a),(b) Current Waveform, FFT Analysis before Filter for Cascaded 11 Level DC Link Inverter with RL Load using PD SPWM

Figure 3(a) gives the SPWM generation for 11 level contains five carrier waves and one reference sine wave having modulation index of 0.8888, Figure 3(b) gives the voltage and FFT analysis using R load, figure 8 gives the voltage and FFT analysis for RL load with filter and without filter, figure 9 gives the current waveform, FFT

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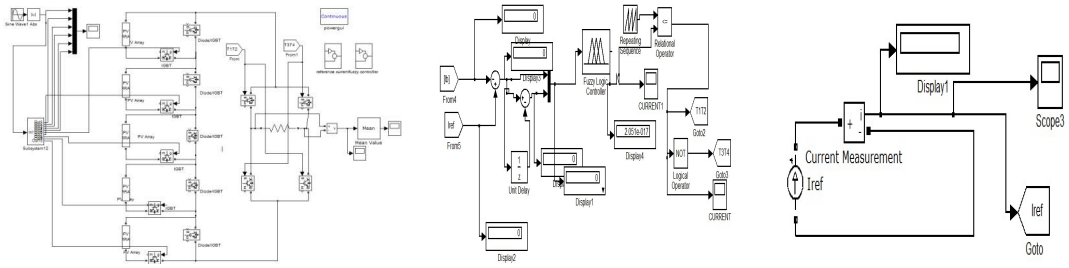
analysis before filter for Cascaded 11 level DC link inverter with RL Load using novel Hybrid PWM technique

Proposed Novel Hybrid Pulse Width Modulation (HPWM) Technique:

The simulation diagram for eleven level inverter using Hybrid Pulse Width Modulation is shown in figure 6. The modulation index for this waveform is 0.8888 which yields better sinusoidal waveform among all the MI values ranging from 0.5888-0.9888. The variations of output voltages for Modulation Index are shown in table 3. The results are in terms of fundamental (Hz) and Total Harmonic Distortion (THDs) with filter and without filter.



(a) (b) (c)

Figure 6: (a) Cascaded 11 level DC Link Inverter with R Load using Novel Hybrid PWM (b) & (c) Internal Fuzzy Block, Reference Current

The novelty in this work is Cascaded 11 level DC link inverter is performed by both SPWM and Fuzzy controllers. i.e., it contains at level generation, normal PD SPWM and at single phase full-bride inverter, Fuzzy logic controller. However in conventional method, it contains level and polarity generation PD-SPWM technique only. The advantage of this control technique is at level generation PO-SPWM technique and at polarity generation fuzzy controller is used to achieve more reduction of harmonic components in the output voltage when compared to the conventional SPWM technique.

Fuzzy logic controller Rules:

The Fuzzy rules for this hybrid controller is given in table 2. Where N is negative, V is voltage, P is positive, B is Big, M is medium, S stands for small and ZE is zero. For example we read the first row as negative big, negative voltage medium, negative voltage small, Zero, positive voltage small, positive voltage medium, positive voltage big etc.

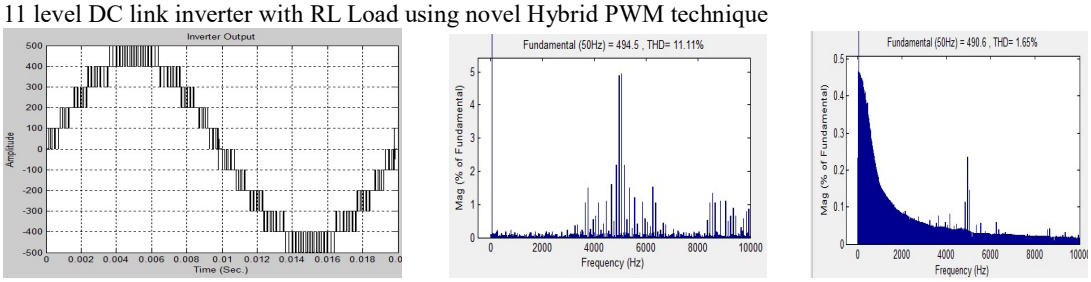
Table 2: Fuzzy Rules for Eleven Level Inverter.

	NVB	NVM	NVS	ZE	PVS	PVM	PVB
NVB	NVB	NVB	NVB	NVB	NVM	NVS	ZVE
NVM	NVB	NVB	NVB	NVM	NVS	ZVE	PVS
NVS	NVB	NVB	NVM	NVS	ZVE	PVS	PVM
ZVE	NVB	NVM	NVS	ZVE	PVS	PVM	PVB
PVS	NVM	NVS	ZVE	PVS	PVM	PVB	PVB
PVM	ZVS	ZVE	PVS	PVM	PVB	PVB	PVB
PVB	ZVE	PVS	PVM	PVB	PVB	PVB	PVB

The simulink model for fuzzy controller is shown in figure 6(b). The reference current in figure 6(c) is taken as 15 amps. The generated DC output voltage from fuzzy controller can be more tuned than the existing PD SPWM technique.

Simulation Results for Proposed Novel Hybrid PWM Technique:

Figure 7 gives the voltage and FFT analysis using R load, figure 8 gives the voltage and FFT analysis for RL load with filter and without filter, figure 9 gives the current waveform, FFT analysis before filter for Cascaded 11 level DC link inverter with RL Load using novel Hybrid PWM technique



(a) (b) (c)

Figure 7: (a) Voltage Waveform, (b) FFT Analysis before Filter and (c) FFT Analysis after Filter for Cascaded 11 Level DC Link Inverter with R Load using Novel Hybrid PWM Technique.

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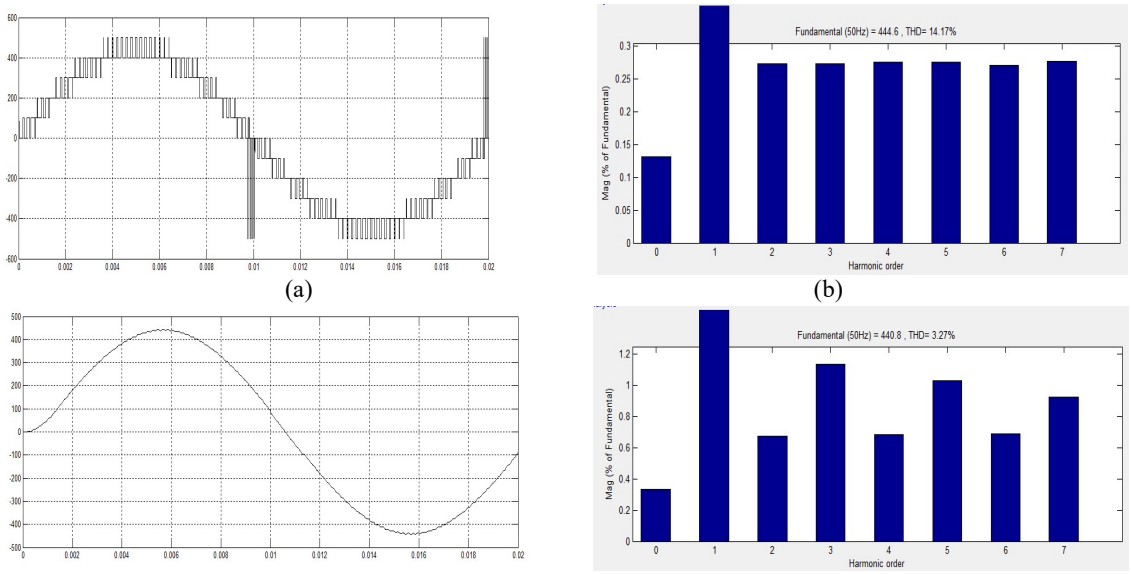
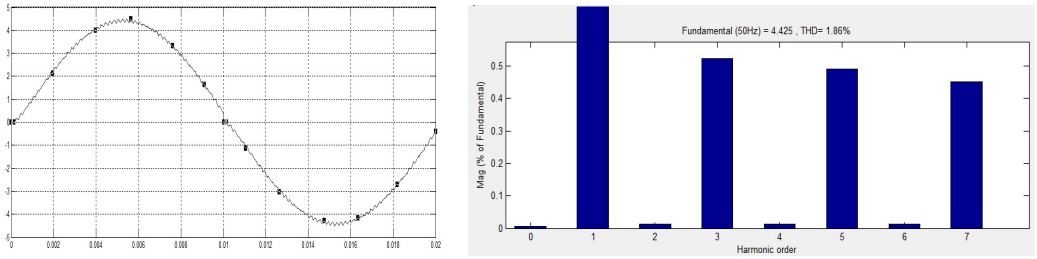


(a) (b)

(c) (d)

Figure 8: (a) Voltage Waveform, (b) FFT Analysis before Filter and (c) Voltage Waveform, (d) FFT Analysis after Filter for Cascaded 11 Level DC Link Inverter with RL Load using Novel Hybrid PWM Technique.



(a) (b)

Figure 9: (a) & (b) Current Waveform, FFT Analysis before Filter for Cascaded 11 Level DC Link Inverter with RL Load using PD SPWM

Observations: 1) output voltage and current waveforms & FFT analysis are better improved by using novel Hybrid PWM technique than the conventional PD SPWM technique. It can observe from figure 3 &7 for R load, From figure 4 & 8 for RL load output voltages. Figure 5 & 9 for current waveforms. 2) Modulation Index at 0.8888 is giving better results for both existing and novel Hybrid PWM techniques and is shown in table 3.
The comparison results at different modulation index values with R load are shown in table 3. The modulation index at 0.8888 is better performed than other values. At this MI the voltage magnitude and THD are better for novel Hybrid technique than the conventional PD-SPWM technique. Table 4 gives the comparison of results for RL load with proposed method for Cascaded 11 level DC link inverter.

Table 3: Performance Comparison Table for Different MI Values for Existing and Proposed with R Load.

Modulation Index (MI)	PD-SPWM with R load				Novel Hybrid PWM technique with R load (PD-SPWM & Fuzzy controller) (Proposed)			
	Before filter		After filter		Before filter		After filter	
	Fundamental (HZ)	THD	Fundamental (HZ)	THD	Fundamental (HZ)	THD	Fundamental (HZ)	THD
0.5888	293.3	20.8	290.6	5.17	294	18.88	292.1	1.71
0.6888	342.5	19.68	340.2	5.19	344.5	16.53	341.7	1.70
0.7888	391.8	17.27	389.6	5.40	394.7	13.90	391.4	1.68
0.8888	442.8	14.86	438.2	5.39	444.5	11.11	441.6	1.65
0.9888	600.5	25.59	595.7	9.95	605.1	22.40	600.3	20.30

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Table 4: Performance Comparison Table for Existing and Proposed with RL load at MI=0.8888.

Parameter	PD-SPWM with R load				Novel Hybrid PWM technique with RL load (PD-SPWM & Fuzzy controller) (Proposed)			
	Before filter		After filter		Before filter		After filter	
	Fundamental (HZ)	THD	Fundamental (HZ)	THD	Fundamental (HZ)	THD	Fundamental (HZ)	THD
Voltage	441.7	20.53	438.4	6.69	444.6	14.17	440.8	3.27
Current	4.4	8.12	-	-	4.425	1.86	-	-

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Conclusion
The inverter has performed by Phase Disposition Sinusoidal Pulse Width Modulation technique and novel Hybrid Pulse Width Modulation (combination of Phase Opposition SPWM technique at level generation and Fuzzy controller at polarity generation) for eleven levels. The results are analyzed with Matlab/Simulink environment. The observation concluded that the hybrid pulse width modulation gives better output voltage and THD when compared to the conventional PD-SPWM for different values of modulation indexes ranging from 0.5888 to near one. The better modulation value performed is 0.8888 for eleven level cascaded MLDC-link inverter. There by the overall PV generation system conversion efficiency increases.

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