IJCTA, 10(02), 2017, pp. 241-251

Analysis on Power Quality Issues of VSI with an Improved Modulation Strategy

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Abstract : The diode assisted buck–boost voltage source inverter improves the boosting capability without using large boost duty ratio, which gives a wide range of voltage regulation in the dc-ac conversion. The paper explores the advantages of the pulse-width modulation (PWM) strategies. With the efficient utilization of the intermediate dc-link voltage two types of strategies are explained with their harmonic spectrums to obtain maximum linear voltage gain and reduce the switching stress. The paper explains the operation principle and the realization of various strategies used in the experiment for the reduction of the various stresses in the circuit. Simulation and experiments are conducted to compare the existing strategies with each other. Various analyses have been conducted using the strategies to bring out the efficient results. Various THD spectrums are analyzed for respective duty ratios. With the newly improved strategies the diode assisted voltage source inverter promises better performance than the existing one. The VSI finds applications in the field of induction motor drives. Furthermore, this method can be extended to control the current source inverter with respective modifications.

Keywords : DC-link, PWM Technique, boost voltage, gain, voltage source inverter(VSI), stress voltage.

1. INTRODUCTION

Nowadays, the interest in buck-boost inverters is growing notably with the development of sustainable energy systems. Renewable energy from the wind, sun, water, wave, tidal, etc., is inexhaustible but irregular and fluctuates dramatically with the weather and season. Thus the buck boost inverter with the improved strategies functions as a power system conditioner. The diode-assisted buck–boost VSI further extends the voltage transfer ratio and avoids the extreme duty ratio of switching device in the front boost circuit for the wide range buck and boost power conversion .An Diode assisted capacitor network is connected in X-shape between the bridge inverter and the boost Inductor is shown in Fig 1 [1]-[4]. In order to perform the parallel capacitive charging and Series capacitive discharging in subsequent intervals the diodes in the network are allowed to conduct naturally with a high dc link voltage across the inverter bridge. Here two distinct modulation schemes are explained with the first gaining a better symmetrical waveform quality and the second gaining a lower commutation count without stressing the active and passive. The X-Shaped capacitor network presents a rapid midway dc-link voltage change of the inverter bridge in a single switching period. But the PWM Technique [1] offered employs only the active vectors when the capacitors are connected in series for an output AC voltage. When Switch S1 is turned OFF the Capacitor voltage becomes same as the intermediate Dc-link voltage Vi since the diodes are Forward biased and the capacitors are connected in parallel. The AC Output voltage is zero when the 3-phase VSI operates under null state during the above interval. Also in one switching time period the adequate consumption of intermediate Dc link Voltage will advance the voltage transfer ratio which ultimately reduces the capacitor

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voltage ratings. This paper generally inspects the possibilities of the inverter in employing it as an efficient drive for the future motor applications. It analyzes the THD values for the improved modulation strategies named IPWM1 and IPWM2.

2. WORKING PRINCIPLE WITH EQUIVALENT CIRCUIT

Diode assisted buck-boost inverter uses a voltage boost circuitry to boost its dc input voltage by controlling the conductive duty ratio of switch SW. Capacitor voltage V_C and peak AC output voltage $\hat{v}$ of the inverter can explicitly be expressed as,

$$V_C = \frac{1}{(1-k)} V_{dc} \hat{v}$$

$$= M \frac{1}{2(1-k)} V_{dc} \quad (1)$$

Where k refers to the conductive duty ratio of SW, M represents the modulation index and $1/(1-k)$ is defined as the voltage boost factor. To produce a higher gain, while avoiding the use of a large k, the diode-assisted inverter shown in Fig.1,where a diode-capacitor network replaces the single dc capacitor placed between SW and the three-phase VSI Bridge. By turning ON SW, the diodes become reverse–biased and the inductive current i_L flows solely from the *dc* source to boost the magnetic energy stored in inductor L according to the equivalent circuit shown in Fig. 2. Besides inductive charging, capacitors $C_1$and C_2 are found to be in parallel. Having a larger *dc*-link voltage now also means the switches SX and SX' (X = A, B, and C) in the rear-end three-phase bridge have to block a voltage which is given by $2V_C$.

$$v_i = v_{c1} + v_{c2} = 2v_c ;\ (C_1 = C_2 = C) \quad (2)$$

On the other hand, with SW turned OFF, the inductor current i_L flows through the diode–capacitor network according to the equivalent circuit shown in Fig. 3, where diodes D_1 and D_2 are now forward-biased to connect C_1 and C_2 in series.

$$v_i = v_{c1} = v_{c2} = v_c ;\ (C_1 = C_2 = C) \quad (3)$$

The active vectors and the null vectors [1] produced as a result of the switching. Therefore, quite intuitively, for producing a higher voltage gain, the inverter active states (six in total) must be placed only within the SW = ON interval.

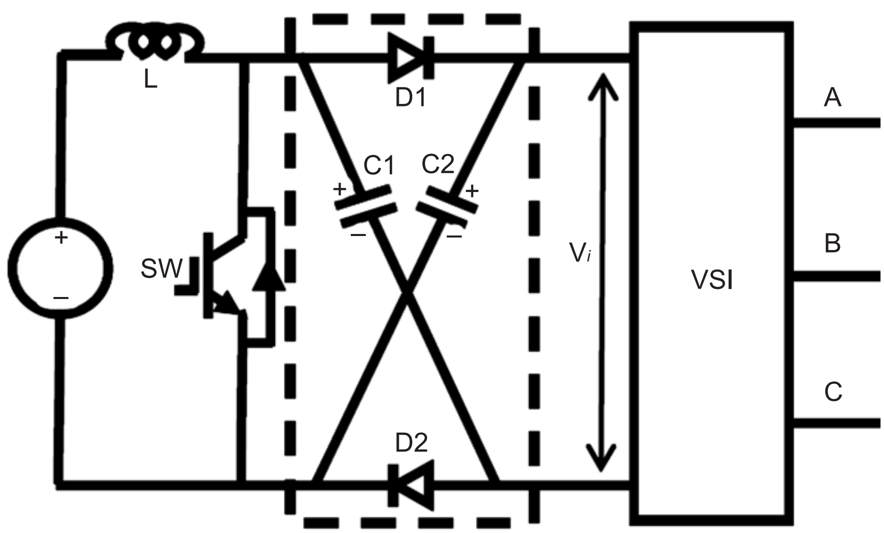


Figure 1: Diode-assisted buck–boost VSI with diode-capacitor network

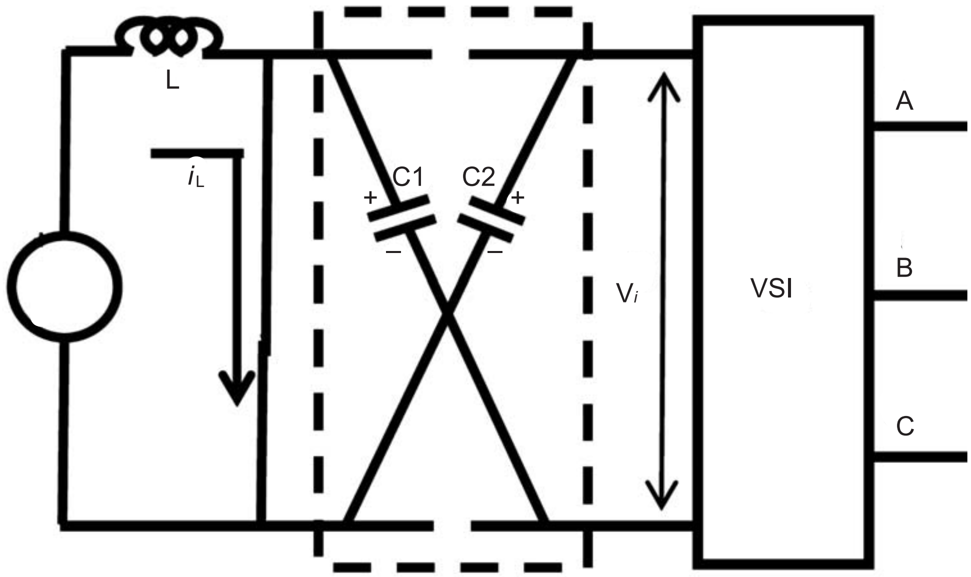


Figure 2: Equivalent circuit for diode-assisted inverter when SW is ON

For deriving the inverter voltage transfer gain expression, steady-state constraints applied to the inductor L are analyzed with the inductive current i_L observed to rise with a slope of V_{dc}/L during the SW = ON interval and fall with a slope of $-(V_C - V_{dc})/L$ during the SW = OFF interval. Equating the incremental rise and fall of i_L during the two intervals in the period T, voltage V_C across each capacitor is calculated.

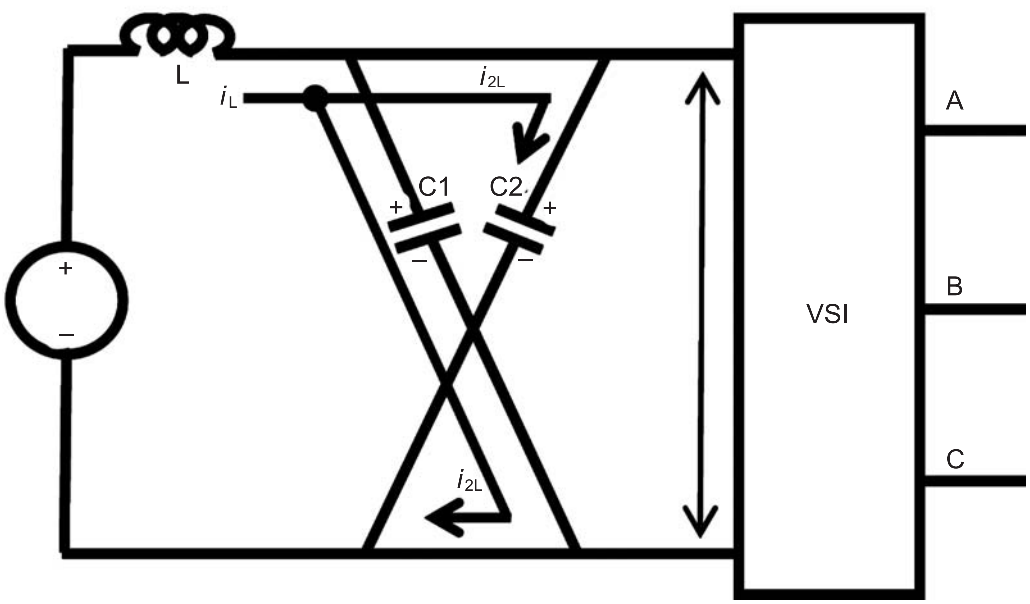


Figure 3: Equivalent circuit for diode-assisted inverter when SW is OFF

$$\frac{V_{dc}}{L}kT = \frac{V_c - V_{dc}}{L}(1-k)T \tag{4}$$

Comparing (4) and (2), the ac output voltage of the diode assisted buck-boost inverter is observed to experience a voltage boost, assuming that all control parameters are set equally.

3. MODULATION STRATEGIES

A. Improved PWM Strategy (IPWM1)

In this PWM technique the switching frequency is *fs* for all power devices. The switching loss of the power devices in the boost network is reduced to about 50% due to turning On and OFF of S1 once per two switching periods. The operation of S1 in null states is also instructed in Fig.4 as the boost network and the inverter bridge switching frequencies are *fs*/2 and *fs* respectively. In the first section the Vectors V1, V2, V3 and V4 are used to synthesize the output reference vectors for IPWM1. By solving the Equation (5) gives the IPWM1 strategy.

$$
\begin{aligned}
d_{v1} &= k_s.\ \sin\left(\frac{\pi}{3}-\theta\right).\ k_{\text{off}}.\ \text{T}_s \\
d_{v1} &= k_s.\ \sin(\theta).\ k_{\text{off}}.\ \text{T}_s \\
d_{v2} &= k_s.\ \sin\left(\frac{\pi}{3}-\theta\right).\ k_{\text{on}}.\ \text{T}_s \\
d_{v4} &= k_s.\ \sin(\theta).\ k_{\text{on}}.\ \text{T}_s \\
d_{v0-\text{on}} &= \left(1-k_s.\sin\left(\frac{\pi}{3}+\theta\right)\right).\ k_{\text{on}}.\ \text{T}_s
\end{aligned}
\tag{7}
$$

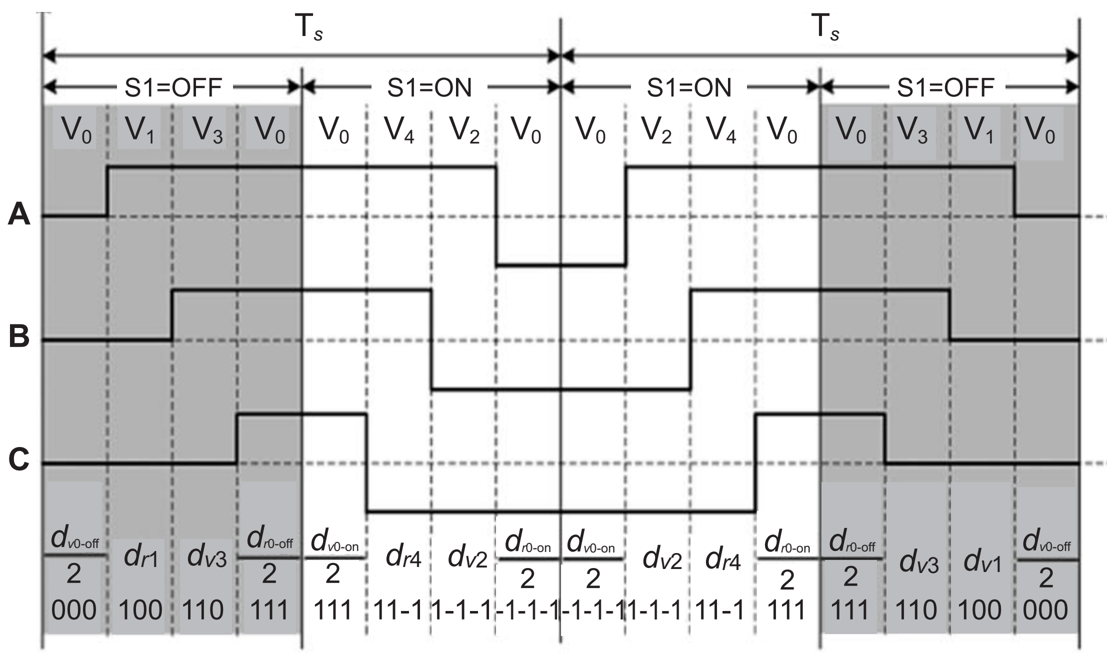


Figure 4: First sextant of IPWM1

B. Improved PWM Strategy (IPWM2)

In the way to reduce the 50 % Switching frequency harmonic distortion, IPWM2 technique is offered to ensure symmetrical employment of switching states for a single switching period. In IPWM2, the first section is separated into zones A and B. The highlighted feature of this modulation approach is that S1 turns ON and OFF once with S1 = ON interval symmetrically inserted. The V1 vector introduces an added switching state. Hence IPWM2 will introduce an added switching action in the inverter bridge during the S1 = OFF interval in one phase leg and the switching frequency in the bridge inverter due the power devices will be (1 + 1/6)*fs*. To synthesize the reference vector (V*r*) in zone A, active switching vectors (V_1, V_2, and V_4) as shown in Fig.5and for zone B, active switching vectors (V_2, V_3, and V_4) are used as shown in Fig. 6. With the similar design tactic, the switching states for other sections also be obtained.

$$
\begin{aligned}
d_{v1} &= k_s.\ k_{\text{off}}\ .\text{T}_s \\
d_{v0-\text{off}} &= (1-k_s).\ k_{\text{off}}\ .\text{T}_s
\end{aligned}
$$

$$dv_2 = \left(\frac{1+k_{on}}{2}\sin\left(\frac{\pi}{3}-\theta\right)-\frac{1}{2}k_{off}\right).k_s.\,T_s \tag{9}$$

$$d_{v4} = \frac{1+k_{on}}{2}\cdot\sin(\theta).k_s.T_s$$

$$d_{v0-on} = \left(k_{on}-\frac{1+k_{on}}{2}\sin\left(\frac{\pi}{3}+\theta\right).\,k_s+\frac{1}{2}k_s.\,k_{off}\right).T_s$$

Solution of the above Equations gives the IPWM2 strategy.

4. SIMULATION RESULTS FOR THE PROPOSED STRATEGIES

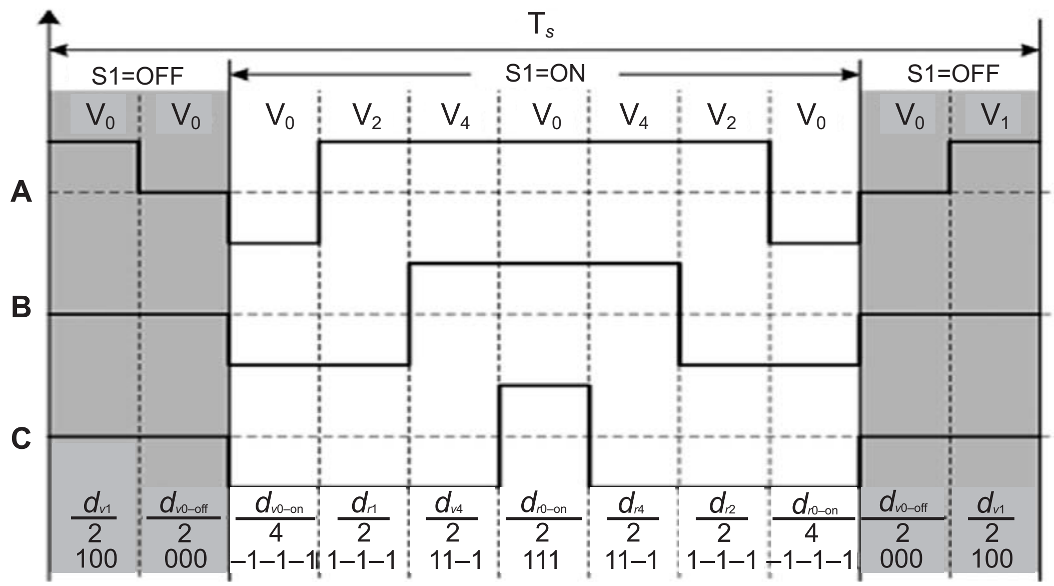


Figure 5: Voltage vectors in the first sextant for IPWM2- zone A

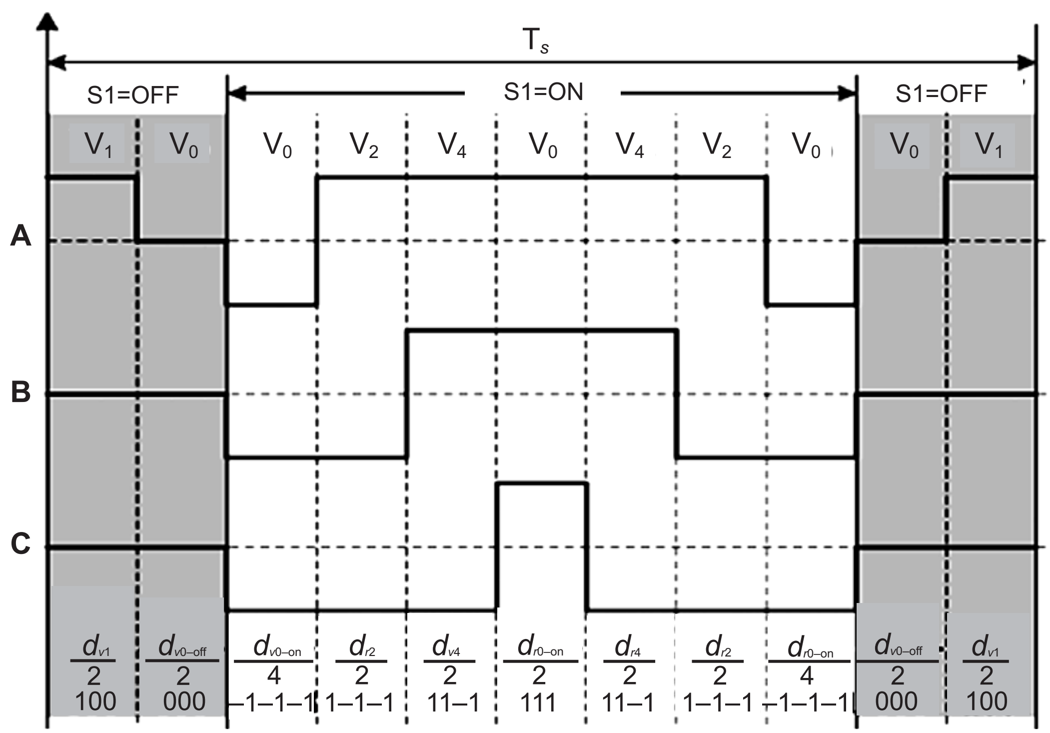
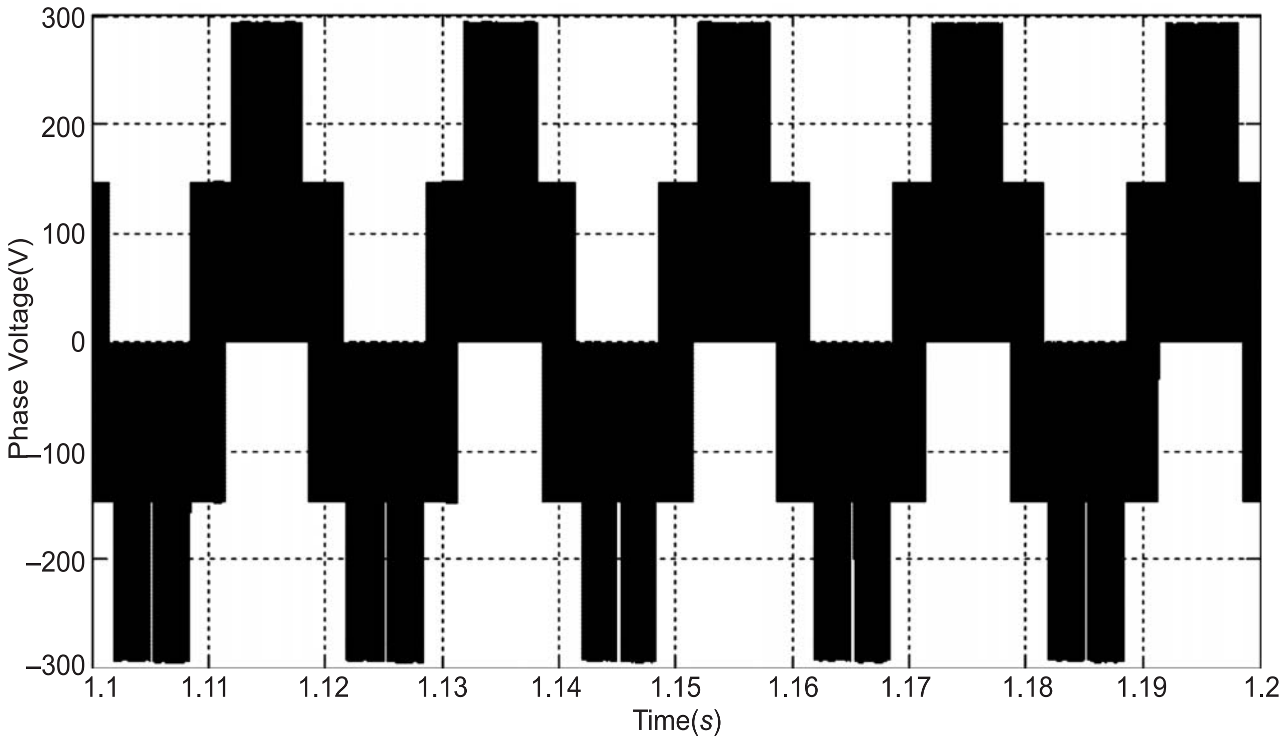
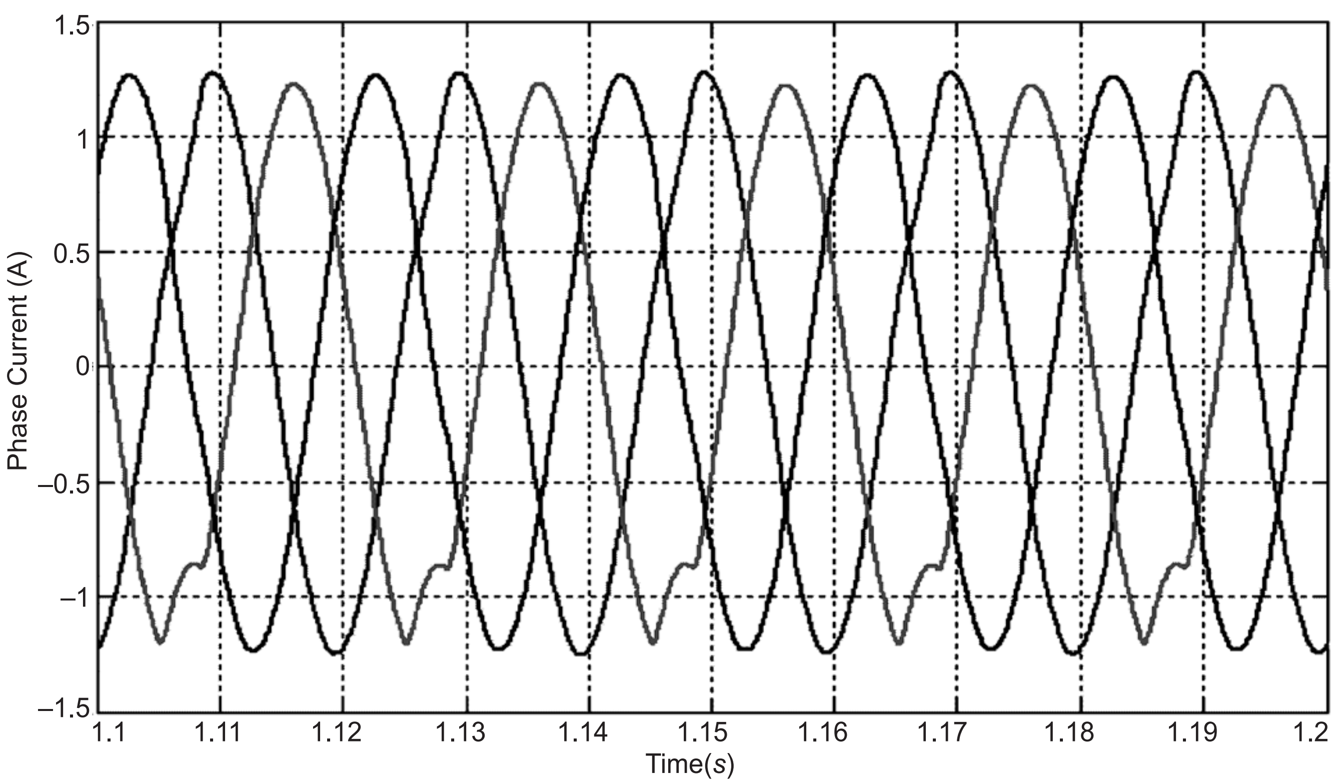


Figure 6: Sequences of voltage vectors in the first sextant for IPWM2-zone B

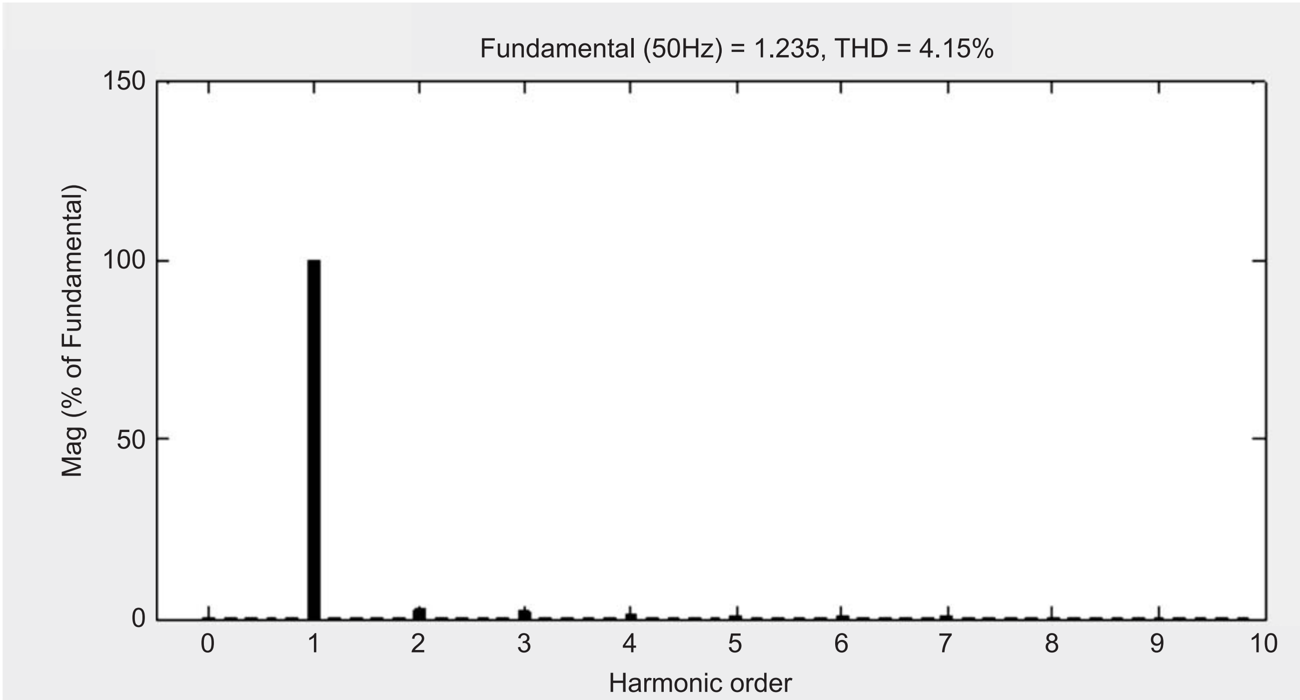
The Diode assisted buck boost VSI is simulated (Fig. 9) using MATLAB/SIMULINK to verify the improved PWM strategies. The specifications of the components and devices used in the circuit are given in the TABLE1.The circuit is simulated for various duty cycles and for various load inductance value by keeping the duty ratio constant in $k = 0.5$.



(a)

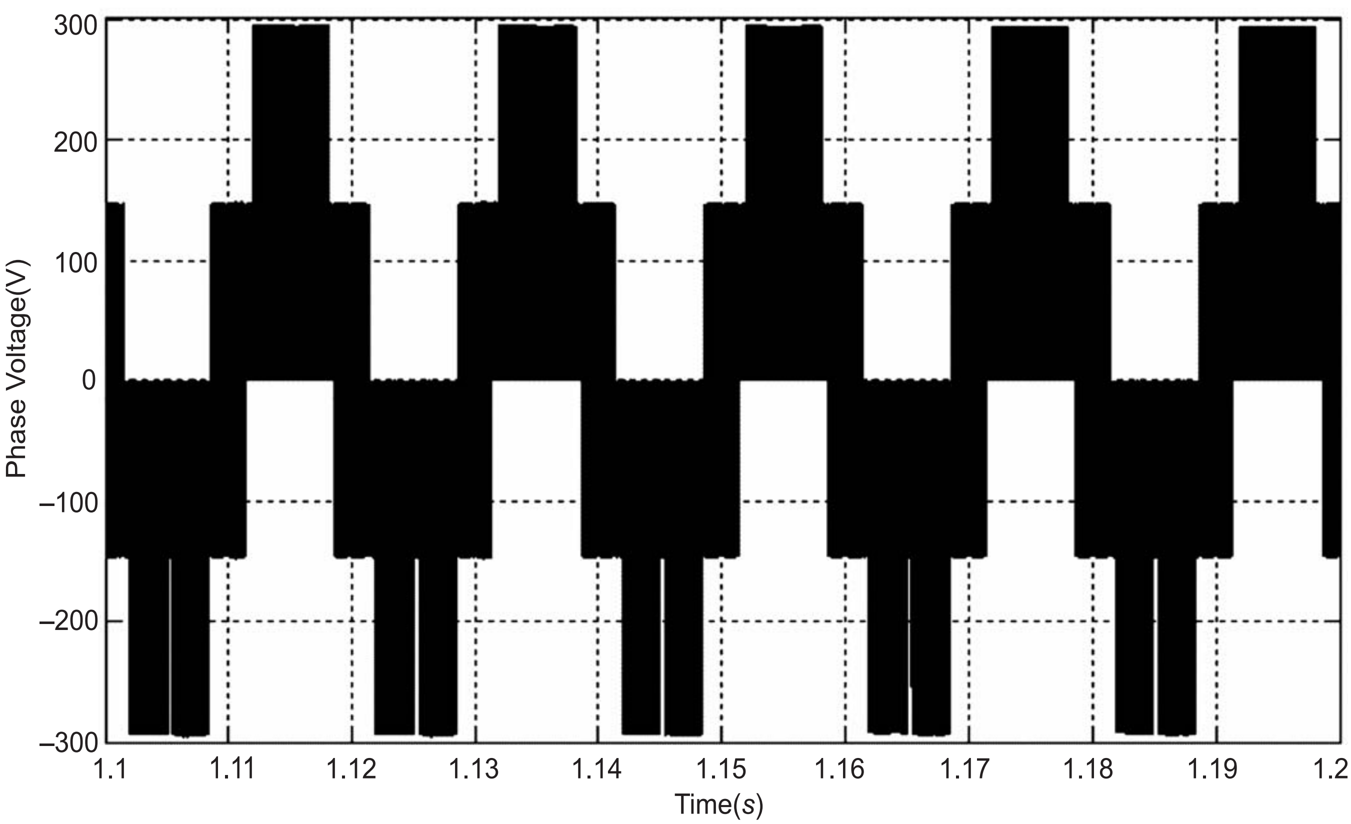


(b)

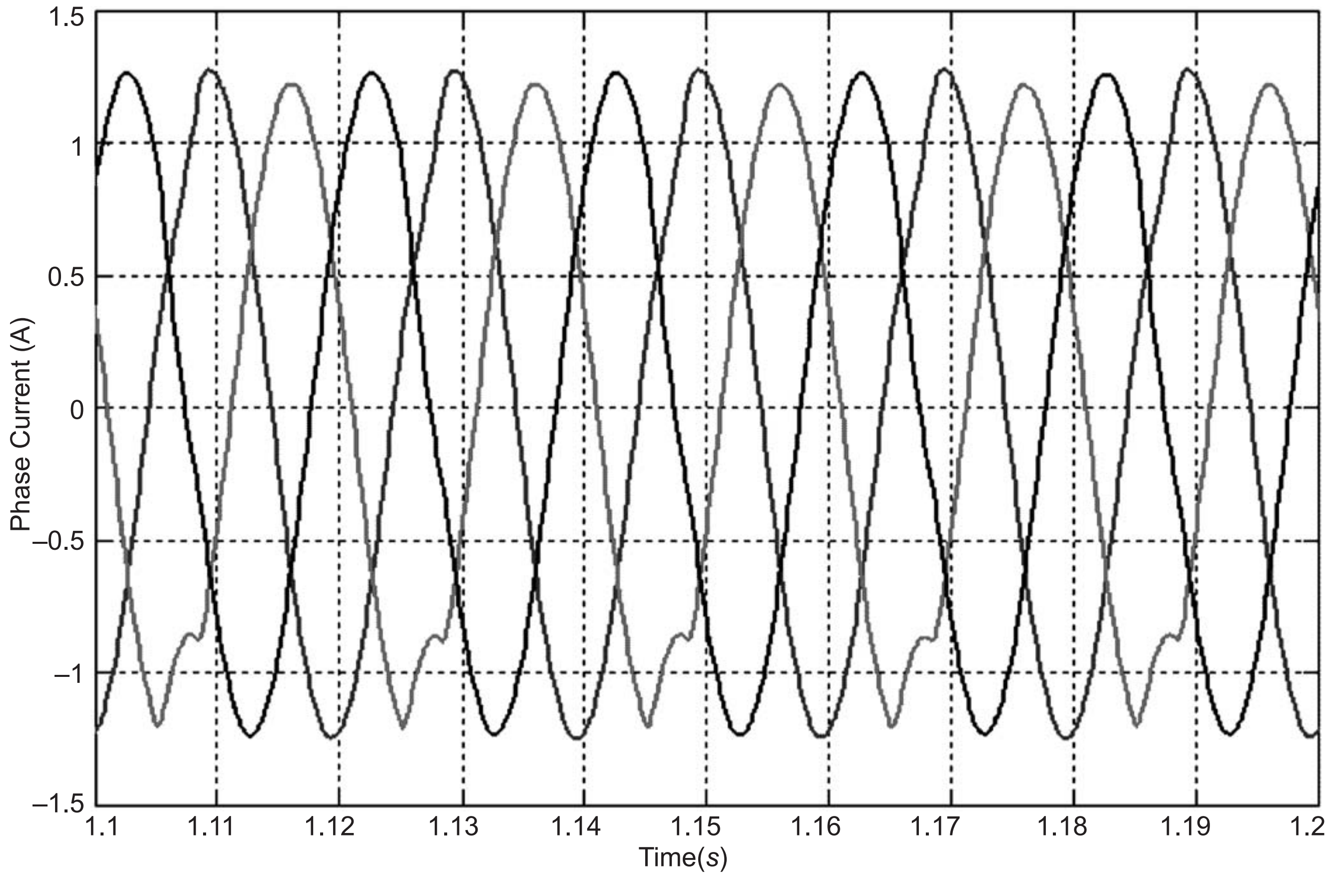


(*c*)

Figure 7: Simulation waveforms of IPWM1 with (k_{on} = 0.5, and V_{dc} = 100 V). (*a*) Output phase voltage. (*b*) Output line current. (*c*) Harmonic spectrum



(*a*)



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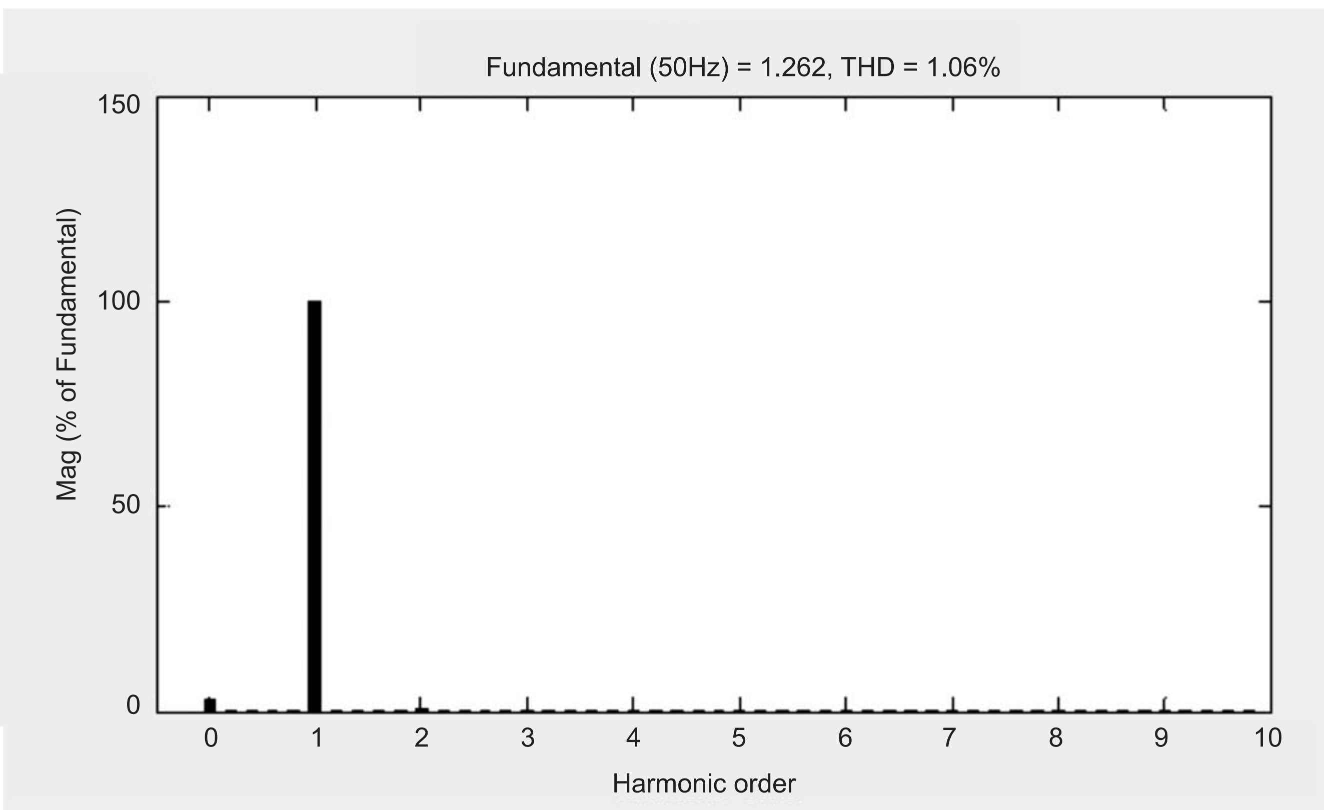

(*c*)

Figure 8: Simulation waveforms of IPWM2 with (k_{on} = 0.5, and V_{dc} = 100 V). (*a*)Output phase voltage. (*b*) Output line current. (*c*) Harmonic spectrum

Table 1
Specifications of the setup

Switching Device	*SW*	*IGBT(IGW40T120)*
	Sap,San,Sbp, Sbn, Scp,Scn	*IGBT(IGW25N120) DIODE(IDP18E120)*
Inductor	L	4μH
Diode-Capacitor Network	D1 and D2	DIODE
	C1 and C2	500μF
Filter Circuit	L_f	400μH
	C_f	35μF
RL Load	R	40Ω
	L	2μH
Switching Time Period	T_s	100 μ*s*
Software	MATLAB/SIMULINK 8.0	

Table 2
Corresponding THD value for various duty cycles

Duty cycle	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
IPWM1 THD in %	17.04	16.73	17.41	18.75	20.12	21.14	23.00	29.93	37.80	37.80
IPWM2 THD in %	14.73	14.48	14.97	16.24	17.73	18.73	20.79	27.93	35.76	35.76

The tables explain the performance of the two improved strategies that has been mentioned in the paper. In the Table1, the experimental setup has been given. Table 2 shows the THD value in % for various duty cycles and the Table 3 shows the THD value in % for various load inductance values. The figures Fig.9 and Fig 10 show the graphical representation of the THD value against the duty cycles and the load values.

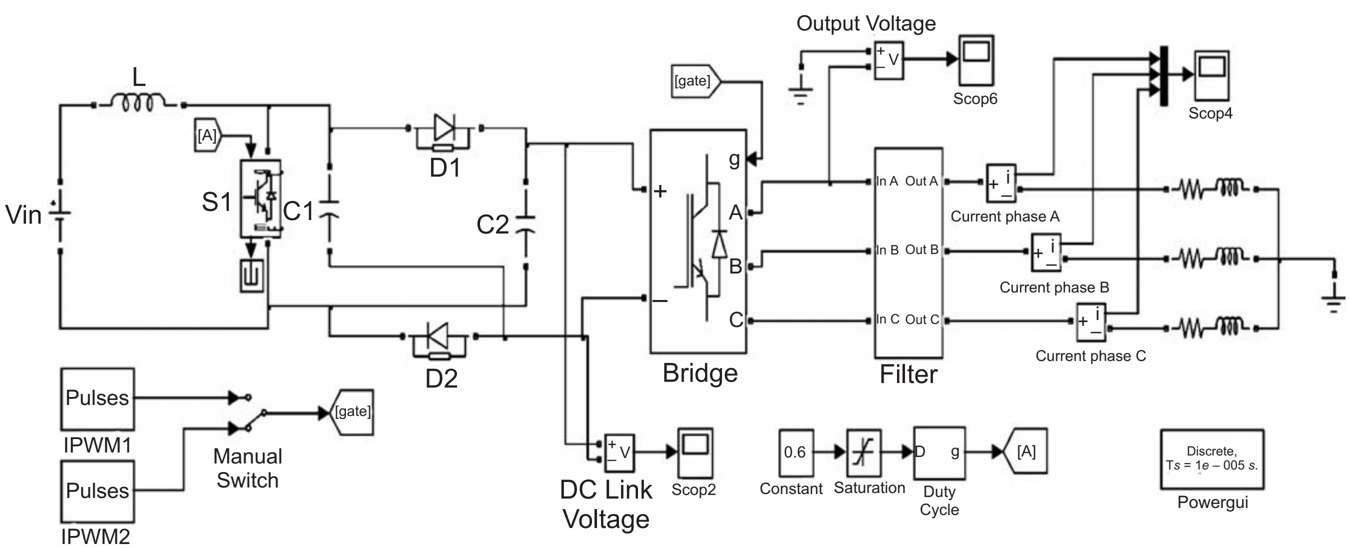

Figure 9: Simulation circuit for the diode assisted buck-boost VSI

Table 3
THD for various loads

L in mH	2	4	6	8	10
IPWM1 THD in %	21.14	21.17	21.20	21.24	21.27
IPWM2 THD in %	18.73	18.74	18.75	18.77	18.79

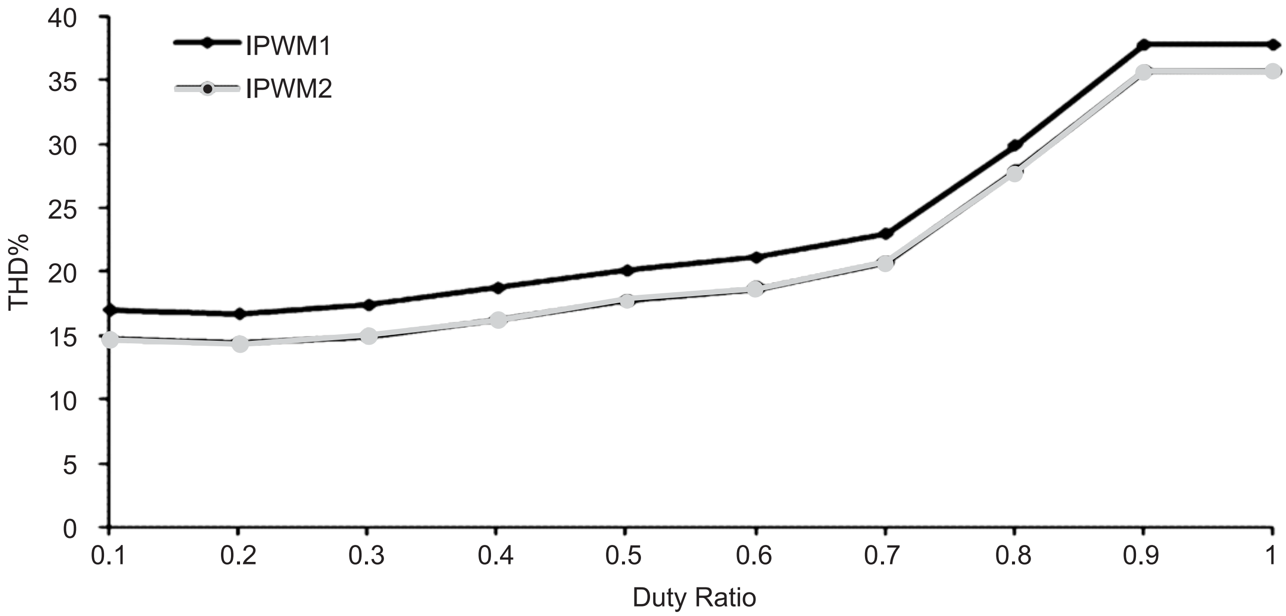

Figure 10: THD versus Duty Ratio for the improved strategies

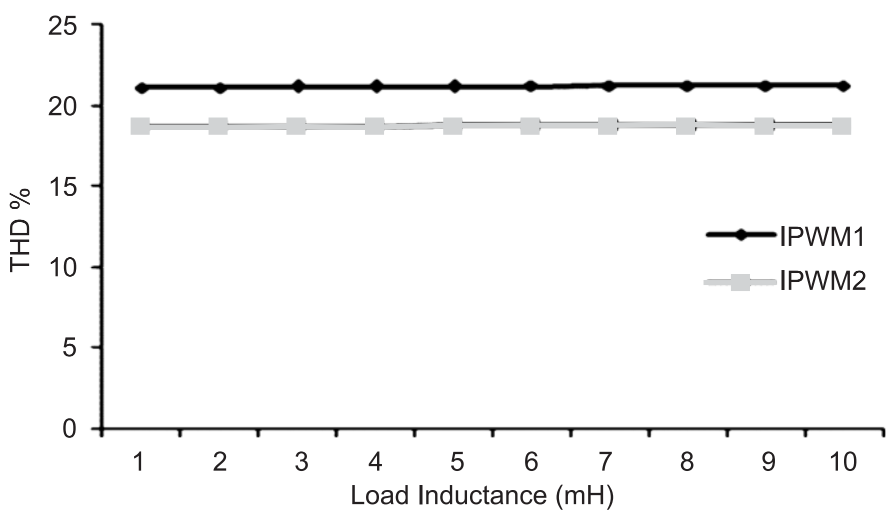

Figure 11: THD versus Load Inductance values for the improved strategies

5. CONCLUSION

Initially, the paper analyses the working of the diode assisted buck-boost voltage source inverter using the two improved strategies IPWM1 and IPWM2, its realization and the generation. The improved strategies reduce the conduction losses of the switch. This paper mainly compares the performances of IPWM1 andIPWM2 and various analysis has been done in the field of harmonics. From the spectrum itself it is clear that the improved strategies can perform well that the old existing ones. Simulation results and the harmonic spectrum are given to distinguish the two strategies. With the results we can conclude that the improved strategies are advantageous and it gives high gain with low boost duty ratio. The strategies are applicable for the control of the AC drives used in the industrial applications like elevator industry.

6. REFERENCES

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