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Research Article

DESIGN OF AN ISOLATED FULL BRIDGE MICRO INVERTER

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A R T I C L E I N F O

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A B S T R A C T

Micro inverter converts direct current into alternating current by using individual solar photovoltaic (PV) panel. A full bridge micro inverter design comprising of high frequency full bridge converter and line commutated inverter is proposed here. Sinusoidal Pulse Width Modulation is suitable techniques among all other voltage control signal techniques. The performance of this inverter is evaluated in terms of Total Harmonic Distortion (THD), power conversion efficiency, California Energy Commission (CEC) efficiency and European Union (EU) efficiency. Simulations results of 400W single phase full bridge micro inverter was performed and it results in maximum power conversion efficiency up to of 95.39% and total harmonic distortion of 2.07%.

INTRODUCTION

The demand of energy is increasing day by day so the search of energy sources is required which are cost efficient. The PV modules include several solar cells, which convert the solar energy directly into electrical energy. They are connected as in series or parallel or both connection to provide desired levels of dc current and voltage [1] [2].

Dc to ac converters are known as inverters. Inverter are classified into three types namely centralized, string and micro inverter. In a micro inverter each solar panel module has its own individual inverter. Micro inverter optimizes solar harvesting also reduces installation costs. Micro inverters tend to be lower powered, which tends to lower internal loss and improves reliability [3] [8]. Single phase inverter developed for small distributed power generators, includes low cost, high efficiency and tolerance for extremely wide range of input variations due to this parameters inverter development towards simpler topologies and structures lower components counts and tighter modular design [4].

A high frequency full bridge converter, along with pseudo dc link filter and a line commutated inverter is well matched to the requirements for higher efficiency dc to ac grid tied and standalone converters. It is found that by using high frequency full bridge micro inverter reduces device losses, flexible control and low harmonic distortion [5] [9].Single PWM, Multiple PWM, Sinusoidal PWM, Modified PWM and Phase Displacement Control are various voltage control techniques. Among them Sinusoidal PWM provides less Total Harmonic Distortion suitable for micro inverter [6].

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High Frequency Pulse Width Modulation waves can decrease the size of inductor and capacitor in the inverter, achieving a low volume and a lightweight as needed. DSP alongwith High Resolution Pulse Width Modulationcan be used to generate Sinusoidal PWM up to switching frequency of 1 MHz [7].

The working principle of full bridge micro inverter, design of transformer and ac filter calculations are explained in section II.Simulations results of proposed 400W micro inverter are shown in section III. In section IV performance analysis is carried out based on FFT, loss analysis ofsemiconductor switches and output at various loads. Conclusion of this study is drawn in section V.

Proposed Full bridge micro inverter

The input voltage for micro inverter is very low of one PV panel, voltage gain must be needed to increase the voltage level for a single phase system. There are certain limitations of the transformer-less design to amplify the voltage up to utility level. High frequency transformer with the required turn's ratio provides voltage gain and isolation, which is full bridge micro inverter topology with isolation as shown in Fig1.

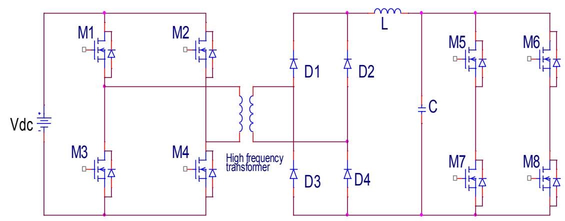

Fig 1 Proposed Full Bridge Inverter

MOSFET1 and MOSET4 are ON as shown in Fig.2 (with MOSFET2 and MOSFET3 OFF) i.e. due to the inverted gate signal is provided to another leg of full bridge, current passes through the high frequency transformer. MOSFET2 and MOSFET3 are ON as shown in Fig.3 (with MOSFET1 and MOSFET4 OFF), the current passes through high frequency transformer. Thus, transformer will not float in negative cycle and it will reset properly. According to turn‘s ratio, high frequency low voltage, high current dc pulses are amplified to high voltage, low current ac pulses at the secondary output of the transformer.

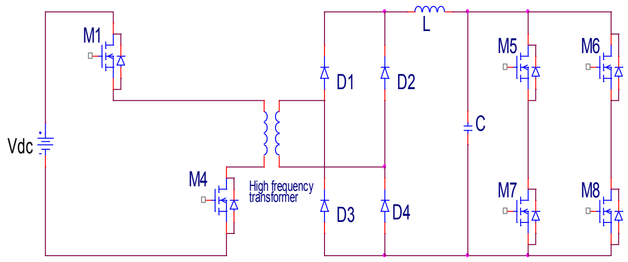

Fig 2 Conduction Mode 1

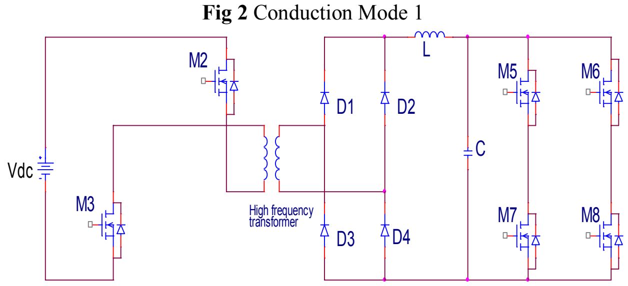

Fig 3 Conduction Mode 2

The diode rectifier consisting of D1-D4 converts this high frequency high magnitude ac signal to rectified sinusoidal voltage having line frequency envelope. An LC filter is used to eliminate the high frequency modulation and produce the rectified output. Proper cut-off frequency must be chosen to provide adequate filtration at very high frequency. An unfolder bridge circuit is switched diagonally at 50Hz frequency to produce utility grid voltage 220 V with 50 Hz frequency.

Design Parameters

Design of transformer

$$\frac{N_2}{N_1} = \frac{V_{Out}}{V_{in}} = \frac{310}{36} = 8.61 = 9 \qquad (1)$$

Primary turns selected to satisfy the ac voltage stress and core saturation property.

$$N_p = \frac{V_{in}T}{BA_e} = \frac{V_{in}}{FBA_e} = 0.37 \qquad (2)$$

Where,
N_p= Minimum Primary turns
V_{in}= Maximum Primary DC Voltage
T= Maximum period for MOSFET
F= Switching Frequency = 100 kHz
A_e= Effective Center pole area of the curve (0.97 cm^2) [8]
B= Magnetic Flux Swing typically 200mT

Find the value of primary inductance of coil wound on core.

$$L_p = A_L {N_P}^2 \qquad (3)$$

Where,
L_p = Primary inductance value
A_L= 3 µH for ETD34 core
N_p = Primary turns
L_s =Secondary inductance value

$$L_s = N^2 L_P \qquad (4)$$

AC filter calculation

$$L = \frac{V_{in}}{4\, fs\, \Delta I_{pp}} \qquad (5)$$

$$f_c = \frac{1}{2\pi\sqrt{LC}} \qquad (6)$$

Where,
f_c= Corner Frequency =10 kHz
f_s=Switching Frequency =100 kHz
L= Filter Inductor
C=Filer Capacitor
V_{in}= Input DC Voltage
ΔI_{pp}= Inductor Ripple Current

Inductor is designed such a way that it can tolerate 10% of current. The compromised value of the inductor is 4mH. Capacitor can be calculated by choosing the corner frequency 10% of the switching frequency [13]. The compromised value of the capacitor is 2µF.

Table I Components of system

Components	Parameters
Primary Switches	IRFZ40
Transformer	Turns ratio 1:9 L_p=41µH L_s=3.6mH ETD34 core
Secondary Switches	IRF460
Secondary Diodes	MUR4100
AC filter Inductor	4mH
AC filter Capacitance	2µF

SIMULATION RESULTS

In this study, simulation analysis was carried out using Windows 7 Ultimate operating system Intel(R) core(TM) - i7 3770 CPU @ 3.40GHz having 4 GB of RAM and 64bit operating system. The proposed micro inverter was simulated by using Orcad Capture CIS Lite 17.2. The performance parameters for the inverter are total harmonic distortion, power conversion efficiency CEC and EU efficiency.

Sinusoidal PWM Generation

Sinusoidal PWM shown in Fig. 4 is generated by comparing the high frequency triangular wave and low frequency sine wave. This is conceptual SPWM as 100 kHz frequency is not visible for given span. Sinusoidal PWM at 100 kHz shown in Fig.5.

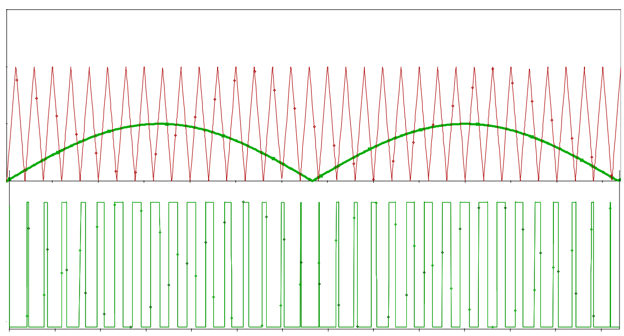

Fig 4 Conceptual SPWM generation

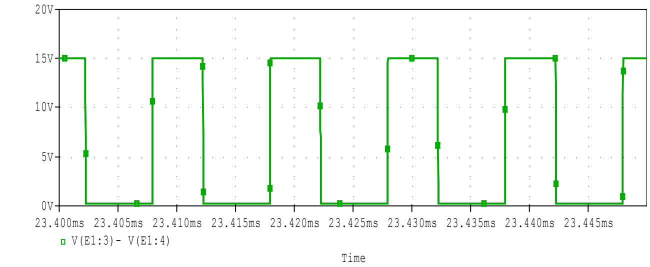

Fig 5 Sinusoidal PWM at 100 kHz frequency

Inverted Sinusoidal PWM is required for another leg of MOSFETs as shown in Fig.6.

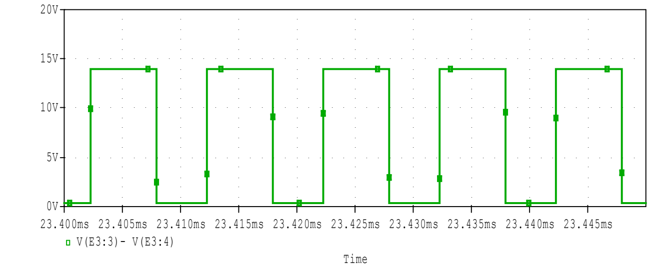

Fig 6 Inverted Sinusoidal PWM at 100 kHz frequency

Gate Drive Pusles for Unfolder MOSFET

To convert the rectified sine wave in to full sine wave, line commutated circuit is simulated. Here for full bridge unfolder MOSFET is used such a way that M5 and M8 are turn on at a time and inverted pulsed of 50Hz are provided to M6 and M7. Fig7 and Fig8 gives gate drive pulses of Unfolder Bridge for 20ms time period.

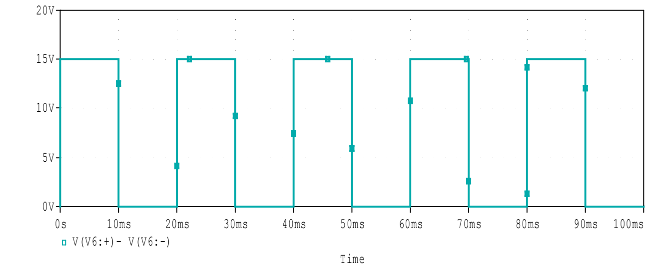

Fig 7 Gate Drive Pulses for M5 and M8 at 50Hz frequency

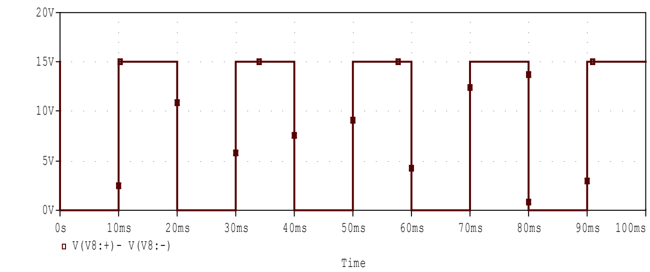

Fig 8 Gate Drive Pulses for M6 and M7 at 50Hz frequency

Input and Output Results

Here the solar PV panel of 400W power is conceptualized with input voltage of 36V dc and input current of 11.83 A are provided at the input of micro inverter. Fig.9 shows input voltage and Fig.10 shows average input current.

The proposed full bridge micro inverter will be operated in Mode 1 and Mode 2 (Fig. 2 and Fig. 3 respectively) and low voltage and high current SPWM pulses at 100 kHz will be generated at the primary side of transformer.

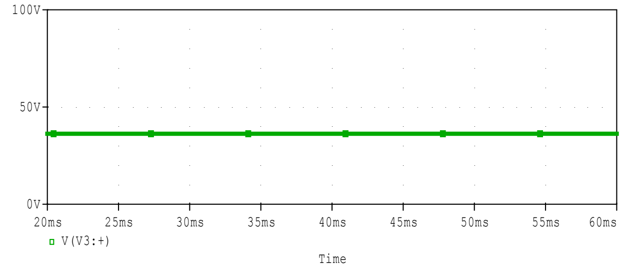

Fig 9 Input Voltage

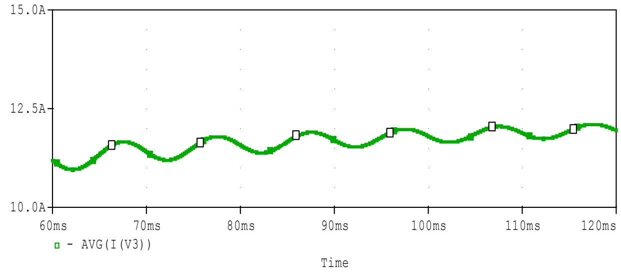

Fig 10 Input Average Current

The output of the bridge is now boost up by transformer according to the turn's ratio 1:9. The secondary side of the transformer is now high voltage low current pulses and the schottkey diode bridge will convert pulsating output into rectified output. This rectified output will passed through LC filter and then Unfolder Bridge will convert into full sine wave output.

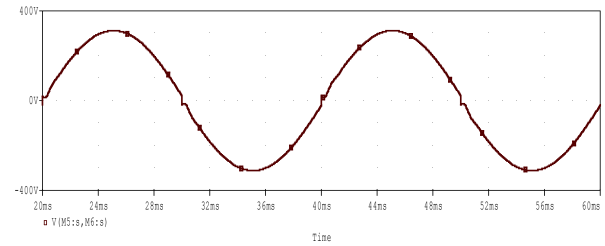

Fig. 11 Output Voltage

The output voltage shown in Fig. 11 is measured across resistive load. The output voltage is available as 312.43V peak or 220.62V rms. The output current is measured as 2.58A peak and 1.83A rms (Fig 12).

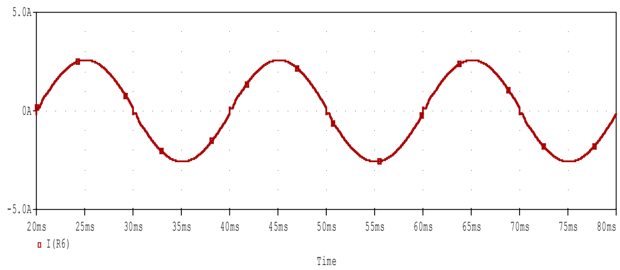

Fig. 12 Output Current

Performance Analysis

In this section, the proposed full bridge micro inverter is analyzed for various load conditions and various loss analysis is performed.

Table II shows the specifications of the overall system.

Table II Specification of system

Parameter	Value
Power Rating(W)	400
Input Voltage(V)	36 dc
Input Current(A)	11.85
Output Voltage(V)	314.12(Peak) & 222.78 (RMS)
Output Current(A)	2.57(Peak) & 1.822 (RMS)
Switching Frequency(kHz)	100
Power Conversion Efficiency	95.45%
Total Harmonic Distortion	2.07%
Simulation Tool	Orcad Capture CIS Lite 17.2 &Orcad Capture Pspice Lite 17.2

Fourier Analysis

THD is the summation of all harmonic component of voltage waveform compared against the fundamentalcomponent of the voltage.

Fig. 9 shows Fourier analysis of the output voltage and it is revealed that peak value is found at 50 Hz frequency.

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_o} = 2.07\% \quad (10)$$

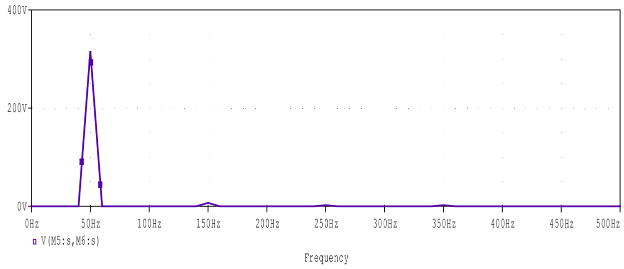

Fig 9 FFT of Output Voltage

Loss analysis

In any power conversion topology there are mainly two types of losses are present conduction loss and switching loss. The conduction loss and switching loss for MOSFET is calculated by eq. 11 and eq.12 respectively.

MOSFET loss

$$P_{CON} = I_{drms}^2 \times R_{DS} \quad (11)$$
$$P_{sw} = \frac{1}{6} V_{ds} \times I_d \times (t_r + t_f) f_s \quad (12)$$

Where.
P_{CON}= Conduction Loss
P_{sw}= Switching Loss
R_{DS}= on state resistance
t_r= Rise Time
t_f= Fall Time
I_d= Drain Current
V_{ds}= Drain to source voltage
f_s= switching frequency

Fig. 10 shows the Switching and conduction loss for input side MOSFET.

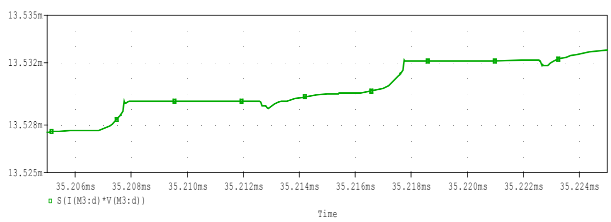

Fig 10 Input MOSFET Loss

Fig 11 show the switching and conduction loss for unfolder MOSFET

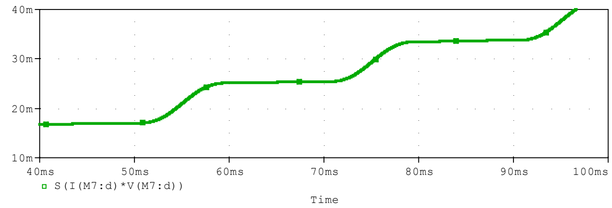

Fig 11 Unfolder MOSFET Loss

Fig 12 show the switching and conduction loss for Bridge Diode

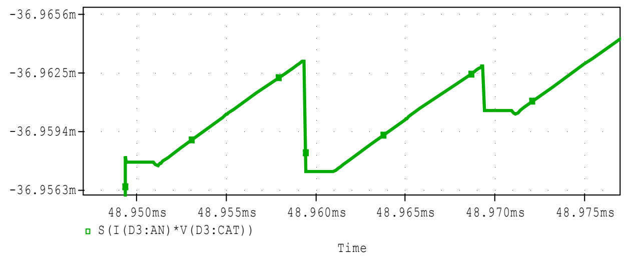

Fig 12 Diode Loss

Table III Loss analysis

Parameter			Values
MOSFET Loss	Input MOSFET Loss	Switching Loss	2W
		Conduction Loss	1.6W
	Unfolder MOSFET Loss	Switching Loss	1.64W
		Conduction Loss	0.12W
	Diode Loss	Switching Loss	8.47W
		Conduciton Loss	5.48W
Total Loss			21.08W

Input power is calculated by using eq13 and output power is calculated by using eq14 based on that efficiency is found by using eq15 .[10][12]

$$P_{in} = V_{in} \times I_{in} = 36 * 11.80 = 424.8\ W \quad (13)$$

$$P_{out} = \frac{V_{out}}{\sqrt{2}} \times \frac{I_{out}}{\sqrt{2}} = 221.58 * 1.83 = 405.49\ W \quad (14)$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{405.49}{424.8} \times 100 = 95.45\% \quad (15)$$

Where,
P_{in}= Input Power
P_{out}= Output Power
V_{in}= Input Voltage
V_{out}= Output Voltage
I_{in}= Input Current
I_{out}= Output Current
η = efficiency

CEC and EU Efficnecny

Proposed full bridge micro inverter is tested for various load conditions and peak efficiency is found 95.45%. Hence it is not sufficient to be efficient hence efficiency is calculated by using California Energy Commission and European Union efficiency and it is found to be 94.08% and 93.71% respectively.

$$CEC = 0.04 * \eta_{10\%} + 0.05 * \eta_{20\%} + 0.12 * \eta_{30\%} + 0.21 * \eta_{50\%} + 0.53 * \eta_{75\%} + 0.05 * \eta_{100\%} \quad (16)$$

CEC= 94.08%

$$EU = 0.03 * \eta_{5\%} + 0.06 * \eta_{10\%} + 0.13 * \eta_{20\%} + 0.10 * \eta_{30\%} + 0.48 * \eta_{50\%} + 0.20 * \eta_{100\%} \quad (17)$$

EU=93.71%

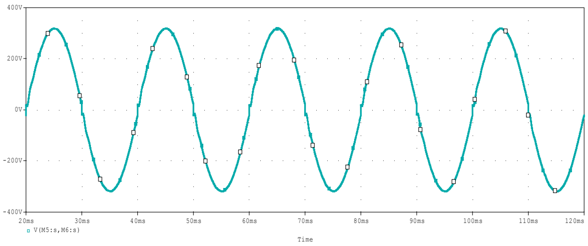

Fig 13 output voltage at 75% load

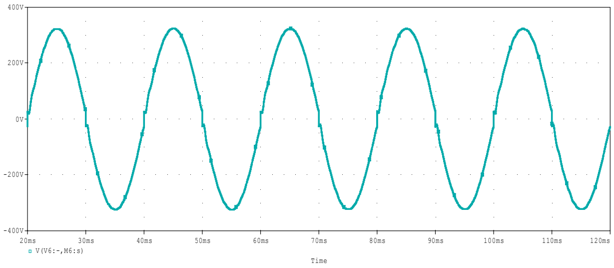

Fig 14 Output Voltage at 50% Load

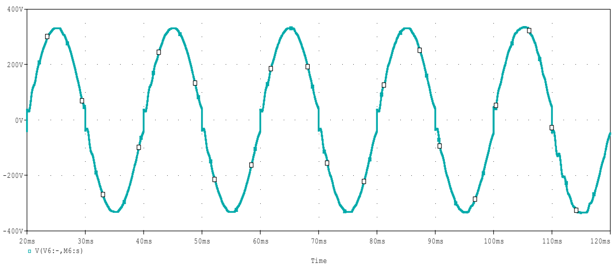

Fig 15 Output Voltage at 30% load

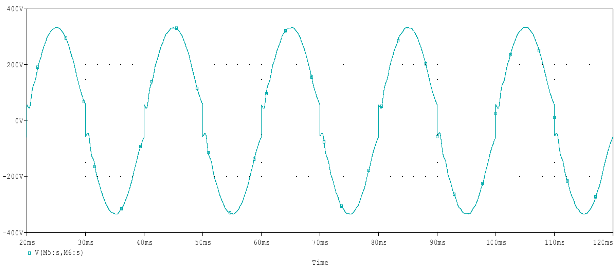

Fig 16 Output Voltage at 20% load

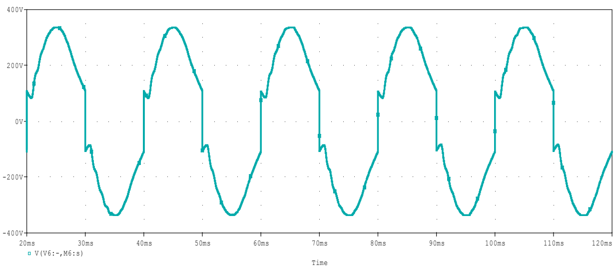

Fig 17 output voltage at 10% load

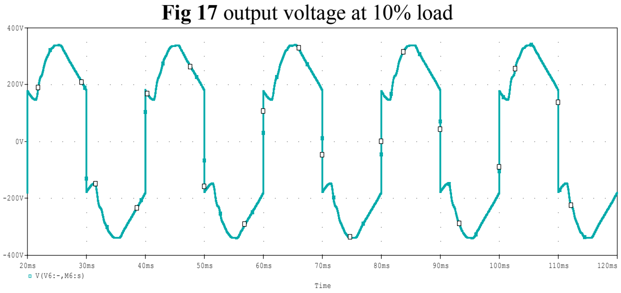

Fig 18 output voltage at 5% load

TableIVshowsvarious parameters for different load conditions

Table IV Performance at Various Loads

Parameter		Value						
L (%)		100	75	50	30	20	10	5
P(W)		400	300	200	120	80	40	20
R (Ω)		121	161	242	403	605	1210	2420
Vin (V)		36	36	36	36	36	36	36
Iin(A)		11.80	9.36	6.4	4	2.78	1.48	0.881
Vo	Peak	312	319	323	332	337	341	346
(V)	RMS	222.7	226.2	229.07	235.46	239	241.8	245.4
Io	Peak	2.58	1.98	1.33	0.824	0.559	0.285	0.142
(A)	RMS	1.822	1.404	0.94	0.59	0.396	0.202	0.101
Pin(W)		426.6	336.96	230.4	144	100.08	53.28	31.72
Po(W)		405.9	316.76	215.32	138.9	94.64	48.85	24.78
η (%)		95.45	93.99	93.45	96.45	94.56	91.68	78

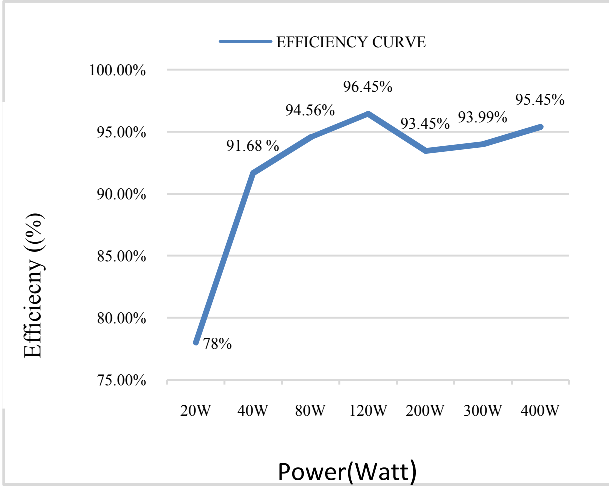

Fig 19 efficiency curve

CONCLUSION

The paper discusses design and simulation of single phase full bridge micro inverter with isolated output which produces grid equivalent voltage from low input dc voltage at 100 kHz switching frequency. The filter parameters are optimized to get very low harmonics in the output voltage such that THD becomes as low as 2.07%. The other parameters are chosen such that overall power conversion efficiency is available up to 95.45%. The proposed inverter is checked for various load conditions and loss analysis is carried out in detail using Orcad capture CIS Lite 17.2 software.

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