A Hybrid Resonant Pulse Width Modulation Power Factor Correction Converter with High Gain

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Abstract — *The AC-DC power factor correction (PFC) converter is a key element for high voltage DC applications. Hybrid resonant bridgeless AC-DC PFC boost converter operating in continuous conduction mode (CCM). This hybrid resonant boost converter has two active switches that operate in pulse-width modulation and hybrid resonant modes of operation. This combined modulation technique is called Hybrid Resonant PWM (HRPWM). This converter with HRPWM features has several benefits. The gates of the two active switches are tied together so,the converter does not need any extra circuitry to sense the positive or negative line cycle operation. The semiconductor devices operate with a voltage stress close to the output voltage. The resonant tank components are relatively small in size and the hybrid resonant mode of operation alleviates the reverse recovery losses for the body diode.The inherent inrush current limiting capabilities improve the system reliability. HRPWM converter connect with different types of gain cell. The HRPWM bridgless AC-DC power factor correction converter is simulated using MATLAB/simulink R2014a software. The converter is controlled using dsPIC30F2010 microcontroller. Hardware is implemented and results are verified.*

Keywords — *Put your keywords here, keywords are separated by comma.*

I. INTRODUCTION

The AC-DC power factor correction (PFC) converter [1] is a key element for industrial and electric vehicle battery chargers. In these applications, proper topology selection for the AC-DC charger with PFC is essential to meet the regulatory requirements of input current harmonics, output voltage regulation, and implementation of PFC. In boost derived PFC converters, it is very important to design proper circuitry to reduce the inrush current as they inherently have high inrush current at start up and lack of lightning and surge protection due to the direct connection of the AC input voltage through the PFC diode and PFC inductor to the bus capacitors. In these converters, inrush currents occur when the PFC circuit is connected to an input voltage with a peak higher than the instantaneous DC bus voltage. Similarly, if an AC power interruption occurs during normal operation for a period long enough for the dc bus capacitor to discharge below the peak of the AC input, inrush currents will ow upon restoration of AC power. Addressing these drawbacks in boost derived converters requires additional circuitry, complexity, and often impacts system e_ciency. Hence, for practical applications these converters require inrush current and surge limiting to prevent damage on connection to AC power.

Unlike the boost PFC converter, there is no diode bridge rectifier in the dual boost or bridgeless boost converter topology[2]. Hence, the bridgeless converter reduces conduction losses and associated heat management issues in the input rectifier bridge.

The H bridge converter is also realizes bridgeless circuit operation. However, it requires three isolated current sensors which add circuit complexity. The totem pole converter has the same number of semiconductor devices as the bridgeless boost converter. The totem pole converter uses the MOSFET intrinsic body diode to carry the load current, resulting in reverse recovery losses, which makes it unfavorable to use in CCM.

To reduce the reverse recovery losses of the body diode, the topologies in [3] have been proposed. However, with these topologies, it is necessary to sense the positive and negative line-cycle operation to properly control the pulse width modulation (PWM) switches, requiring more complex control and increased cost. The totem pole converter can be driven with the same PWM signals for both PWM switches. The drawback of this converter is the increased number of passive elements. The converter is realizes high utilization of the power semiconductors, while reducing the boost inductor size and line filter requirements. The drawback of this converter is the high number of semi-conductor devices. A significant drawback of the boost derived PFC converters is high inrush current and lack of lightning and surge protection due to the direct connection of the ac input voltage through the PFC diode and PFC inductor to the bus capacitors. In these converters, inrush currents occur when the

PFC circuit is connected to an input voltage with a peak higher than the instantaneous dc bus voltage. Similarly, if an ac power interruption occurs during normal operation for a period long enough for the dc bus capacitor to discharge below the peak of the ac input, inrush currents will ow upon restoration of ac power. Addressing these drawbacks in boost derived converters require additional circuitry, complexity, and often impacts system efficiency.

Transformerless DC-DC switched-inductor converter is introduced, analyzed and validated in [5]. Compared to other high voltage gain PFC converters, the circuit structure of the proposed PFC converter is very simple and the number of component is less, contributing to improve power density and total cost.

There is different topologies to achieve higher voltage gain[7] low switch stress, low ripple, and cost efficient converters. Here Dickson multiplier cell to prove its superiority compared to other cell. By using this gain cell Low voltage stress and switch utilization factor which reduces the cost of the active switch. Another advantage is that Less energy volume of the inductor which reduces the cost and size of the converter. Dickson multiplier cell is the best and efficient converter to implement in stand alone or grid connected PV applications.

This chapter is to propose a hybrid resonant pulse width modulated (HRPWM) AC-DC PFC converter with high gain. The circuit is analysed by simulating different type of gain cells in [10,11] and prototype is depending upon the performance of the circuits, which has inherent inrush current limiting capabilities. The converter architecture also enables simple implementation of lightning and surge protection systems. Moreover, this converter can survive sustained over voltage events and can limit the voltage stress on the converter and downstream components. These properties help to make a robust and reliable converter system.

II. TOPOLOGICAL DERIVATION OF HYBRID RESONANT PWM PFC CONVERTER WITH HIGH GAIN

This hybrid resonant boost converter has two active switches that operate in pulse width modulation (PWM) and hybrid-resonant modes of operation. This combined modulation technique is called hybrid resonant PWM (HRPWM). The proposed converter with HRPWM features several benefits. The gates of the two active switches are tied together. So, the converter does not need any extra circuitry to sense the positive, or negative line cycle operation. The semiconductor devices operate with a voltage stress close to the output voltage. The resonant tank components are relatively small in size and the hybrid resonant mode of operation alleviates the reverse recovery losses for the body diode.

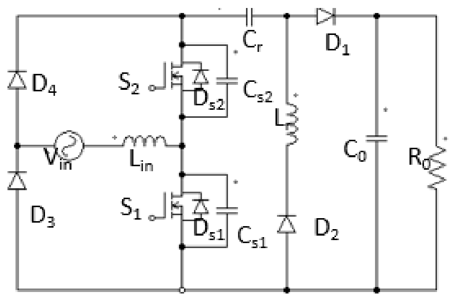

Fig 2.1 HRPWM PFC converter

HRPWM PFC converter improve the gain by using different type of gain cell .The most predominately used HG cell are given below Figure 3.3.

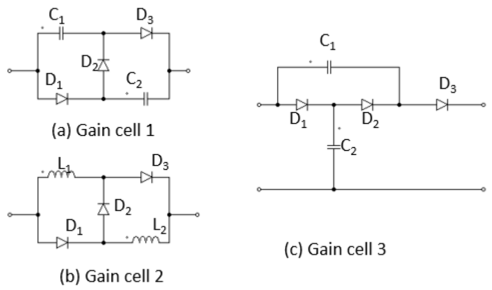

Fig 2.1 Types of gain cell

III. MODES OF OPERATION

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A. HRPWM PFC Converter With Gain Cell 1

The operating modes of HRPWM PFC converter with gain cell 1 and gain cell 2 are same.

Mode 1

This mode starts when switches S_1 and S_2 are turned ON. The input current iin stores energy in the stores energy in the input inductor L_{in}. This mode ends when the resonant current i_{Lr} is zero. C_1,C_2 discharge and C_0 charging.

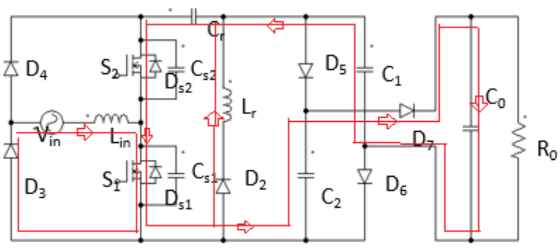

Fig 3.1. Mode 1

Mode 2

This model starts when D_2 stops conducting and there is no current in the resonant branch. In this mode the inductor L_{in} stores energy similar to traditional boost operation. This interval ends when S_1 and S_2 are turned off.

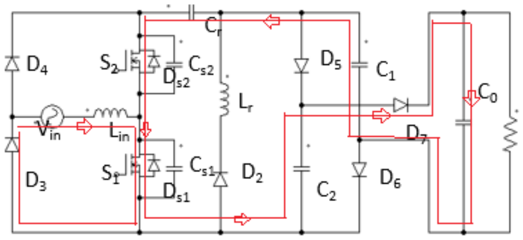

Fig 3.2. Mode 2

Mode 3

In this mode, the energy stored in the input inductor Lin is transferred to C_1 and C_2. This interval ends when S_1 and S_2 are turned on in mode 1. C_1,C_2 charging and C_0 discharging.

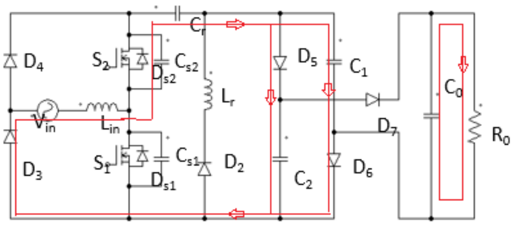

Fig 3.3. Mode 3

B. *HRPWM PFC Converter With Gain Cell 3*

Mode 1

This mode starts when switches S_1 and S_2 are turned ON. The input current iin stores energy in the stores energy in the input inductor Lin. This mode ends when the resonant current iLr is zero. $C_{1,}C_{01}$,C_{02} discharging.

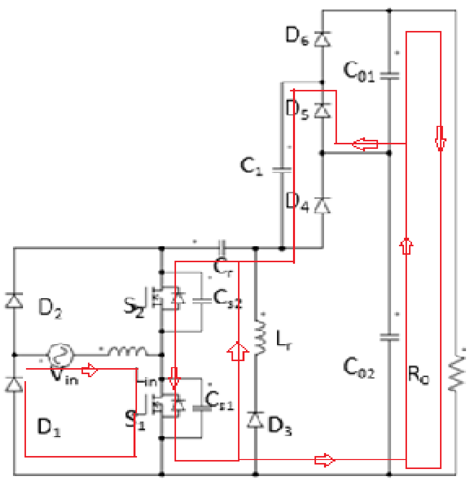

Fig 3.4. Mode 1

Mode 2

This model starts when D_2 stops conducting and there is no current in the resonant branch. In this mode the inductor L_{in} stores energy. This interval ends when S_1 and S_2 are turned off.

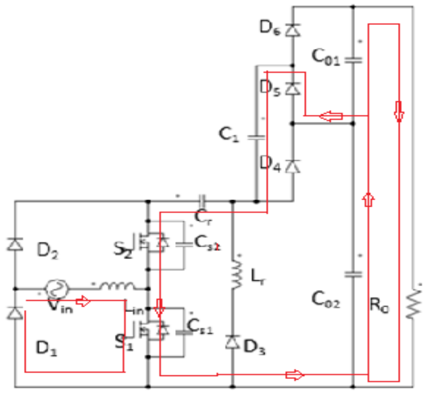

Fig 3.5. Mode 2

Mode 3

In this mode, the energy stored in the input inductor Lin is transferred to load. This interval ends when S_1 and S_2 are turned-on in mode 1. C_1,C_2 charging and C_0 discharging

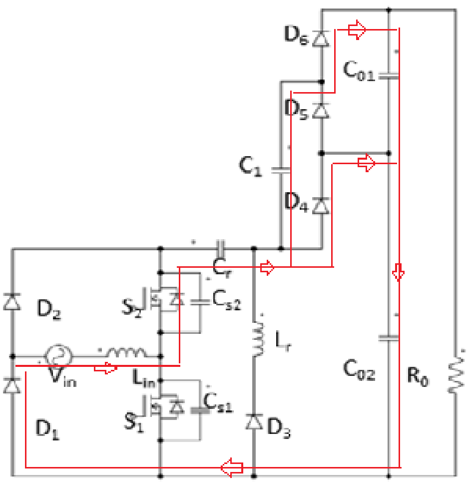

Fig 3.6. Mode 3

IV. DESIGN OF COMPONENTS

In this converter AC input voltage of 120 V and 600 V DC is set as output. The load resistance is 600 for an output power of 600 W. The switching frequency is 70 kHz. Duty Ratio is chosen as 70%.

A. *Design of Inductors*

$$L_{in} \geq \frac{V_{in}D}{\Delta\ I_{Lin}f_s}$$

$$L_{in} \geq \frac{120 * .70}{3.25 * 70000} \geq 3.69 * 10^{-4}H$$

Take 370 μH.Assume the ripple current of the inductor current ΔI_{LO} is 3.25 A.

$$L_r \geq \frac{1}{4*\pi^2*f_r^2} \geq \frac{1}{4*\pi^2*64000^2} \geq 6.18\mu H$$

Where resonant frequency fr is taken as 64 kHz. The ripple current of the inductor current. Take 6 μH

$$L_1 \geq \frac{D*V_{in}}{f_s*\Delta I_L} \geq \frac{.70*120}{70000*2.25} \geq 533\mu H$$

Take 570 μH. L_1 and L_2 are same.

B. *Design of Capacitors C*

$$C_r \geq \frac{I_0}{2*f_s*V_{Cmax}} \geq \frac{1.6}{2*70000*25} \geq 0.45\mu F$$

Assume capacitor maximum voltage 25V. Take 1 μF

$$C_0 \geq \frac{P_0}{4*f^2*V_0*\Delta V_0} \geq \frac{600}{4*50*600*12} \geq 416\mu F$$

Take 720 μF

Here $C_0=C_{01}=C_{02}$

V. TABLE I
SIMULATION PARAMETERS

Input Voltage V_{in}	120 V
Switching Frequency f_s	70 kHz
Resonant Frequency f_r	64 kHz
Inductor L_{in}	370 μH
Inductor L_r	6 μH
Capacitor C_r	1 μF
Capacitor C_0	1000 μF
Load R_0	250 Ω

VI. SIMULINK MODEL OF HRPWM PFC CONVERTERS

HRPWM PFC Converter is simulated with 3 gain cell using MATLAB 2014.

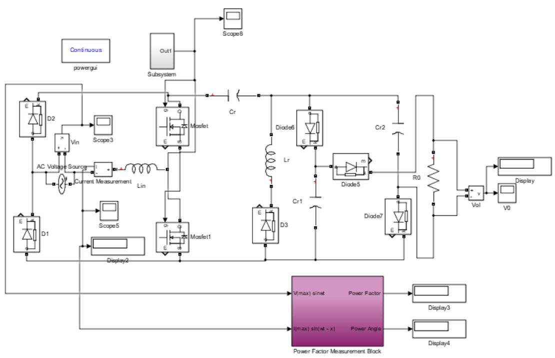

Fig 6.1 Simulink model of HRPWM PFC Converter with gain cell 1

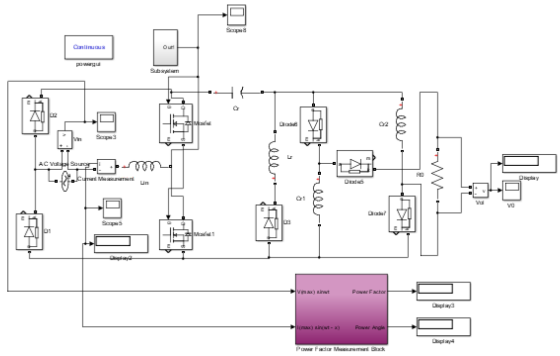

Fig 6.2 Simulink model of HRPWM PFC Converter with gain cell 2

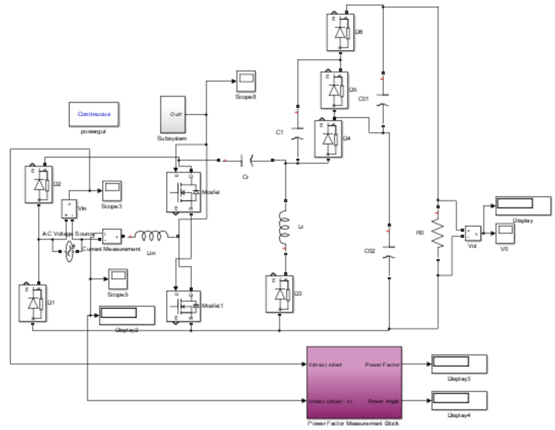

Fig 6.3 Simulink model of HRPWM PFC Converter with gain cell 3

VII. SIMULATION RESULTS

A. *Simulation Results of HRPWM PFC Converter with Gain Cell 1*

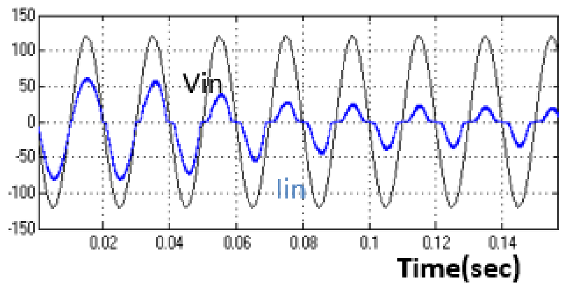

Fig 7.1 Input voltage and Input current

The input-output voltage, input-output current waveforms of the proposed converter are provided in Fig 7.1 and 7.2. For input voltage 120 V we get 580 V output. Here the gain is 4.8. The inrush current is 60 A and Power Factor is .89.

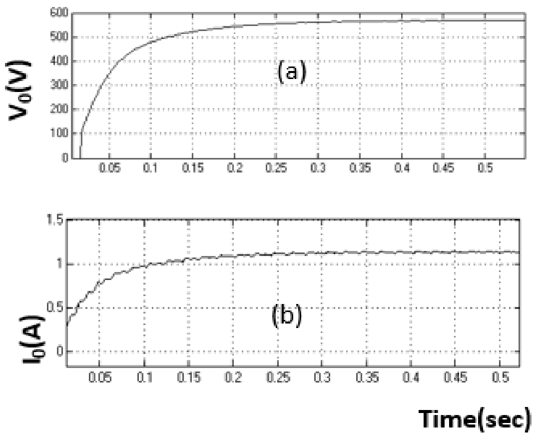

Fig 7.2 (a) Output voltage (b) Output current

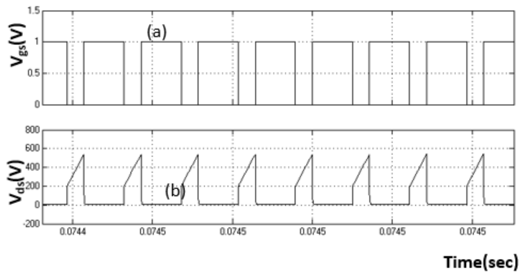

Fig 7.3 (a) Switching pulse (b) Voltage stress

Waveforms of the voltage across switch and the gating signal for switches are provided in Fig.7.3. Waveforms of the voltage across switch and gating signals for S_1 and S_2 are same.

B. *Simulation Results of HRPWM PFC Converter with Gain Cell 2*

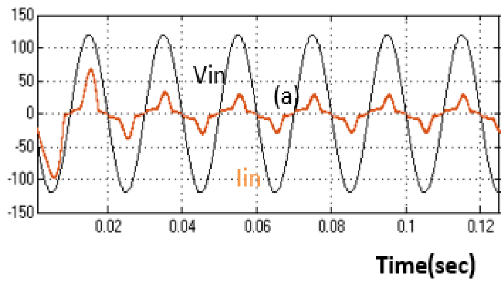

Fig 7.4 Input voltage and Input current

The input-output voltage, input-output current waveforms of the proposed converter are provided in Fig 7.4 and 7.5. For input voltage 120 V we get 580 V output . Here the gain is 4.8. The inrush current is very high as 80 A and Power Factor is .87.

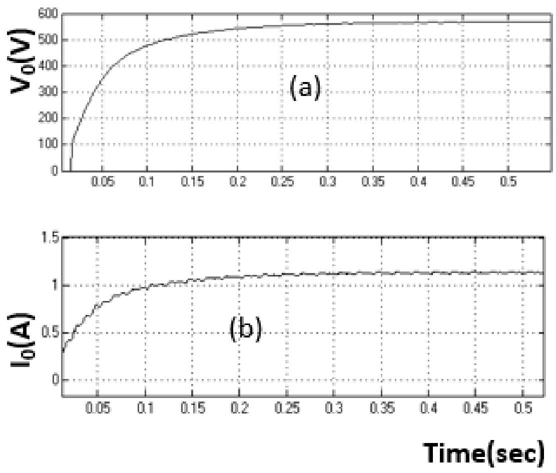

Fig 7.5 (a) Output voltage (b) Output current

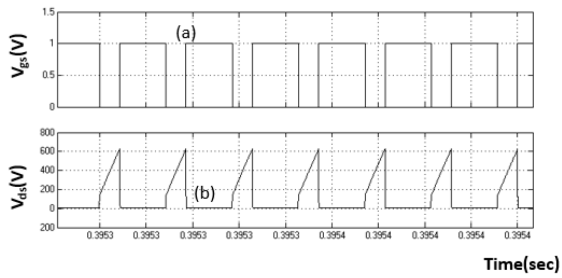

Fig 7.6 (a) Switching pulse (b) Voltage stress

The voltage stress across switch is 620 V. Waveforms of the voltage across switch and gating signals for switches S_1 and S_2 are same.

C. *Simulation Results of HRPWM PFC Converter with Gain Cell 3*

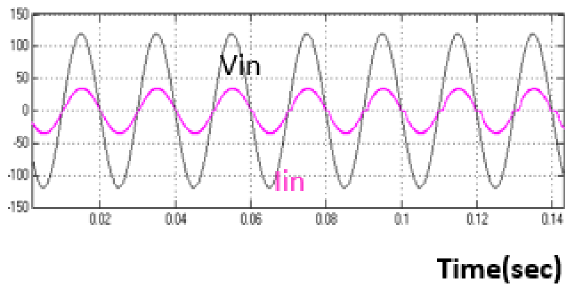

Fig 7.7 Input voltage and Input current

The input-output voltage, input-output current waveforms of the proposed converter are provided in Fig 7.7 and 7.8. For input voltage 120 V we get 600 V output . Here the gain is 5. The inrush current is very high as 40 A and Power Factor is .97.

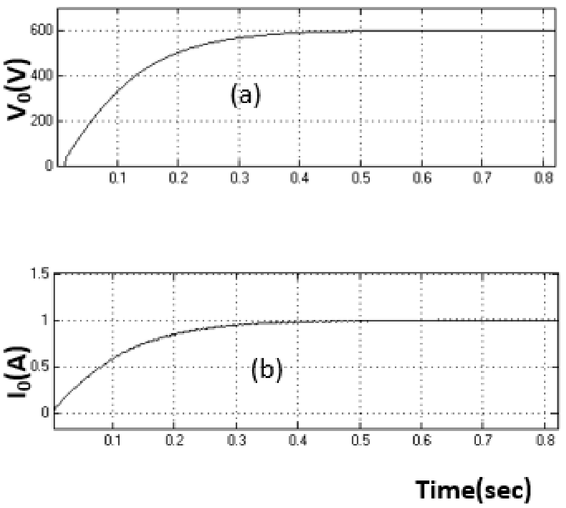

Fig 7.8 (a) Output voltage (b) Output current

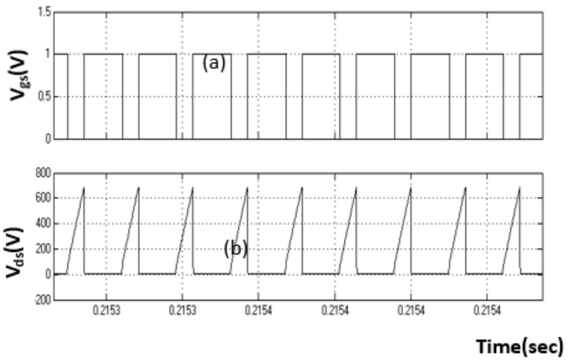

Fig 7.9 (a) Switching pulse (b) Voltage stress

The voltage stress across switch is 680 V. Waveforms of the voltage across switch and gating signals for switches S_1 and S_2 are same.

Analysis

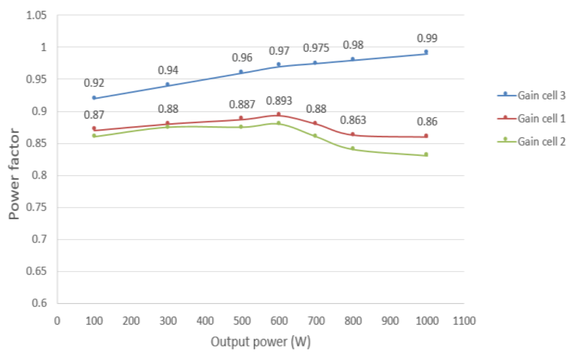

Fig 7.10 Power factor versus output Power waveform

Curves of the measured power factor versus output power for HRPWM PFC Converter with gain cell 1, cell 2 and cell 3 are provided in Fig 7.10. The power factor is greater than 0.99 at 1000 W power for gain cell 3.

The maximum gain is 5.33 for .9 power factor for gain cell 3. Voltage gain versus Duty ratio plot of cell 1 same as cell 2.

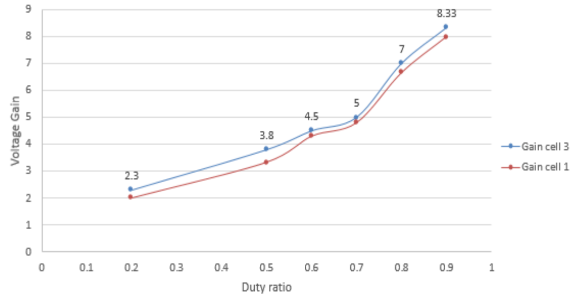

Fig 7.10 Voltage gain versus Dutyratio waveform

Comparison table

TABLE II COMPARISON

	Conventional bridgeless pfc	HRPWM pfc	HRPWM with high gain cell 1	HRPWM with high gain cell 2	HRPWM with high gain cell 3
Power Factor	0.76	0.97	0.89	0.87	0.97
Inrush current	100 A	10 A	60 A	80 A	40 A
Gain	3.25	3.33	4.8	4.8	5
Switching loss	390 V	410 V	620 V	620 V	680 V
Number of Components					
Diode	2	4	6	6	6
Switch	2	2	2	2	2
Inductor	1	2	1	3	2
Capacitor	1	2	4	2	4

The Table II shows the comparison between conventional PFC converter and HRPWM PFC converter. From this table we can say that converter with gain cell 3 shows the best performance. So hardware for Hybrid resonant pulse width modulation power factor correction converter with gain cell 3 is implemented.

VIII. EXPERIMENTAL SETUP WITH RESULTS

A prototype of Hybrid resonant pulse width modulation power factor correction converter with gain cell 3 is implemented.

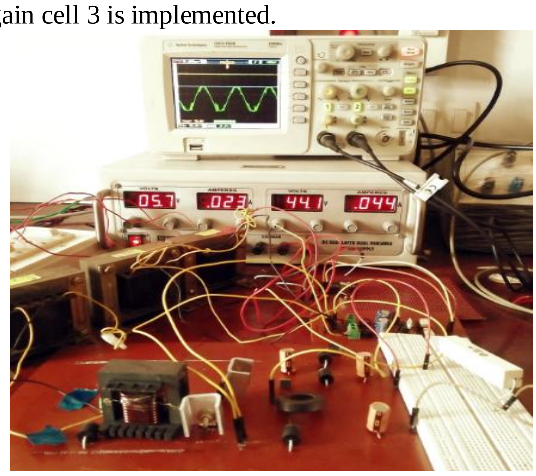

Fig 7.11 Experimental setup

Control pulses for MOSFET switches are generated using dsPIC microcontroller. Control pulse is amplified by driver circuit composed of TLP250. It also provides isolation between control and power circuit. The experimental setup is shown in Figure 6.7.

It consist of control circuit, driver circuit and power circuit. Control circuit is composed of dsPIC microcontroller and its power supply. The pulses from microcontroller is amplified by driver circuit composed of TLP250. Power circuit forms the Hybrid resonant pulse width modulation power factor correction converter with gain cell 3.

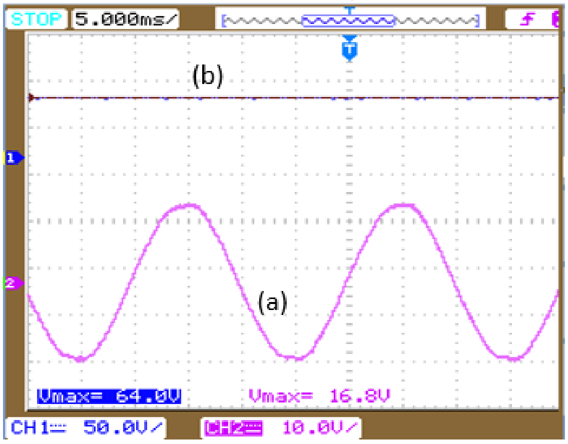

Fig 7.12 Input voltage and Output voltage

Fig 7.12 shows the output voltage of prototype. An output voltage of 64 V AC is obtained with an DC input of 12V and switching frequency of 50 kHz.

IX. CONCLUSION

A high performance hybrid resonant pulse width modulation power factor correction converter with gain cell 3 topology has been presented. The AC-DC converter presented here has a high gain. This converter topology has been analyzed and performance characteristics presented. There is no diode bridge rectifier which helps to reduce the losses. The theoretical waveforms were compared and analysis. The converter topology shows a high input power factor and high efficiency over the entire load range. Power factor is obtained as 0.97. It has Inrush current limit capability. The converter is a promising topology option for single phase PFC solutions in high power rectifier applications.

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