International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-2 Issue-4, March 2013

Implementation of a Hybrid High Power Factor Three-Phase Unidirectional Rectifier

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Abstract-This paper presents a new hybrid three phase rectifier composed by the parallel association of a single switch three phase boost rectifier with a pwm three phase unidirectional rectifier. According to this proposal each rectifier processes about half of the output rated power. The diode rectifier operates at a low frequency and has a higher output power rating Therefore ,the pwm unidirectional rectifier is designed to operate with a small power rating and a high switching frequency. In the proposed scheme, dsPIC30F2010 controller is used to produce signals. A resistive load(Two incandescent lamps with different watts) are used as load for testing the developed hardware. Textronics TDS2024B storage oscilloscope is used to store the gate pulses and waveforms. The perfectly sinusoidal input currents with improved power factor can be obtained by this hybrid rectifier.

Keywords – Active rectifier, Bridge, IGBT, MOSFETs, passive rectifier, Sensors.

I.INTRODUCTION

In the last decade, numerous topologies and modulation strategies have been introduced and studied extensively. In high power applications, three-phase rectifiers desirable requirements are; high efficiency, high reliability, simple control scheme and high quality input currents. The latest advances in high power semiconductor devices have introduced newer solutions for high power conversion systems, however, the degree of acceptance of each technology vary in accordance with various industries and applications.

Traditionally, three-phase AC-to-DC conversions are performed by diode or phase-controlled rectifiers. Due to the commutation of these structures to be done by the zero current crossing, they are also called "line-commutated" rectifiers. These rectifiers are extremely robust and present low cost, but draw non-sinusoidal currents or reactive power from the source, deteriorating the electrical power system quality. To compensate the harmonic distortion generated by the standard diode rectifiers, passive linear filters or power factor correction structures can be employed. Recent trends in high power rectifiers introduces new class of three-phase rectifiers; the Hybrid Rectifiers. The term “Hybrid Rectifier” denotes the series and/or parallel connection of a line-commuted rectifier and a self-commuted converter. Moreover, the line-commuted rectifier operates with low frequency and it handles the higher output power rating. Therefore, the active rectifier is designed to operate with small power ratings and with high switching frequency.

Manuscript published on 30 March 2013.
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Following these tendencies, this paper proposes a new hybrid high power rectifier with the characteristic of the power distribution, combining the robustness and the efficiency of the line-commuted rectifiers with the low harmonic current production of the self-commuted rectifiers.

The developed hardware is tested on a resistive load(Two incandescent lamp with different watts) . According to the requirement, a software program is written and is fed to the digital signal controller (dsPIC30F2010) for the necessary action. The perfectly sinusoidal input currents with improved power factor can be obtained by this hybrid rectifier. The various graphs/waveforms are analyzed and studied on ***Digital Storage Oscilloscope***.

II. BLOCK DIAGRAM AND ITS EXPLANATION

A. System overview

The proposed unidirectional three phase hybrid rectifier block diagram and circuit diagram are as shown in fig.1and fig.2. This block diagram consists of transformers, single switch three phase boost rectifier, three phase unidirectional rectifier, voltage sensor, current sensors, control unit, gate drive unit.

The hybrid rectifier is composed of a single-switch diode bridge boost-type rectifier in parallel with a pulse width modulation (PWM) three-phase unidirectional boost rectifier. Here to step down the voltage 3 transformers are used of rating 220/110v, 250w. These are connected in star connection. The output voltage of these transformers is fed to the current sensors and voltage sensor. The dc output voltage regulation is provided by the voltage control loop. The signal obtained at the output of voltage controller is used to adjust the currents’ references in case the load or input voltage changes. The inductor current of the single-switch boost rectifier is sampled and compared to a constant reference. The error produced by this comparison is applied to the boost current compensator, and the PWM modulator generates the gate signal of the boost switch.

Currents $ia1\ (t)$, $ia2\ (t)$, and $ia3\ (t)$ are indirectly controlled by sensing the mains currents and comparing them with their respective sinusoidal references. The errors produced by the comparisons between the sampled signals and reference signals are applied to their respective compensators, and the PWM modulators generate the gate signals of the active rectifier.

The single-switch diode bridge boost-type rectifier (passive rectifier) consists of three phase full bridge rectifier and a boost converter. The full bridge rectifier consists of 3 legs, each leg having three diode sets, each set has three diodes(IN5408) (upper &lower) connected in parallel to increase the current rating and it also has carbon composition resistor which has a low value of inductance ,from which peak current is reduced during turn on of the switch.

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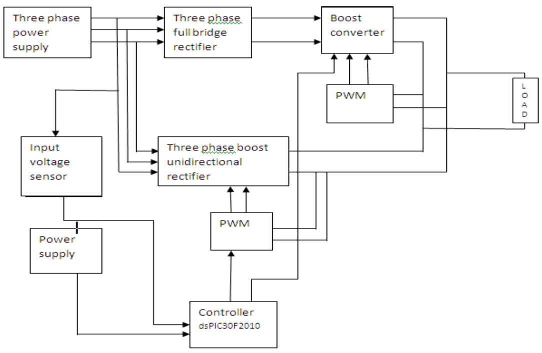

Fig1. Block diagram of the proposed system

The output of the rectifier is fed to the boost converter which has an IGBT (FGA25N120ANTD), diodes (uf5408), inductors which boost the input voltage. This rectifier operates at a low frequency & has a higher output power rating. Three phase boost unidirectional rectifier consists of 3 MOSFETS & the 6 diodes are connected around the three MOSFETS. Hence this rectifier consists of 18 diodes(IN5408). The rectifier is designed to operate with a small power rating and at a high switching frequency. In this work an optocoupler TLP50 is used to isolate the gate drive circuit and the MOSFET, IGBT based converter circuit. The optocoupler consists of an infrared light-emitting Diode and a silicon phototransistor. The input signal is applied to the IRLED and the output is taken from the phototransistor.

A digital signal controller (dsPIC30F2010) is used to implement the core of the control function, which simplifies the hardware setup.

B .Control circuit

The control circuit of the proposed scheme consists of a Digital signal Controller dsPIC30F2010.A Digital Signal Controller (DSC) is a single-chip, embedded controller that seamlessly integrates the control attributes of a Microcontroller (MCU) with the computation and throughput capabilities of a Digital Signal Processor (DSP) in a single core. The dsPIC DSC has the “heart” of a 16-bit MCU with robust peripherals and fast interrupt handling capability and the “brain” of a DSP that manages high computation activities, creating the optimum single-chip solution for embedded system designs. The dsPIC30F devices contain extensive Digital Signal Processor (DSP) functionality within high-performance 16-bit microcontroller (MCU) architecture. It also consists of two opto-coupler for isolating the control and power circuits. In this work an optocoupler TLP250 is used to isolate the drive circuit and the MOSFET-based power circuit.

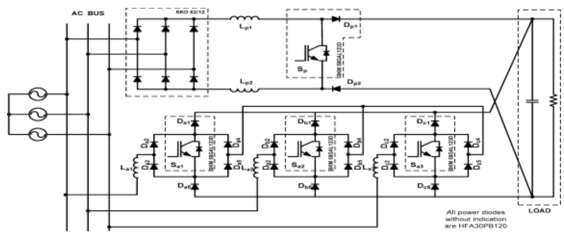

Fig 2 Hybrid three-phase high-power-factor rectifier. The traditional single-switch three-phase boost rectifier and the three-phase boost unidirectional rectifier connected in parallel

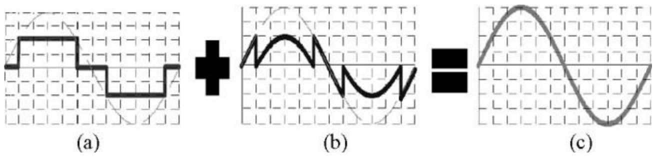

Fig 3. Expected current waveforms of the hybrid rectifier.
(a) Current waveform imposed by the single-switch boost rectifier
(b) Current waveform that should be generated by the active rectifier. (c)Desired sinusoidal waveform.

III. EXPERIMENTAL SET UP AND ITS RESULTS

The hybrid three phase rectifier developed hardware is tested with load. The proposed control system is implemented by a DSC (dsPIC30F2010) based PWM inverter. C language is used to develop the program. The device is programmed using MPLAB Integrated Development Environment (IDE) tool. It is a free, integrated toolset for the development of embedded applications employing Microchip's PIC and dsPIC controllers. For execution of C-code, MPLAB compiler is used. In this work, In this work two incandescent lamps (in series)of power rating 100W,40W,60W have been used to test the load.

The hardware set is developed and tested in power electronics laboratory and the photograph of complete setup is shown in fig 3.4. The test is carried out on incandescent bulbs for different loads and voltages. DC voltages and DC output voltages for different loads are tabulated.

In the complete experiment the oscilloscope used is Tektronix TDS2024B Digital Storage Oscilloscope (DSO) to store gate pulses and voltage waveforms.

Table 3.1.3.2, 3.3,3.4 & 3.5 shows the output for variable voltages and variable loads, corresponding waveforms are taken from the DSO and are shown in figs . The gate pulses are observed for different loads and voltages are shown in the figs , 3.2, 3.3.

I)Table 3.1 Experimental results for Resistive load(60W and 40W incandescent lamps)

Sl. No	Input voltage	Output voltage	Output Voltage with boost (without passive rectifier)	Output voltage With boost (without Active rectifier)	Output voltage without boosting operation
1.	20V	27.5V	25.6V	12.1V	5.4V
2.	40V	53.5V	48.3V	41.2V	20.6V
3.	60V	81.1V	83.3V	68.2V	34.9V
4.	80V	111.8V	121.4V	100.2V	48.2V
5.	100V	154.9V	145.6V	115.7V	59.9V
6.	110V	178.3V	190.3V	123.8V	68.1V
7.	130V	219V	208V	141.9V	84.8V
8.	150V	263V	257V	156.8V	93.6V
9.	170V	336V	303V	179V	102.4V

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II)Table 3.2 Experimental results for Resistive load(60W and 60W incandescent lamps)

Sl.no	Input voltage	Output voltage	Output voltage with boost (without passive rectifier)	Output voltage with boost (without active rectifier)	Output voltage without boosting operation
1.	20V	15V	13.1V	15.7V	5,6V
2.	40V	37.4V	45.3V	31.8V	20.2V
3.	60V	68.7V	67V	60.4V	33.9V
4.	80V	98.7V	94.6V	86.2V	46.9V
5.	100V	118.6V	120.2V	118.6V	60.6V
6.	110V	--------	132.7V	119.8V	-------
7.	120V	152.1V	--------	---------	73.3V
8.	130V	--------	157V	138.9V	-------
9.	140V	172V	-------	---------	-------
10.	150V	--------	168.1V	166.6V	93.9V
11.	160V	186.7V	---------	---------	--------
12.	170V	--------	181.9V	172.6V	101.2V

III)Table 3.3 Experimental results for Resistive load(100W and 60W incandescent lamps)

Sl.no	Input voltage	Output voltage	Output voltage with boost (without passive rectifier)	Output voltage with boost (without active rectifier)	Output voltage without boosting operation
1.	20V	8.1V	10.5V	13.8V	8.2V
2.	40V	36.7V	35.6V	30V	20.6V
3.	60V	64.8V	72.7V	55.9V	34V
4.	80V	92.1V	92.3V	76.8V	46.4V
5.	100V	118V	126.2V	106.5V	60.6V
6.	110V	124.8V	--------	121.6V	73.5V
7.	120V	133.5V	140.6V	130.4V	86.8V
8.	130V	--------	--------	--------	-------
9.	140V	138.5V	-------	147.8V	100.8V
10.	150V	--------	169V	---------	--------
11.	170V	159.3V	180.9V	159.6V	114.5V

IV)Table 3.4 Experimental results for Resistive load(100W and 40W incandescent lamps)

Sl.no	Input voltage	Output voltage	Output voltage with boost (without passive rectifier)	Output voltage with boost (without active rectifier)	Output voltage without boosting operation
1.	20V	8.9V	9.6V	10.6V	8.5V
2.	40V	36.7V	36V	33.5V	21.4V
3.	60V	73.6V	69.9V	62.4V	34.7V
4.	80V	94.1V	104.3V	94.9V	48.4V
5.	100V	112.3V	136.3V	121.3V	61.4V
6.	120V	123.4V	169.9V	145.5V	74.6V
7.	140V	148.4V	183.7V	148.3V	88.4V
8.	160V	156.7V	192.6V	164.8V	103.8V

V)Table 3.5 Experimental results for Resistive load(100W and 100W incandescent lamps)

Sl.no	Input voltage	Output voltage	Output voltage with boost (without passive rectifier)	Output voltage with boost (without active rectifier)	Output voltage without boosting operation
1.	20V	22.5V	13.6V	14V	11.4V
2.	40V	42.9V	40.8V	35.8V	23.5V
3.	60V	63.2V	56V	55.4V	36.5V
4.	80V	84.7V	79.6V	76.1V	47.7V
5.	100V	108.8V	104.8V	102-8V	64.2V
6.	110V	120.7V	---------	115.1V	68.7V
7.	120V	---------	123.1V	--------	76.2V
8.	130V	146.9V	--------	143.6V	81.9V
9.	140V	--------	133.6V	--------	-------
10.	150V	178.2V	--------	170.5V	103V
11.	170V	199.1V	146.1V	199.7V	111.2V

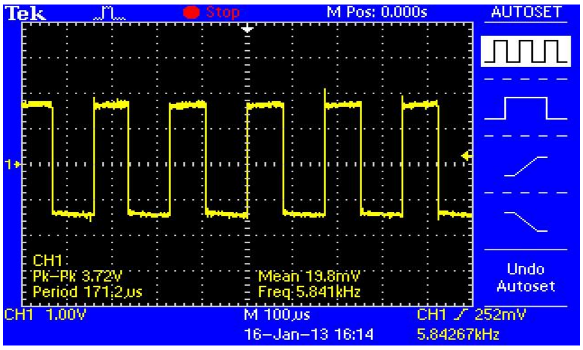

Fig 3.2.a Gate pulse waveform of passive rectifier at 20v(for 200w incandescent bulbs).

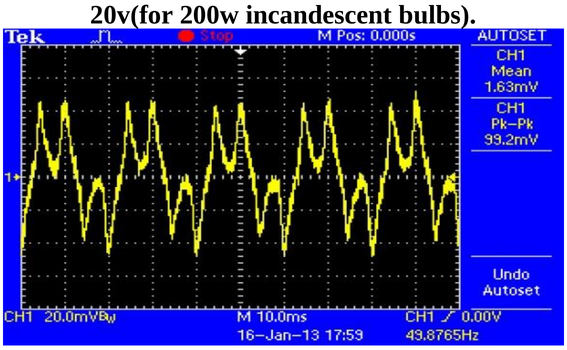

Fig.3.2.b Gate pulse waveform of active rectifier at 130v(for 200w incandescent bulbs).

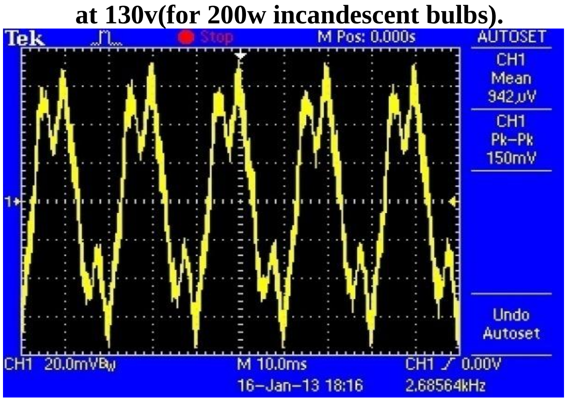

Fig.3.3.a Gate pulse waveform of active rectifier at 130v(for 200w incandescent bulbs)

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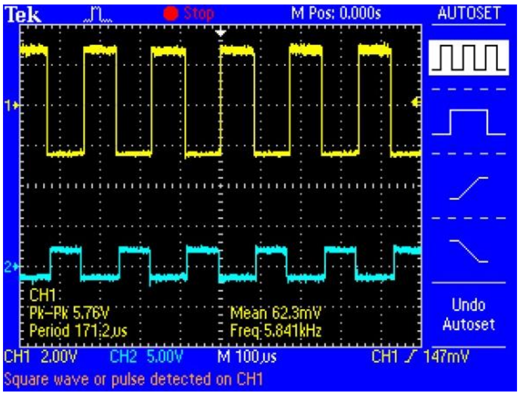

Fig.3.3.b Gate pulse waveform of passive rectifier at 20v(for 200w incandescent bulbs).

Fig 3.4 Photograph of the complete designed system

V. CONCLUSION

The hybrid three phase high power factor rectifier is done successfully and the developed hardware is tested with load. The proposed control system is implemented by a DSC (dsPIC30F2010) based PWM inverter. C language is used to develop the program. The device is programmed using MPLAB Integrated Development Environment (IDE) tool. It is a free, integrated toolset for the development of embedded applications employing Microchip's PIC and dsPIC controllers. For execution of C-code, MPLAB compiler is used.In this work two incandescent bulbs of rating (connected in series)40W,60W,100W has been used to test the load.

The hardware set is developed and tested in power electronics laboratory and the photograph of complete setup is shown in fig 7.3. The test is carried out on universal motor and bulb. DC input voltages and DC output voltages for different loads are tabulated.

In the complete experiment the oscilloscope used is Tektronix TDS2024B Digital Storage Oscilloscope (DSO) to store gate pulses and voltage waveforms.

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