International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 16 (2019) pp. 3566-3572

Analysis of Single Phase Bi-Directional Converter for Improvements in Power Factor and Reduction in Harmonic Distortions

Dr. Rahul Mapari[1*], Rahul Parbat[2]

Pimpri Chinchwad College Of Engineering and Research, Pune, India.

Abstract

This paper present an investigation of bi-directional converter utilizing continuous switching pulse width modulation (CSPWM) and sinusoidal pulse width modulation (S-PWM) methods. The investigation is completed by methods for amendment and reversal activity utilizing two cases. In first case CSPWM procedure is utilized for the amendment activity and S-PWM is for reversal task. Also, in second case both the rectification and inversion are actualized using S-PWM system. The investigation depends on the parameters like power factor, voltage control, harmonic distortion and bi-directional activity. With just two IGBT switches, the rectifier can produce symmetrical flows in the line and regulated voltage with no vital synchronous switches. These converter topologies are assessed based on the partial implementation of software and hardware, simple techniques, number of switches required. The proposed converter is bridgeless, transformer-less and yield current sensor less which features its high productivity, high power factor and low distortion mutilations for the amendment utilizing CSPWM system and inversion using S-PWM method. The detailed investigational constraints are accomplished on a 1KW laboratory model.

Keywords: AC-DC-AC converters, Continuous switching pulse width modulation (CSPWM), Power factor revision (PFC) converters, Sinusoidal pulse width modulation (SPWM), Voltage regulation.

1 INTRODUCTION

Traditionally, ac – dc converters, which are likewise called rectifiers, are produced utilizing diodes and thyristors to furnish controlled and uncontrolled dc power with unidirectional and bidirectional power stream [1]. They have the negative marks of poor power quality regarding infused current harmonics, caused voltage mutilation and poor power factor at ac mains and moderate shifting ripple dc output at load side, low effectiveness and huge size of ac and dc filter channels [2]. The least difficult line-commutated converters use diodes to change the electrical vitality from AC to DC. The utilization of thyristors takes into consideration the control of energy flow. The primary drawback of these normally commutated converters is the harmonics generation and amenable reactive power.

The Single switch rectifier has one of the most straightforward circuit structures. Ordinary voltage and current waveforms for the circuit, utilizing hysteresis current control are enunciated to in [3-5]. Hysteresis band is made extensive in the figure for illustrative purposes. The two switch rectifier [6] and [7] plays out indistinguishable changing activity from the single-switch rectifier however the benefit of higher throughput.

VIENNA rectifier is three-switch, unity power factor assisted rectifier. This rectifier works by making a DC voltage over the two changes associated with the primary of transformer [8-10]. The VIENNA rectifier, despite the fact that it works with just three switches perseveres through higher worries than that of six switch converter. This sort of converter in any case, has issues with start-up over current, just as absence of current preventive at over-load conditions and bi-directional task is beyond the imagination in VIENNA rectifier.

Generally, the control structure of a three-stage six switch PWM boost converter comprise of an inward current control circle and external voltage control circle [11]. The present controller detects the internal current and contrasts it with a sinusoidal current reference. To acquire the present reference, the phase data of the utility voltage or current is required. This data is gotten by utilizing a phase lock loop (PLL), which makes transients if the frequency proportional rations changes [12]. To improve the control structure, one-cycle-control (OCC) based AC-to-DC converter has been proposed [13-15]. To maintain a strategic variation in power factor, OCC Bi-directional high power factor AC-to-DC converter is proposed in [16].

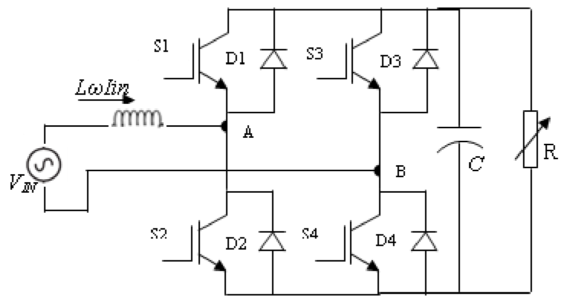


Fig. 1. Single-Phase full bridge converter.

This strategy utilizes saw-tooth wave to create PWM beats which consolidate low recurrence of harmonics. One-cycle-control (OCC) gives a few disadvantages inherent its physical acknowledgment: the controller and its parameters cannot be adjusted without equipment redesign; in addition they are impacted by temperature floats, normally for analog systems. Another weakness is the need of both voltage and current estimations [17]. To beat these confinements the OCC procedure is actualized carefully by utilizing Field Programmable Gate Array (FPGA) [18]. This framework utilizes PLL to discover phase data of utility voltage and current. Another downside of this framework is that, controller takes integer numbers only. The split activity is constrained just to partitioning number by an amount of two.

Multilevel flying capacitor dynamic rectifier utilizing hysteresis-based control for single phase supply is exhibited by [19]. The power factor and output load voltage direction is accomplished by controlling the input current. PLL is utilized to discover the phase information of input voltage which makes the transients as the frequency changes. Extreme charger for electrical vehicle utilizing three wire dissemination feeders utilizes six dynamic changes is to accomplish bi-directional flow of supply [20]. This expands switching misfortunes, equipment and complicated circuitry.

This paper not just exhibits the relative examination between two cases (case I-correction with CSPWM and reversal with SPWM conspire, case II-amendment and reversal both with SPWM plot) also addresses the previously mentioned disadvantages. The utilized converter is bridgeless, transformer-less and output DC current sensor less. All the previously mentioned strategies are actualized carefully to with the help of digital implementation. The detail simulation is done using MATLAB/Simulink and to approve it exploratory setup is produced for 1KW framework. The used bridge converter is shown in Fig. 1.

2 Rectification Using CSPWM and Inversion Using SPWM

2.1 CSPWM Realization in Digital Domain

The band is given of 10VDC as an upper edge (310VDC its proportionate step down voltage of 2.58V) and lower edge (290VDC its equal step down voltage of 2.45V). The clarification of digital realization of constant and continuous switching strategy is given in flowing steps:

- Turn ON the supply output DC voltage is to slightly less than that of DC voltage (140VAC x 1.414 = 200VDC) because of voltage drop across the diodes,
- Turn ON active rectifier unit. As per zero crossing detector (ZCD) status (either positive or negative half cycle) controller choose swapping switch of IGBT (S2/S4),
- The fixed duty cycle value of 0%, according to VDCFB duty cycle expands eventually in each 50µsec to accomplish required VDC. It is written to in C programming as,

```
If VDCFB > 775
PDC--
else
PDC++
end
```

Preferred standpoint of this method is that the input current flowing like input voltage because of continual quick switching, thus power factor esteem is closer to unity and the output DC voltage regulation is superior.

Table 1. Parameters used for simulating the single phase bi-directional converter.

Parameter	Symbol	Value
Line RMS voltage	VIN	140V
Boosted DC voltage	VO	300V
Switching frequency	fs	20KHz
Line frequency	f	50Hz
DC link capacitor	C	440µF
Input inductor	L	1mH
Load resistance	R	Variable (90Ω - 225Ω)
Triangular period	Tr	50µsec
Controller current gain	Ki	9
Converter gain	G	40

3.1 SPWM Realization in Digital Domain

Realization of sinusoidal PWM method has been carried out by using digital controller DSPic33FJ64MC802. This controller works on 3.3 VDC input supply voltage. It consists of 10 bit ADC, henceforth its complete full scale count resolution is 210 = 1024. It implies that for analog input of 3.3V to ADC controller gives 1024 check counts. In practice he assumed and deliberated this value as 2.5V. The transformation of AC output voltage to its direct DC value is made by utilizing step down transformer and rectifier with highest precision. The inversion action has been performed by adopting sinusoidal PWM scheme subsequently it achieves 140VAC output. For digital realization, a range of duty cycle percentage change is formed and packed as the look. The look-up table comprises of all out 200 estimations of duty cycles, in view of the line and switching frequencies The figuring are as underneath,

$$\text{Line frequency} = 50Hz \qquad (1)$$

$$\therefore 1/50 = 20msec \qquad (2)$$

This represents the full cycle time retracement, where half cycle time frame is 10msec. The 20 KHz switching frequency has one switch pulse duration of 50µsec. To oblige 200 pulses of 50µsec, 10msec period is required. The determination of duty cycle can be carried out by utilizing the formula given as follow,

$$D = \text{array value x k factor} \qquad (3)$$

Where the *Kfactor* is achieved count from ADC count assessment, shown below,

$$D = \text{array value x k factor} \qquad (3)$$

$$Kfactor = \frac{actual\ ADC\ count}{full\ scale\ count} \times 2.5 \qquad (4)$$

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 16 (2019) pp. 3566-3572

At the point when power is ON, at first *Kfactor* amount is fewer for delicate start mechanism. Gradually it increments with the augmentation value 0.1 to accomplish required AC voltage that is 160V. It is expressed with the help of C programming as bellow:

```
On the off chance that VACFB < 775
Kfactor+=0.1
Else
Kfactor-=0.1
```

Above loop is refreshed at delay of each 1msec, and duty cycle value is refreshed after each 50µsec.

3 Simulated and Laboratory Observations of Rectification Utilizing CSPWM and Inversion Utilizing SPWM (Case - I)

Performance determination and investigation of CSPWM method for rectification and inversion utilizing SPWM method detail simulation is accomplished on high performance MATLAB Simulink software. The parameters chose for the simulation are recorded in Table 1 and for the investigation are in Table 2. The output DC voltage 380V keeping steady and the DC side load varied from 1KW to 400W. The trial waveforms are balanced on screen utilizing divider arrangement for clear perception.

3.1 CSPWM Rectification-Inversion Results and Discussion

The results representing simulated vs experimented waveforms for rectification mode of operation are given in Fig. 3. Trace 1 of Fig. 3a demonstrates the simulated waveform of line current following the line voltage to show the unity power factor. The exploratory outcome for the equivalent is shown in Trace 2 of Fig. 3a. This demonstrates the precisely comparable outcomes like simulated waveform. The channel 1 is at 50V/Div and channel 3 is at 5Amp.

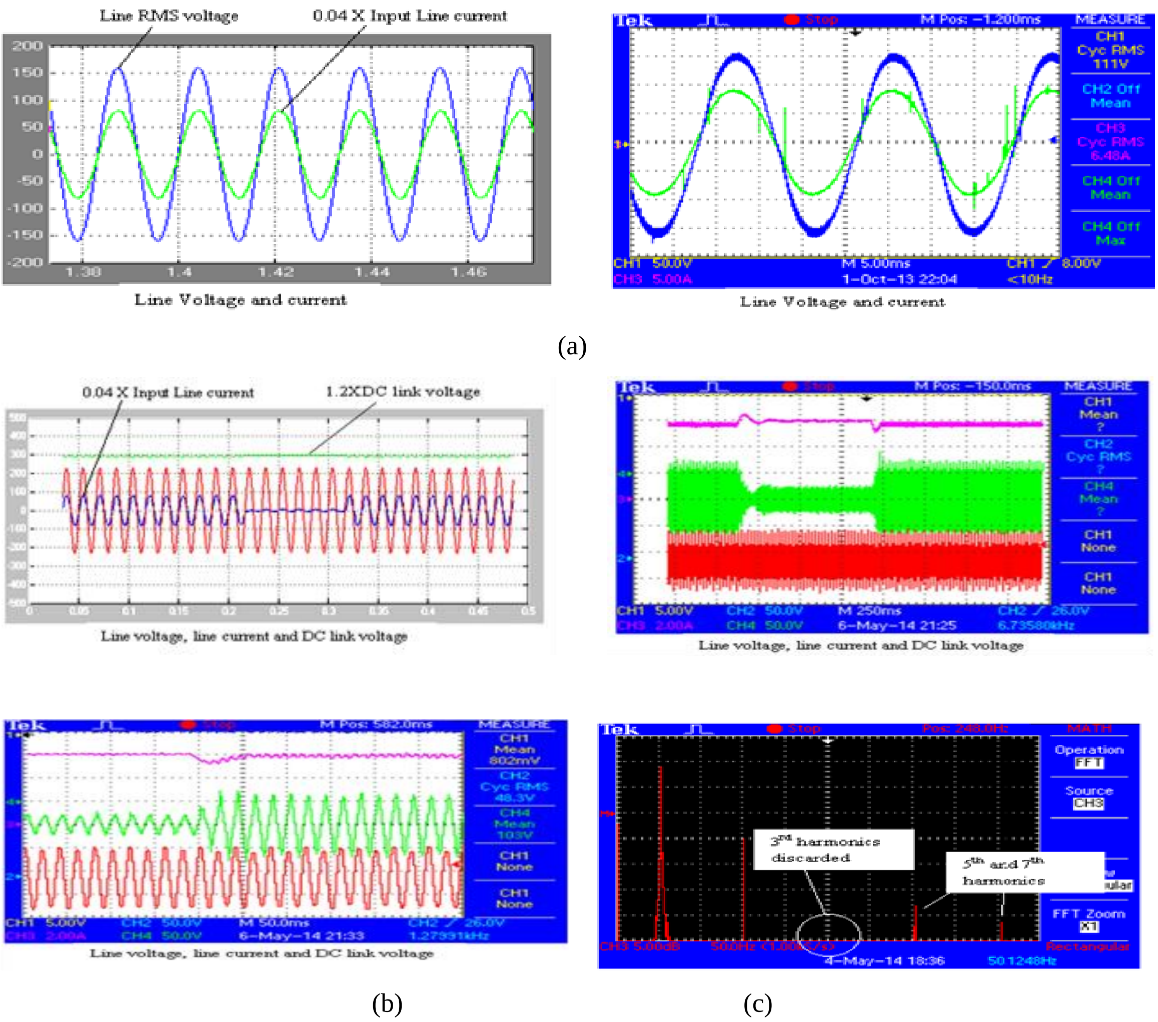
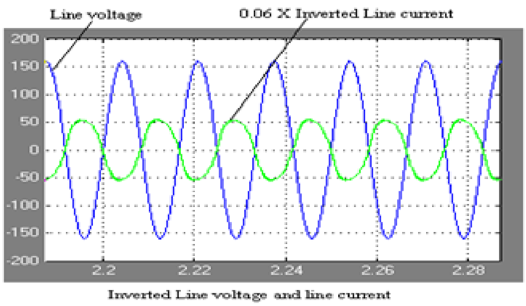


Fig. 3. (a) Simulation vs experimental line current and line voltage to indicating high power factor. (b) Simulated and tested line voltage, line current and DC linked voltage when load changes from 80% to 5% intermittently to demonstrate voltage adjustment period. (c) Harmonic Pattern of line current indicates third harmonic disposed of and decrease in fifth and seventh harmonics.

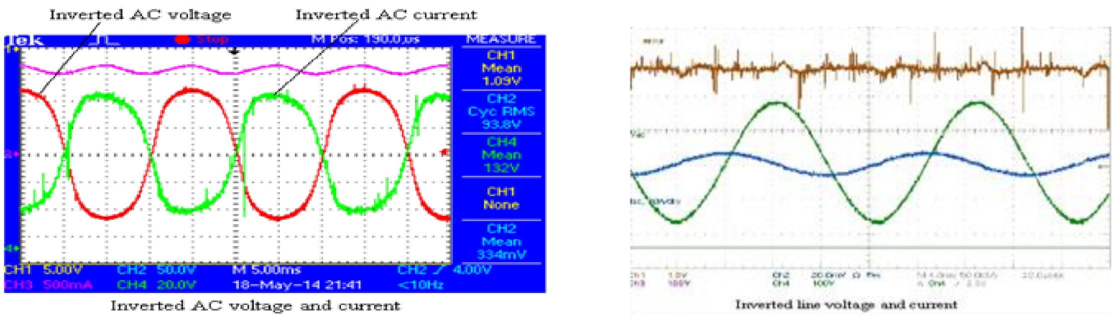
DC load changes from 5% to 80% frequently to demonstrate the output voltage regulation which is shown in Fig. 3b. Trace graph 1 of Fig. 3b shows simulated result, it tends to be seen that as load changes from 80 % to 5% and from 5% to 80% the DC link voltage stays regulated. Trace graph 2 demonstrates experiment result for the corresponding case. It tends to be seen that the DC link voltage regulated inside slight period which is irrelevant and negligible when load change happened. Channel 2 and 4 are at 50V/Div and channel 3 is at 2Amp/Div. Trace graph 3 conceives the progression in step and time period of DC link voltage regulation after load change happened. At the point when load changes from 5% to 80%, time/division switch is at 250msec which demonstrates the voltage regulated inside the time period of 40msec, the line current increments and line voltage stays consistent. The line current harmonics shape is shown in Fig. 3c. It tends to be seen that all the lower order harmonics and third harmonics are completely disposed although fifth and seventh harmonics are decreases up to negligible levels.

3.2 Results and Discussions using SPWM Method

To demonstrate the bi-directional operation utilizing a identical converter the inversion operation is demonstrated in Fig. 3. The simulated result in Fig. 4a demonstrates the inverted current is actually 180o of altered-inverted voltage. The experiential results are noted for purely resistive and inductive load in Fig. 4b. Follow 1 of Fig. 4b demonstrates that for the purely resistive load, inverted voltage are in same phase where concerning the inductive load inverted current lags the inverted voltage as shown in Trace graph 2 of Fig. 4b.



(a)



(b)

Fig. 4. (a) simulated values of reversed line current and line voltage at precisely 180° phase moved to demonstrate inversion activity (b) Experimental magnitudes of line voltage and line current for inductive load.

4 Simulated and Laboratory Observations of Rectification Utilizing CSPWM and Inversion Utilizing SPWM (Case - II)

To evaluate the enactment of converter by utilizing SPWM method to obtain the rectification and inversion operations the detailed investigation has been carried out with the help of high performance MATLAB simulation software. Same parameters listed in Table 1 are analyzed for performance investigation.

Table 2. Parameter Values for Detail Analysis of Single Phase Bi-Directional Converter.

A. Case I- Rectification with CSPWM and Inversion with SPWM

Load Resistance in (Ω)	DC load current (Amp.)	Power factor (%)	Efficiency (%)	THD (%)
225	1.3	84.3	83.7	14.4
180	1.6	90.5	89.3	12.2
130	2.3	94.3	93.4	8.3
110	2.7	96.2	94.3	7.2
100	3	96.4	94.9	6.9
90	3.3	96.8	95.2	6.3

B. Case II- Rectification and Inversion both with SPWM

Load Resistance in (Ω)	DC load current (Amp.)	Power factor (%)	Efficiency (%)	THD (%)
225	1.3	73.4	71	28.3
180	1.6	75.7	72.7	26
130	2.3	76.2	74.8	24.6
110	2.7	77.9	76.5	22.7
100	3	78.6	77.3	21.3
90	3.3	80.3	79.4	19.8

Simulated and actual experimented result waveforms for rectification method of operation are appeared in Fig. 5. Trace graph 1 of Fig. 5a demonstrates the simulated waveforms of line current flowing maximum at the peak of line voltage and very approximately zero at the beginning to show the debasement in power factor. The test result for the same is appeared in Trace graph 2 of Fig. 5a. This demonstrates the precisely comparable outcome like simulated waveform. The channel 1 is at 50V/Div and channel 3 is at 5Amp/Div.

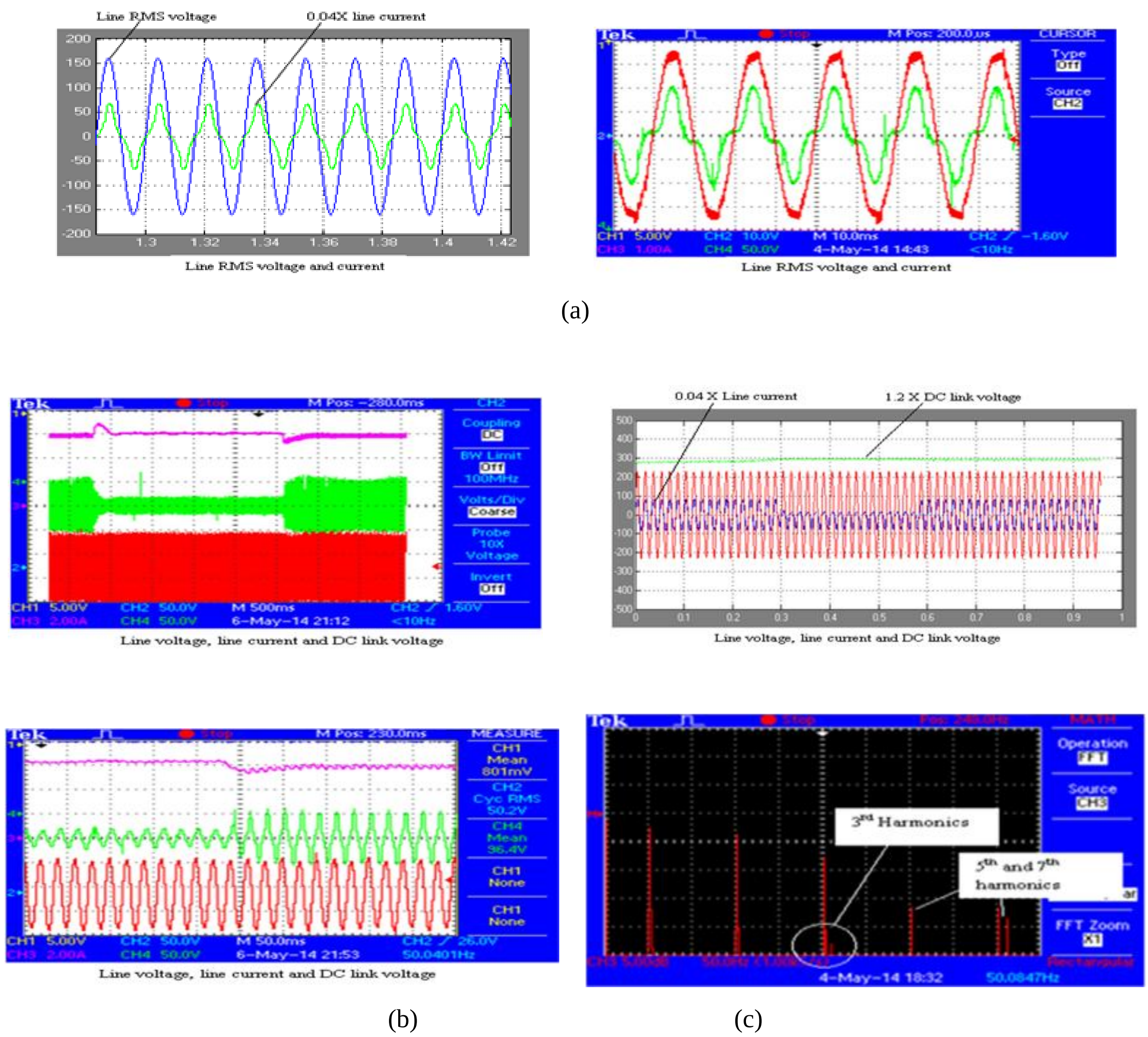
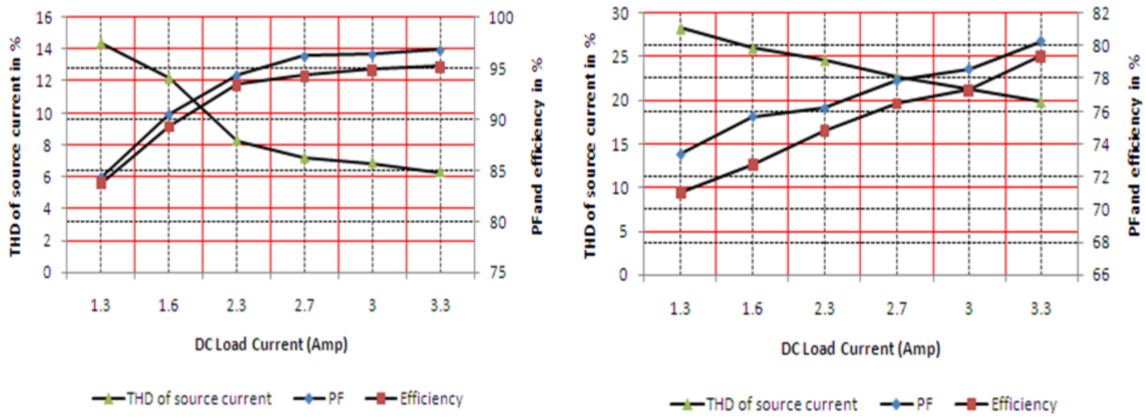


Fig. 5. (a) Simulation and experimental effects of line current and line voltage to indicate degraded power factor. (b) Simulated and experimental magnitudes of line voltage, line current and DC linked voltage when load changes from 80% to 5% intermittently to demonstrate distortions through voltage adjustment and equilibrium period. (c) Line current harmonics outline to indicate third, fifth and seventh harmonics are offered.

As load at DC side is varied from 5% to 80% periodically to demonstrate the regulation in output voltage which is shown in Fig. 5b. Trace graph 1 of Fig. 5b shows simulated result, it tends to be seen that as change in load from 80 % to 5% and from 5% to 80% the DC link voltage winds up unregulated. Trace graph 2 demonstrates experimental results.

5 Comparative Analysis between two methods

The correlation between the two strategies present in IV and V part are made for different loads extending from 90Ω to 250Ω. The parameters perceived throughout the correlation are power factor, efficiency, Total Harmonic Distortion and DC load current. The detail investigation of parameter values are listed Table 2. The detail comparison is shown in Fig. 6a and 6b. Fig. 6a demonstrates the parameters for the IV part (rectification utilizing CSPWM and inversion utilizing SPWM). It tends to be seen that full load efficiency is 95.2% and power factor is 96.8%. The parameters for the V part (rectification and inversion both utilizing SPWM) are shown in Fig. 6b. It is expressed that efficiency is 78.4% and power factor is 80.3% at full load. The laboratory test setup of proposed system is shown in Fig. 7.



(a) (b)

Fig. 6. (a) Variations in power factor, efficiency and total harmonics distortion with modification in load and DC load current for case I-rectification with CSPWM and inversion with SPWM. (b) Variations in power factor, efficiency and THD with modification in load and DC load current for case II-rectification and inversion both with SPWM.

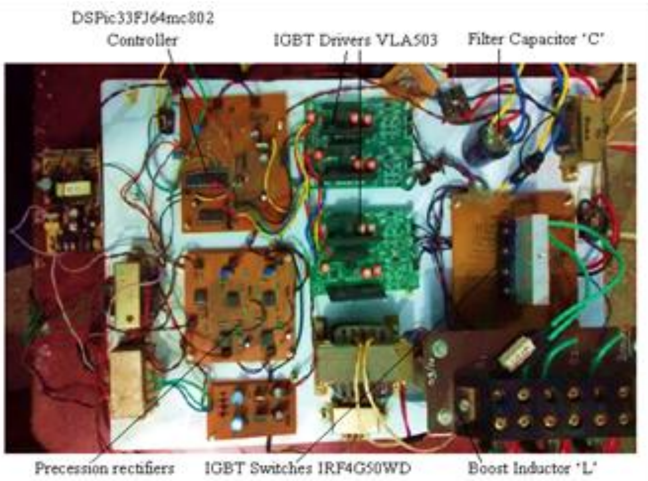


Fig. 7: Photograph of laboratory set-up.

6 Conclusion

Two strategies CSPWM and SPWM are accounted for a same converter for rectification and inversion task. The strategy utilizing rectification with CSPWM and inversion with SPWM show extraordinary benefits in terms of high value of power factor, higher the efficiency, fewer DC link voltage stabilization period and low amount of Total Harmonic Distortions. IN contrast with this method, second method (SPWM by utilizing both rectification and inversion) is less proficient. The complete simulation based investigations are accomplished to demonstrate the correlation and proficiency of the proposed methods. The attainability of the proposed method is committed through the detailed experimental investigations.

References

[1] W. M. Grady, M. J. Samotyj, and A. H. Noyola, "Survey of active power line conditioning

methodologies," IEEE Trans. Power Delivery, vol. 5, 1536–1542, (1990).

[2] Bhim Singh, Brij N. Singh, Ambrish Chandra & Ashish Pandey, "A Review of Single-Phase Improved Power Quality AC–DC Converters", IEEE Trans. Industrial Elect. vol. 50, No. 5, (2003).

[3] Id F. Schlecht & B. A. Miwa. "Active power factor codon for switching power supplies", IEEE Trans on P.E., vol. 2. No. 4, 273-281 (1987).

[4] M. Kazerani, P. D. Ziogas & G. Joos. "A novel active c-t wave shaping technique for solid-state input power factor conditioners", IEEE Trans on I.E., vol. 38, NO. 1, 72-78 (1991).

[5] A. R. Rasad, P. D. Ziogas & S. Manias, "A novel passive wave shaping method for single-phase diode rectifiers", IEEE Trans on Ind. Electron., vol. 37, No. 6, 521-530 (1990).

[6] R. Itoh & K. 1shizaka. "Single-phase sinusoidal convertor using MOSFETS", IEE PIOC., vol. 136. ht B, NO. 5, 237-242 (1989).

[7] A. W. Green & J. T. Boys. "Cumin forced single-phase reversible rectifier. IEE PIOC., vol. 136, M B, NO. 5, 205-212 (1989).

[8] J. W. Kolar, U. Drofenik, and F. C. Zach, "VIENNA rectifier II—A novel single-stage high-frequency isolated three-phase PWM rectifier system", IEEE Trans. Ind. Electron., vol. 46, no. 4, Aug. (1999).

[9] A.D. Pathak, R.E. Locher and H.S. Mazumdar. "3-Phase Power Factor Correction using Vienna rectifier approach and modular construction for improved overall performance, efficiency and reliability", Power electronics conf. in Long Bench, CA, (2003).

[10] J.Kolar, F Zach. "A novel three phase utility interface minimizing line current harmonics of high power telecommunication rectifier modules", IEEE trans. Ind. Electron. vol.44, no.4, August (1997).

[11] D. C. Lee and D. S. Lim. "AC voltage and current sensorless control of three-phase PWM rectifiers", IEEE Trans. Power Electron. vol. 17, no. 6, Nov. (2002).

[12] Heinz Willi, Hans-Christoph, Georg Victor. "Analysis and Realization of a Pulsewidth Modulator Based on Voltage Space Vector", IEEE Trans. on Ind. Applications, vol. 24, no. 1, Jan-Feb (1988).

[13] M. K. Smedley and S. Cuk. "One cycle control of power converters", IEEE Trans. Power Electron. vol. 10, Nov. (1995).

[14] C. Yang and K. M. Smedley, "One-cycle-controlled three-phase grid connected inverters and their parallel operation", IEEE Trans. Ind.Applicat., vol. 44, no. 2, Mar./Apr. (2008).

[15] C. Yang and K. M. Smedley. "Parallel operation of one-cycle controlled three-phase PFC rectifiers", IEEE Trans. Ind. electron, vol. 54, no. 6, Dec. (2007).

[16] Dharmraj Ghodke, Kishor Chattarjee, "Modified One Cycle Controlled Bidirectional High-Power-Factor AC-to-DC Converter". IEEE trans. Ind. Electron., vol.55, no.6, August (2008).

[17] Dharmraj Ghodke, Shreeraj, Kishor Chattarjee, B G Farnandis."One-Cycle Controlled Bi-directional Ac-Dc converter with constant power factor", IEEE 978-1-4244-1668-4/08/(2008).

[18] Mario Barbati, Cristiano Caluisi,Carlo Cecati, "One-Cycle Controlled Active Rectifier for Full Digital Implementation", proc. IEEE, Oct. (2010).

[19] M. Khazraei, H. Sepahvand, M. Ferdowsi and K.A. Corzine, "Hysteresis-Based Control of a Single-Phase Multilevel Flying Capacitor Active Rectifier", IEEE Transaction on power. Electronics, Vol. 28, No.1, pp.-154-164, Jan. 2013.

[20] T. Tanaka, T. Sekiya, H. Tanaka, M. Okamoto, E. Hiraki, "Smart Charger for Electric Vehicles With Power- Quality Compensator on Single-Phase Three-Wire Distribution Feeders", IEEE Transaction on Industrial Electron, Vol. 49, No. 6, pp.2628-2635, Dec. 2013.