One Cycle Controlled Single Phase AC to DC Bidirectional Converter

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Abstract— A one cycle controlled single phase four switch standard bridge boost rectifier is proposed here. One cycle control (OCC) technique is a nonlinear control technique which has fast transient response, excellent power source perturbation rejection, robust performance. The OCC technique is universal and suitable for the control of PWM converter and Resonant based converter for either voltage or current control. The control structure neither require the service of PLL nor the sector information of utility voltage. This makes control scheme robust and simple. The proposed control approach is simple and reliable as it composed of an integrator with reset , along with a few linear and logic component. This controller employ constant frequency modulation , which is desirable for Industrial Application. Detail simulation study is carried out to verify the efficacy of the proposed scheme.

I. INTRODUCTION

Electronic equipment such as computer, communication equipment , appliances, etc. are widely used in homes , industry, space, milatry and aircraft . In many cases,, a rectifier is required to convert electricity to dc for the use of electronic equipment.

Traditional diode rectifier and thyristor bridge rectifier are generally employed to obtain DC voltage output from AC power supply. These rectifier draw pulsed current from ac mains and pollute the utility with low order harmonics, which are difficult to filtered.[1].

PWM converter are used to overcome this problem. They shift the frequency of the dominant harmonics to high value so that they can be easily filtered [2].The PWM bi-directional converter deliver a near sinusoidal input current, while providing a regulated output DC voltage and can operate in 1st and 2nd quadrant of voltage-current plane.[2]. Generally the control structure of PWM boost converter consist of inner current loop and outer voltage loop.[2,3] The current controller sense input current and compare it with a sinusoidal current reference. To obtain this current reference, the phase information is required which is obtained by employing either PLL or current phase observer digital technique. [3,5]. The presence of PLL reduce the robustness of the controller.

The one cycle contol technique (OCC) [7] established a large signal nonlinear pulse-width-modulation (PWM) scheme that features a simple circuit, high performance, and universal application. This technique provide fast dynamic responce, excellent power source perturbation rejection, robust performance, and automatic switching error correction also. This technique is general and it is suitable for the control of PWM converter and Resonant based converter for either Voltage or Current control. OCC has been successfully implemented in many sector of power electronics, including DC/DC converter, amplifier, AC/DC converter ,power factor correction and active power filter. The OCC controller generally uses a integrator with reset to force the controlled variable to meet the control goal in each switching cycle.

In order to overcome of requirement of PLL used in PWM converter and simplify the control structure of the grid connectd system, One Cycle Control based (BOCC) single phase ac to dc converter has been proposed her.re. It do not require the service of PLL or zero crossing detectors to synchronize with grid and can be designed to supply power at near to unity power factor. Detail simulation study is carried out to verify the efficacy of the proposed scheme.

The proposed OCC controller has following features:

- Constant switching frequency
- No need for multiplier that are required to scale the current reference according to the load level, as used in many other control approach.
- Only one integrator with reset along with some logic and linear component is required. So it is simple and reliable.
- Higher supply power factor
- Low total harmonic distortion (THD)
- Stable and reliable operation
- Fast dynamic current tracking capability
- Excellent steady state performance.

II. AC TO DC BIDIRECTIONAL CONVERTER

The schematic circuit diagram of single phase bidirectional ac to dc converter is shown in fig.1.It is also called PWM boost rectifier. It consist of Four switch, a dc link capacitor, source inductance. The PWM rectifier basically operate as a boost chopper with bipolar (AC) voltage at the input and unipolar voltage (DC) at the output, maintaining sinusoidal line current.

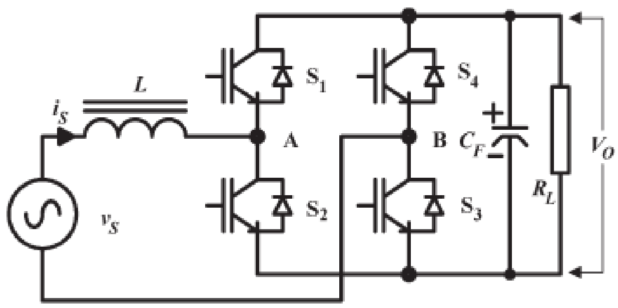

Fig. 1: Single phase full bridge converter

Main features of the PWM Rectifirer:

- Bi-directional power flow
- Nearly sinusoidal input current
- Regulation of the input power factor to unity
- Low Harmonic disotortion of line current
- Adjustment and stabilization of DC link voltage
- Reduced capacitor (Or Inductor) size due to continuous current

III. ONE CYCLE CONTROLLER FOR SINGLE PHASE CONVERTER

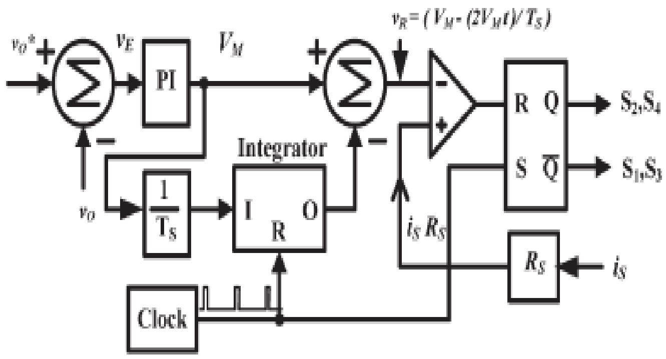

Fig. 2: Control block diagram of proposed BOCC single phase converter[8]

The control block diagram for single phase converter is shown in below fig.2 [8]. Here the DC side capacitor voltage (Vo) is sensed and compare with a reference voltage (Vo*). The error is compensated by a PI controller to produce a Modulating signal (Vm). The goal of PI controller is to maintain the dc volatage of the capacitor. Resettable integrator integrate the modulating signal (Vm) and is reset at the end of every switching cycle. The output of the integrator is linear ramp and slope of it is directly proportional to modulating signal (Vm). Thus bipolar sawtooth waveform whose peak-to-peak value of the Vm is twice (2Vm) that of this reference signal is generated which is proportional to to operating power level of the converter. The frequency of sawtooth waveform is set by free running clock, which also set the switching frequency of the converter. The boost inductor current Is, is multiplied by proper gain of source current sensor Rs and compared it with the saw-tooth waveform. The output of that is given as input of R-S flip flop at input terminal R and clock is given at input terminal S of R-S flip-flop.

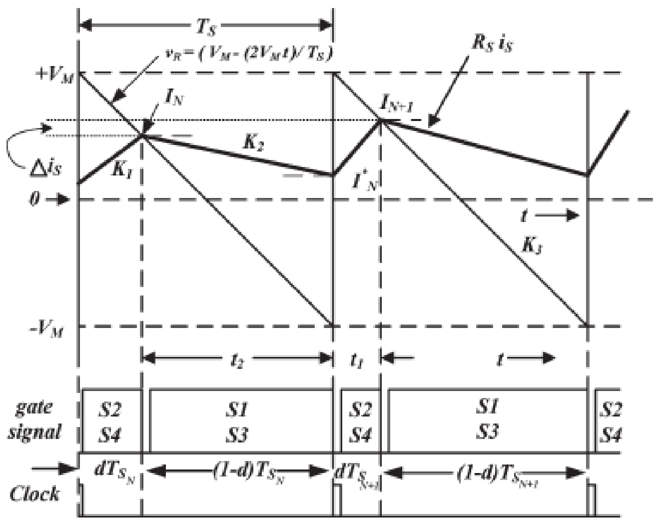

Fig. 3: Switching logic generation for BOCC based convertrer for single phase converter.[8]

At every rising edge of the clock pulse , S2 and S4 are turned on and the inductor current increases. The expression for the rising slope K1 of the sensed source current signal is given as follow:

$$\mathbf{K_1} = \mathbf{R_s}\frac{(\mathbf{V_s}+\mathbf{V_o})}{\mathbf{L}} \qquad (1)$$

Where , Vs-utility voltage

The output of the comparator which compare the inductor current with sawtooth waveform determines the turn off instant of S1 and S3. When S1 and S3 are turned on, the sensed boost inductor current signal falls with slope K2. The value of the slope is given as follow:

$$\mathbf{K_2} = \mathbf{R_s}\frac{(\mathbf{V_s}-\mathbf{V_o})}{\mathbf{L}} \qquad (2)$$

Fig.(3) shows the logic used to generate the switching signal by comparing sawtooth waveform with the source current , wherein *d* is the duty ration of S2 and S4.

The control equation for the converter is given as follow:

$$\mathbf{V_m}\,(\mathbf{1}-\mathbf{2d}) = \mathbf{R_s i_s} \qquad (3)$$

The peak value of the current is given as :

$$\boldsymbol{i_s} = \frac{(\boldsymbol{V_M V_S})}{\boldsymbol{2V_o R_s}} \qquad (4)$$

The approximate value of power handled by the converte is given by:

$$\boldsymbol{P} = \frac{(\boldsymbol{V_M V_S}^2)}{\boldsymbol{V_o R_s}} \qquad (5)$$

IV. MATHEMATICAL MODELLING OF SINGLE PHASE CONVERTER [8]

Using these model the trajectory of the peak value of source current drawn by the converter in each switching cycle is determined. When switches S2 and S4 are on for time duration t_1, inductor current rise with slope K_1 while for the duration t_2 current falls with the slope K_2.

The peak value of current in Nth switching cycle is I_N and in I_N * denotes the magnitude of current at the end of Nth switching cycle .

From fig (3),

$$I_N{}^* = I_N\left(1-\frac{K_2}{K_3}\right) + V_M\frac{K_2}{K_3} \qquad (6)$$

$$I_{N+1} = I_N{}^* + K_1 t_1 = V_M - K_3 t_1 \qquad (7)$$

Where K_3 is the slope of the falling edge of the sawtooth waveform and is given by

$$K_3 = \frac{V_M}{T_I} = \frac{2V_M}{T_S} = \left(2\frac{V_o}{R_e}\frac{R_s}{T_s}\right) \qquad (8)$$

and T_s is the switching time period. Assuming that the change in on time (t_1) of the switch in two consecutive switching cycle is small and using (19) and (20) the duration of t_1 and t_2 from fig. are

$$t_1 = \frac{V_M - R_S I_N + (R_S I_N + V_M)\frac{K_2}{K_3}}{K_1+K_3} \qquad (9)$$

$$t_2 = \frac{R_S I_N + V_M}{K_1+K_3} \qquad (10)$$

The change in current from the Nth to (N+1)th cycle in time $T_S = t_1 + t_2$ is

$$\Delta i_s = I_{N+1} + I_N = \frac{V_S}{L}(t_1+t_2) + \frac{V_S}{L}(t_1-t_2) \qquad (11)$$

$$v_S = L\frac{\Delta i_S}{\Delta t} + \frac{R_S i_S V_O}{V_M} \qquad (12)$$

Considering Vs to be sinusoidal forcing function and neglecting the harmonics in i_s, the steady state phasor form of (25) can be approximated as

$$\bar{\imath}_S = \frac{\bar{v}_S}{\frac{R_S V_O}{V_M} + j\omega L} \qquad (13)$$

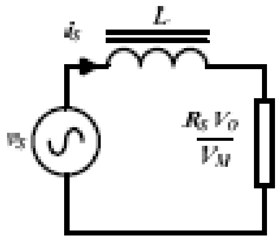

Fig. 4: Phasor model of OCC based single phase converter

V. SIMULATION RESULT OF ONE CYCLE CONTROLLED AC TO DC BIDIRECTIONAL CONVERTER

The proposed one cycle controlled single phase bidirectional ac to dc converter is simulated on MATLAB/ Simulink platform. The parameter used for the simulation model is given in table 1. Fig 5 shows input current and input voltage of the proposed converter. Fig 6 shows output voltage and Fig 7 shows input current, which shows here output voltage is exactly follow the control reference and starting peak of input current is controlled in within one cycle of input voltage and is not much more at transient time. Steady state is obtained within 0.02 sec. Fig8 shows output of PI controller. Fig 9 shows output of integrator which is sawtooth in nature. Fig 10 shows bipolar sawtooth waveform by summing output of PI controller and output of Integrator, whose peak to peak value is twice of modulating signal Vm. Fig 11 shows intersection of bipolar sawtooth waveform and input current i.e. both are compared and output of whose generate switching pulses for switches of the converter which are shown in Fig 12 and Fig.13

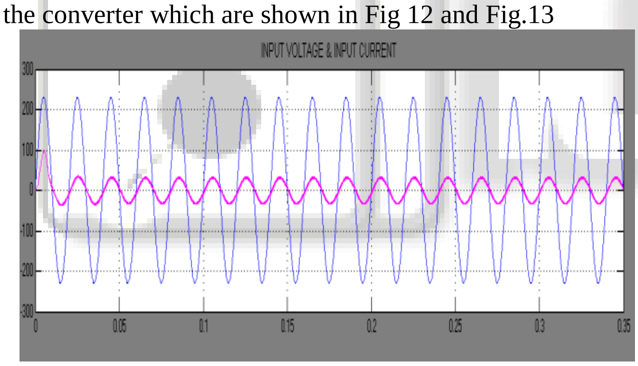

Fig. 5: Input current and input voltage

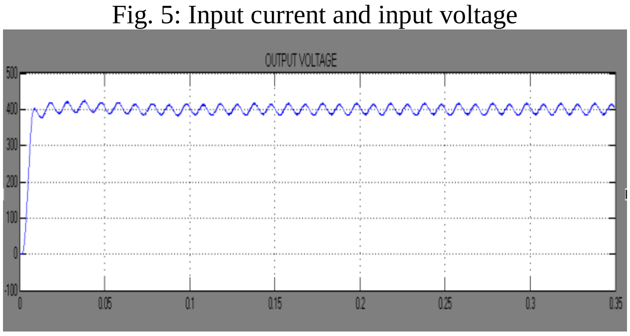

Fig. 6: Output voltgage

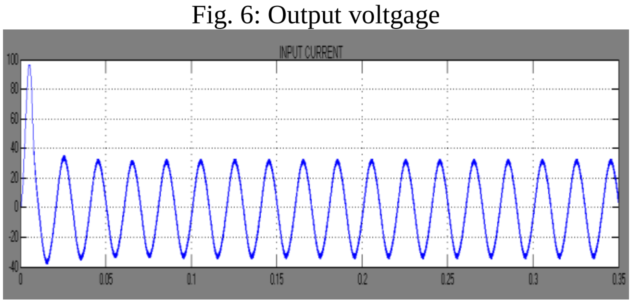

Fig. 7: Input current

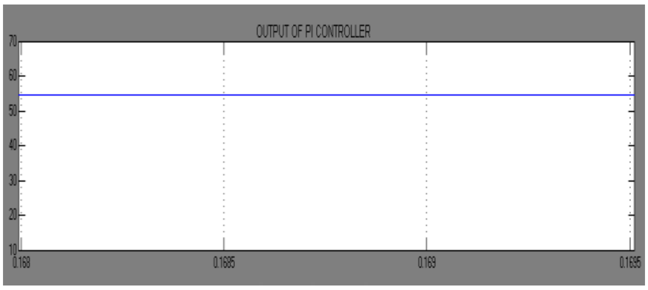

Fig. 8: Output of PI controller

Fig. 14 shows Behaviour of converter at light load condition of R_L=10Ω,which shows that the converter become instable at light load condition. Trace 1 shows input voltage and input current. Trace 2 shows output voltage and trace 3 shows input current.

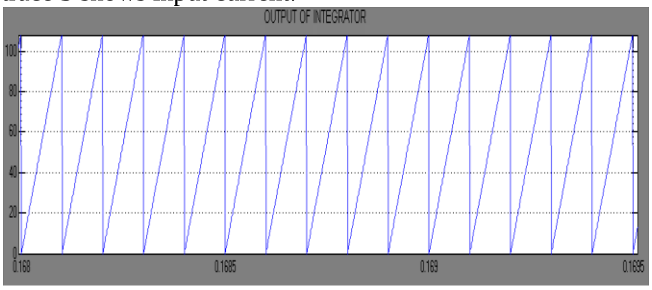

Fig. 9: Output of Integrator

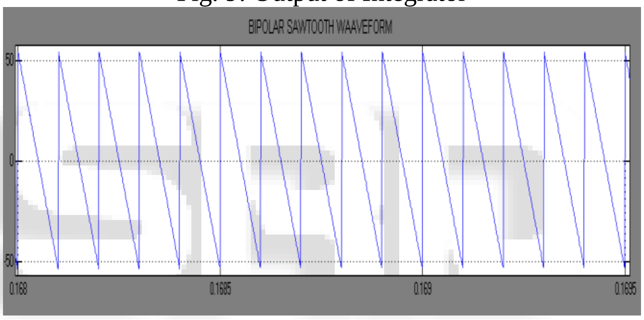

Fig. 10: Bipolar sawtooth waveform

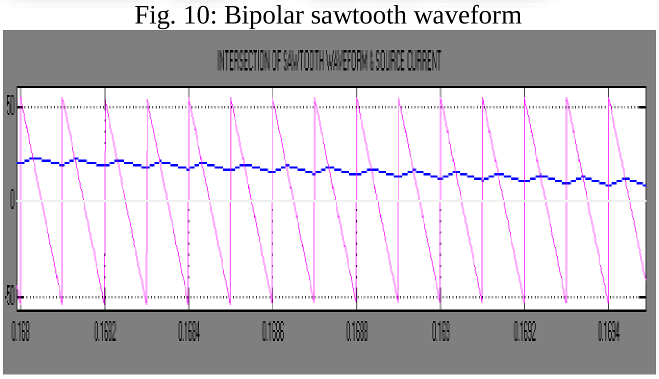

Fig.11: Switching pulse generation by intersection of source current and bipolar sawtooth

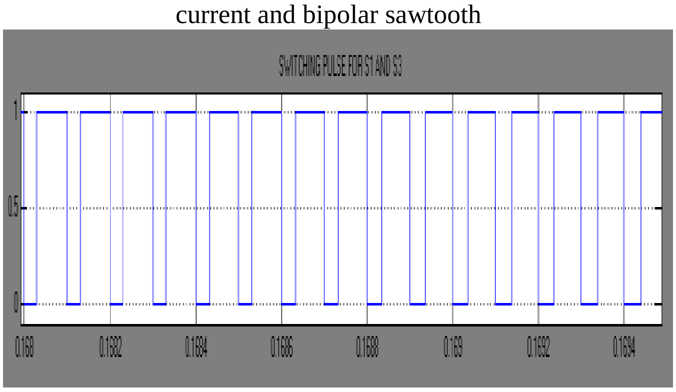

Fig.12: Switching pulse for S1 and S3

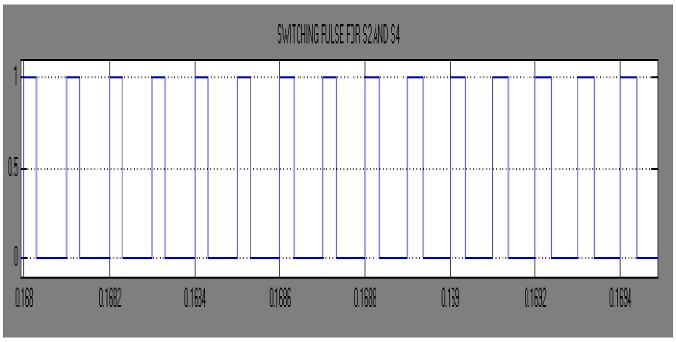

Fig. 13: Switching pulse for S2 and S4

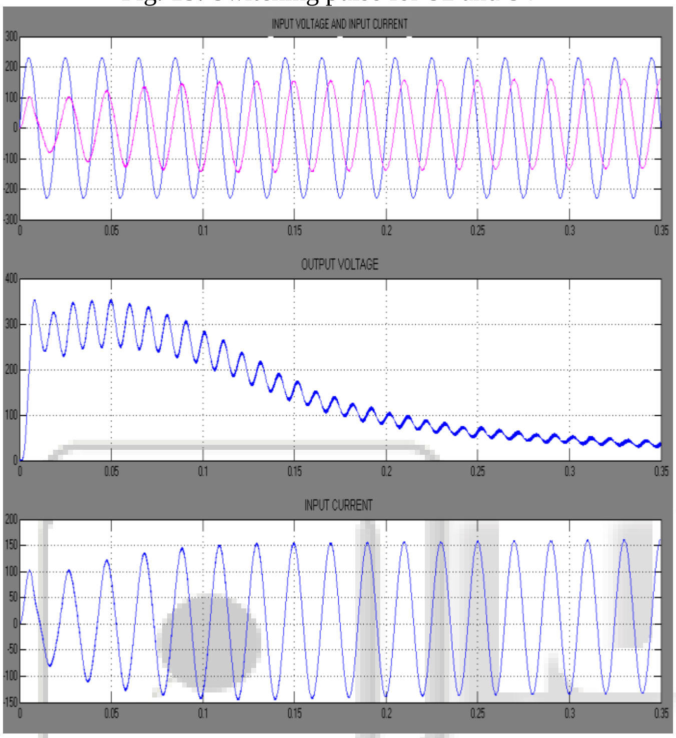

Fig. 14: Behaviour of converter at light load condition of $R_L=10\Omega$

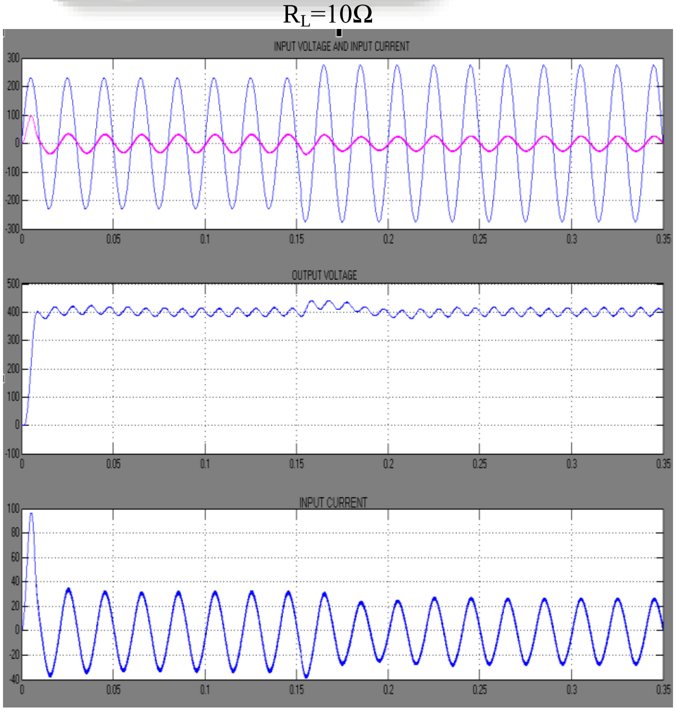

Fig. 15: Behaviour of converter when input voltage is perturbed from 230V to 275V at 0.15 second

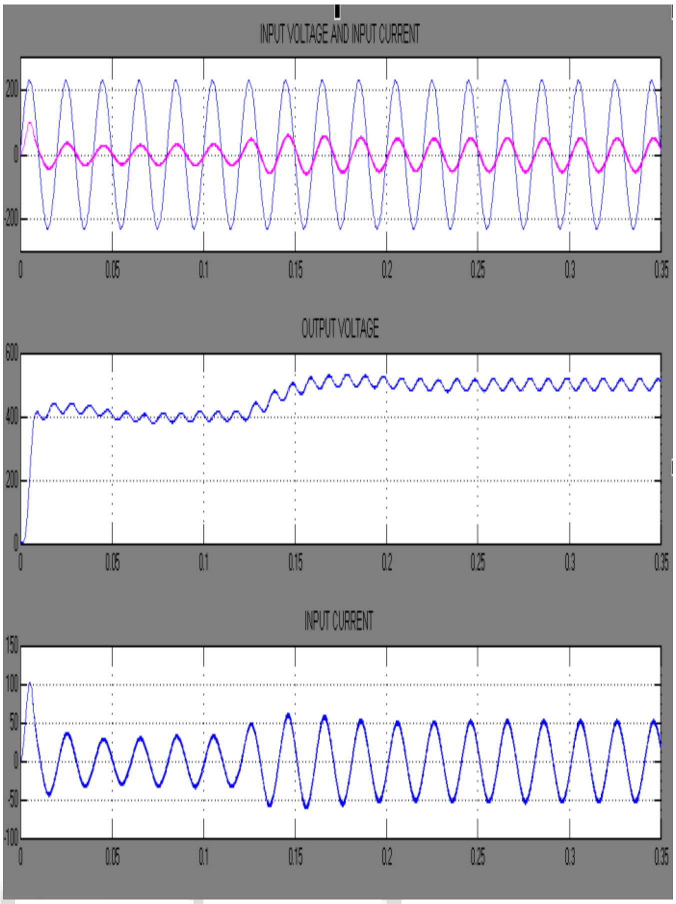

Fig. 16: Responce of converter when there is step change of conrol reference from 400 to 500 at 0.125 second

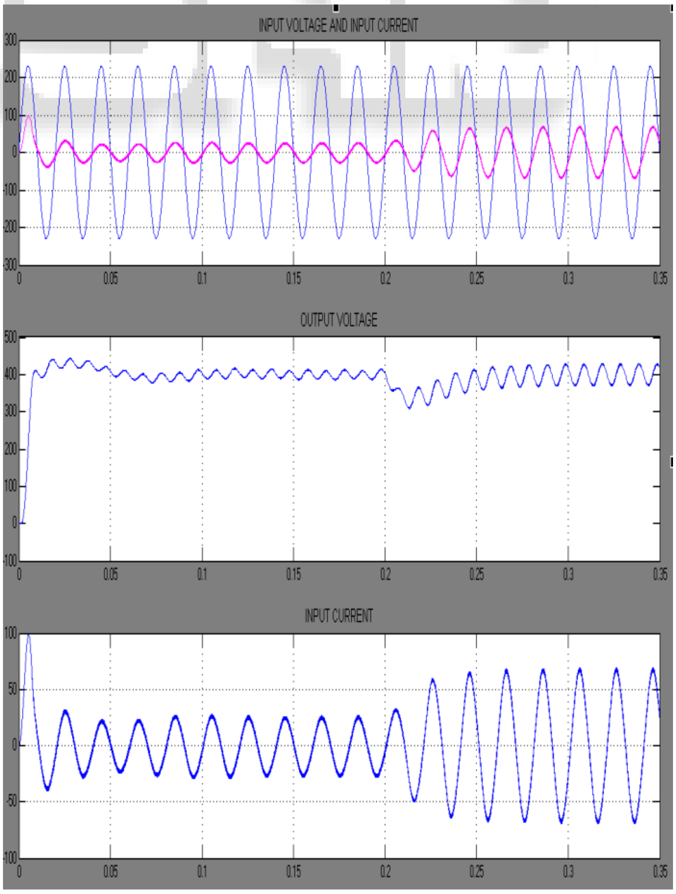

Fig. 17: Responce of converter when there is a change of load from 55 Ω to 40 Ω at 0.2 second

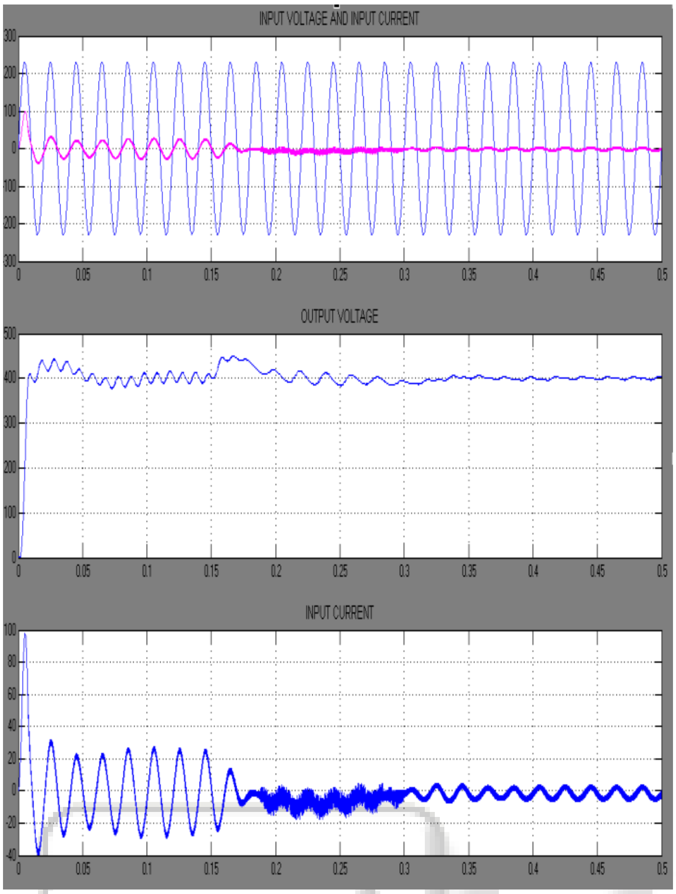

Fig. 18: Repsonce of converter when the converter tries to operate in inverting mode from rectifying mode

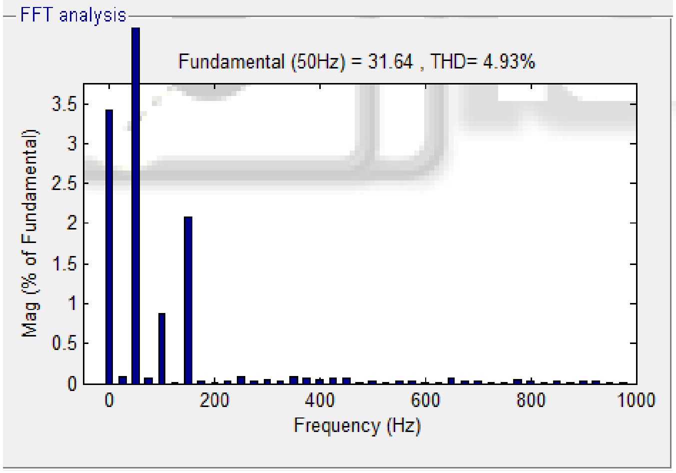

Fig.19: Harmonnic spectrum of input current

Table. 1: Parameters used in MATLAB simulation

PARAMETERS	SIMULATION MODEL
Boost inductor (L)	5 mH
Load resistance	45 Ω
DC fiter capacitor (C)	1000μF
RMS value of AC voltage	230V
Source voltage frequency	50 Hz
Switching frequency	10khz
Proportional gain K_P	0.045
Integral gain Ki	30

Fig.15 shows behaviour of the converter when there is input voltage perturbation fron 230V to 400V. Trace 1 shows input voltage and input current. Trace 2 shows output voltage and trace 3 shows input current. Converter reject the input voltage perturbation and output voltage follow the control reference.

Fig. 16 the Responce of the converter when there is step change of control reference from 400 to 500 at 0.125 second.

Trace 1 shows input voltage and input current. Trace 2 shows output voltage and trace 3 shows input current. Converter is follow the control reference in 0.02 second without unstably. Fig. 17 shows the responce of the converter when there is a change of load from 55 Ω to 40 Ω at 0.2 second. Trace 1 shows input voltage and input current. Trace 2 shows output voltage and trace 3 shows input current. Fig. 18 shows the responce of the converter when it tries to operate in inverting mode, but converter can't shift its operation in inverting mode from rectifying mode. This controller employ constant frequency modulation which is desirable for Industrial application. Fig. 19 shows harmonic spectrum of input current which shows THD of input current is 4.93% which is in desirable limit as per IEEE standard. Table 2 shows the performance of the converter at different load and % THD is presented in the table at different loading condition, it is seen that the THD level is increase at higher load Resistor value.

Table. 2: Performance of single phase one cycle controlled bidirectional converter

Load Resistor	Active Power	Reactive Power	Power Factor	THD%
25	6422	2611	0.9255	3.29%
30	5347	1686	0.9522	3.72%
35	4579	1193	0.9655	4.08%
40	4009	897.7	0.9728	4.46%
45	3562	688.6	0.9778	4.93%
50	3205	552.6	0.9803	5.322%
55	2915	452.6	0.9816	5.81%
60	2673	375.6	0.9821	6.31%
70	2289	272.6	0.9825	7.1%
85	1886	172.3	0.9787	8.71%
100	1606	119.3	0.9734	10.14%

VI. CONCLUSION

A one cycle controlled single phase ac to dc bidirectional converter is proposed here. One cycle controller employ constant frequency modulation and there is no need multiplier and input voltage sensor. It is composed of a resettable integrator which is key component of controller and few logic component. The output voltage or DC link voltage follow the control reference in within one cycle of input voltage it achieve steady state. The proposed control technique is very simple and robust as it do not need of PLL. It become unstable during light load condition and inverting mode operation the simulation result shows that this converter maintain input current sinusoidal with regulated DC output. THD of input current is low and within permissible limit of IEEE standard.

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