An Investigation on Power Quality Enhancement of Unity Power Factor Buck-Boost-Type Rectifier

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ABSTRACT
An investigation on Power Quality Enhancement of Unity Power factor rectifier is sought in this paper. The rapid growth of non linear devices has resulted in degradation of power quality. On long run these distortions in low, medium and high power devices will be a matter of concern on our pace to a smart grid. The devices when connected to the distribution side can bring about distortions to input supply due to their non linearity. Active and passive power factor strategies exist in the current system. The Buck-Boost-Type rectifier in discontinuous mode and the effect of feedback on the Power Quality is dealt in this paper using simulation results. A hardware prototype with power factor correction has been implemented.

Keywords

unity power factor,THD, conventional controllers, non linear carrier controller ,Fuzzy controller

1. INTRODUCTION
Nonlinearities introduced by the power electronic devices have resulted in degradation of power quality. The rapid growth of nonlinear power loads interact with system impedance and can result in distortion of loads itself. On long run these distortions will be a matter of concern on our pace to a smart grid. The effects that will be the offset of these distortions involve overloading, overheating of transformer, failure of conductors, increase in losses in electric motor etc [9]. In 2001, the European Union put EN61000-3-2 into effect to set the harmonic regulation standard on any power grid supplied application with power consumption over 75 watts. This essentially requires input power factor correction (PFC).

The family of power factor corrected switching mode supplies consist of two stages in power circuit i.e. input PFC stage and output dc-dc converter stage. By integrating the two stages, a new class with a single switch topology emerged. Power Factor Correction Topologies in ac-dc converters have been reported in [2].Conventional buck boost, flyback, sepic, Cuk and boost converters are capable of input power factor correction. The transition from hard switching to soft switching has revolutionalised the Power Electronics domain.

Single stage and two stage Topologies exists and some of the single stage topologies suffer from high switching stress, high THD and low efficiency. Economic viability and size optimization along with Power Quality enhancement is other added advantage to single stage topologies. Continuous inductorCurrent mode is characterized by current flowing continuously in the inductor during the entire switching cycle in steady-state operation. Discontinuous inductor current mode is characterized by the inductor current being zero for a portion of the switching cycle [1]-13].

A Buck- boost- buck converter in DCM mode which is capable of input power factor correction is considered. Various control strategies like simple Voltage feedback, feedback using PID controller (Proportional Integral and Derivative Controller), Non linear carrier controller and fuzzy controller are dealt with. Comparisons are made in proposed buck -boost rectifier in buck mode using the MATLAB simulation. Voltage conversion and Power factor correction are proved by simulation. Production of millions of low power devices in the utility side is growing in harmonic progression. Single stage topologies have simple control strategies. Fuzzy control simplifies the nonlinear control [14]-[19].

Section 2-4 denotes the buck-boost-buck converter and its effect on utility side, effect of various feedback and hardware prototype to validate unity power factor operation.

1. BUCK-BOOST-BUCK CONVERTER IN DCM MODE

Buck Boost converters possess the capability to either buck or boost the input voltage. Voltage conversion ratio of conventional buck-boost converter in dc analysis is as given in (1) where D is the duty ratio.

$$M=-\frac{D}{(1-D)} \quad (1)$$

Buck -Boost -Buck cell shown in Fig.2 comprises of two inductors L_1 and L_2.Normalized switch on time is denoted by D_1Ts and off times are denoted by D_2T_s and D_3T_s. Applying Volt Sec Balance to both L_1 and L_2.Let v_i and v_o be the input and output voltage for buck- boost cell in the proposed system shown in Fig 1.From detailed analysis using idealized waveform in Figure3,

$$\text{Voltage conversion}=M=-\frac{D_1^2}{1-D_1} \quad (2)$$

D_1T_s denotes the normalized switch on time as in [5]

Input filter stage takes into consideration of soft switching in the converter and electromagnetic interference susceptibility. The converter has zero current switching capability. Emulated resistance of the converter was obtained by averaging the normalized switch on time as in [5].

$$R_e=\frac{2L_1}{D_1^2T_s} \quad (3)$$

R_e is the emulated resistance of the converter which indicates that when duty ratio and switching time remains constant, the converter operates with unity power factor.

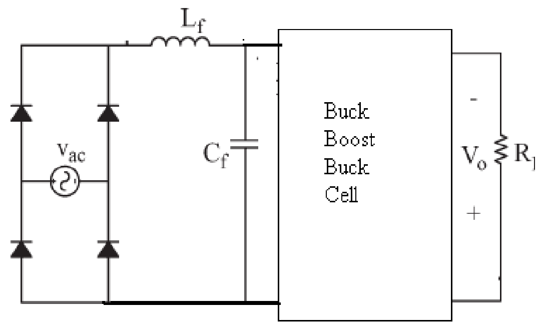

Figure 1: Single switch topology of buck- boost- buck cell

Inductors L_1 and L_2 are selected such that it drives the circuit in discontinuous conduction mode. Inductance should be lower than Critical inductance as in [5].The operating frequency determines the performance of the switch. Switching frequency selection is typically determined by efficiency requirements.Idealised waveform depicts discontinuous mode of operation.

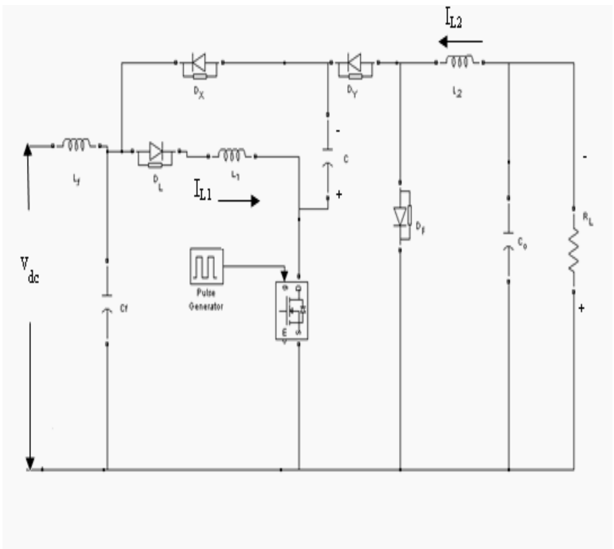

Figure 2: Buck –Boost- Buck Rectifier

There is now a growing trend in research work and new power supply designs in increasing the switching frequencies [6-12].The higher the switching frequency, the smaller will be the physical size and component value. The reason for this is to reduce even further the overall size of the power supply in line with miniaturization trends in electronic and computer systems. However, there is an upper frequency limit where either magnetic losses in the inductor or switching losses in the regulator circuit and power MOSFET reduce efficiency to an impractical level. Higher frequency also reduces the size of the output capacitor.

Simulation of open loop buck- boost converter without input filter in DCM mode were done with following parameters L_1=100µH, L_2=47µF, Duty ratio=0.2323, output power = 50watt.V_{in}=110, Vout=20V. Voltage ripple =0.04,

Switching frequency=60 kHz, Line Frequency=50Hz as in [5] using MATLAB simulation.

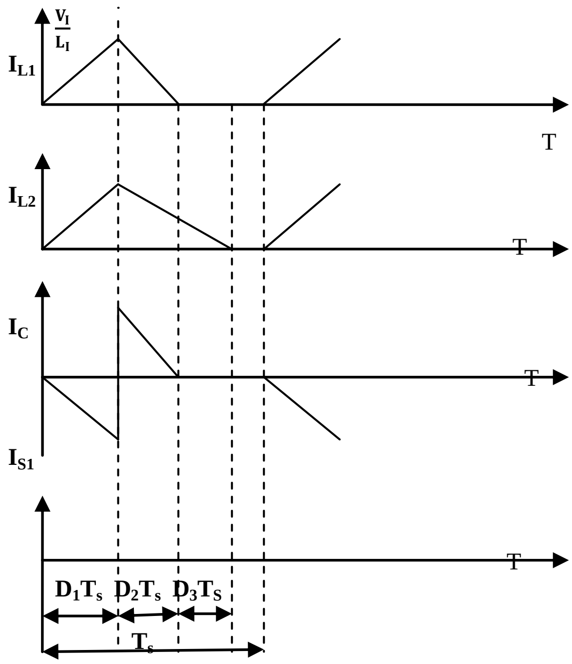

Figure 3: Idealized waveform of the buck boost buck converter

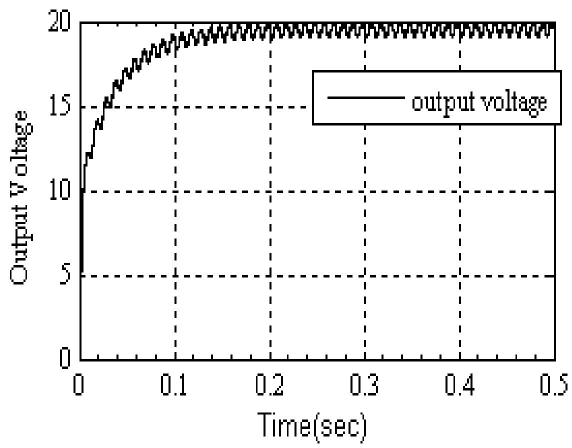

Figure 4*:* Output response of open loop system of proposed converter in DCM.

Unity power factor operation was possible in the above open loop system. Inrush current is lower. Zero current switching with low inrush current can be achieved if the output response is slower as in Fig 4.THD was found to be 3%.Power Factor=0.996.

3.VARIOUS CONTROL STRATEGIES

Various control strategies were applied to the above Buck -Boost -Buck Converter in DCM mode. The output voltage polarity is inverted. The control strategies considered here, are Simple voltage feedback control, non linear carrier control and fuzzy controller with simple feedback control.

3.1 Simple Voltage Feedback Control

Output Voltage is stepped down to compare it with a nominal value to adjust the duty ratio.The error signal is compared with the ramp signal of switching frequency.Hence the duty ratio can be adjusted automatically.Simulation results obtained is given below.

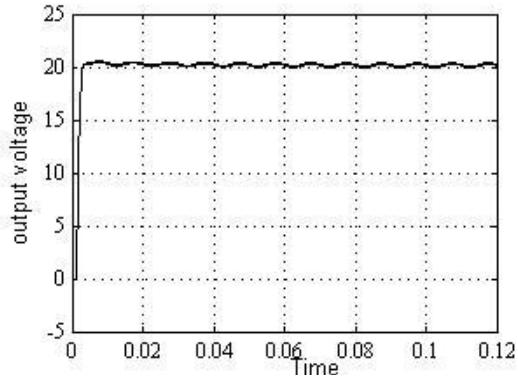

Figure 5: Output Response of Simple Voltage feedback

1 3.2 Voltage Feed Back using Conventional PID controller in Buck–Boost-Buck Converter

Proportional control regulates the delay of response.Slow response limit the inrush current. Integral Controller reduces the steady state error and brings the error to error bound limit.Derrivative controller improves the oscillatory response of the system.Simulation results of PID controller in the voltage feedback is given as follows. P=0.016,I=-20e-20,D=1.66e-18.The constants were obtained by trial and error method.

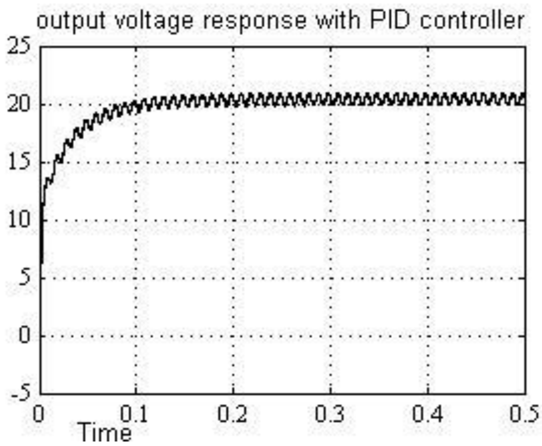

Figure 6: Output response of PID controller implementation

3.3.Nonlinear Carrier Control

Non linear Carrier integrates inner and outer current loop in current mode programming control[15].Nonlinear controller were applied to boost converters in continuous conduction mode.This mode of control simplifies the control eliminating complex controller requirements as inductor current sensing is replaced by switch current sensing.The non linear carrier control has been applied to DCM Buck -Boost -Buck converter.

The controller in Fig 7 represents the non linear carrier controller. The output Voltage is sensed and inverted then compared with a nominal value. The resultant error is fed to a discrete PI controller. The switch current signal is discrete and it is transformed to a voltage signal which is fed to the proportional controller. The resultant signal is compared with a ramp signal of switching frequency and hence the duty cycle can be automatically controlled. Proportional (P) and Integral constants are obtained by optimal tracking in matlab.

Nonlinear controller is more flexible mode of control than current mode programming control. Another added advantage is that the inrush current is lower than simple voltage feedback. Output voltage response is given in Figure 8.

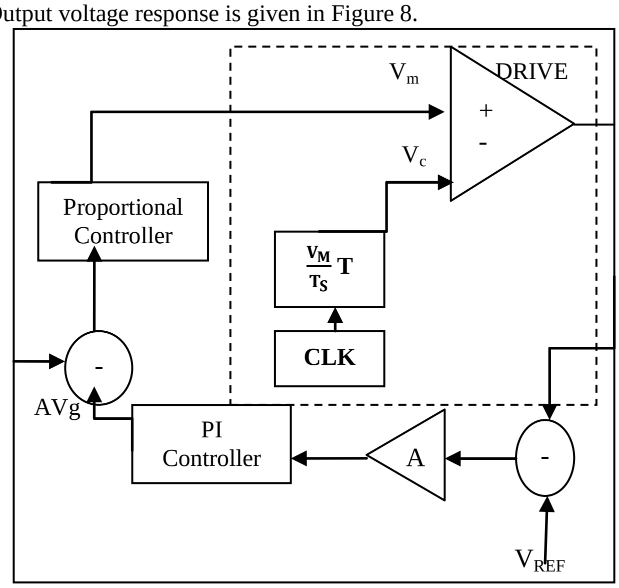

Figure 7: Nonlinear carrier controller for simple feedback of Buck Boost Buck Converter

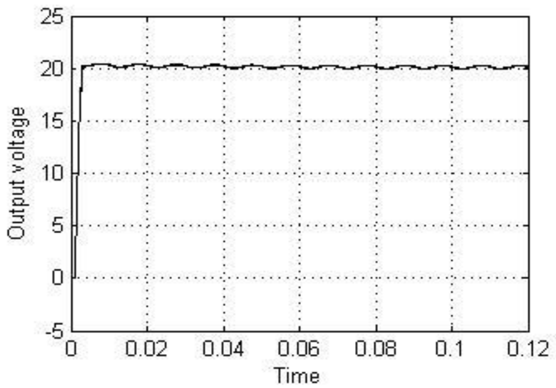

Figure 8: Output Voltage response of nonlinear carrier control

3.4 Fuzzy Logic Controller and Simple Voltage feed back controller

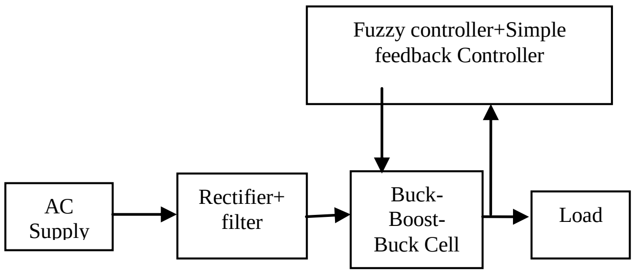

Figure 9: Block Diagram of fuzzy logic controller in the Feedback loop of the converter.

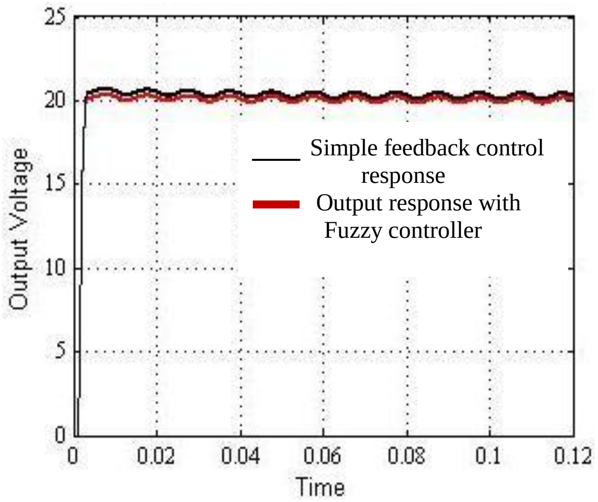

Figure 10: Output Response of Fuzzy Controller with simple Voltage Feedback and Output Voltage of simple voltage feedback.

Fuzzy logic controller has been applied to the buck boost buck converter as in fig 9 and output response has been obtained as in Fig 10. Nonlinear control can be easily done by Fuzzy logic. Duty ratio adjusts automatically as a crisp value is obtained by Fuzzy controller. Error and derivative of error are the input to Fuzzy controller. Nominal value for the error feedback is hence obtained.

Inrush Current of controller combining simple Voltage feedback and Fuzzy controller is lower than that of simple voltage feedback FIS structure used in simulation is Mamdani.Duty ratio limit in DCM mode was applied. The crisp value was obtained by centroid method**.** Fuzzy controller does not require mathematical model of the system. It is suitable for nonlinear control. Comparison of various approaches in terms of input Current THD and output response are done. The inferences are given in Table 1.

Table 1.Comparison of various approaches in the proposed system

Proposed Converter control methods	Output Response	Input Current THD
Openloop	Slower	3%
Simple Voltage Feedback System	Fast	5.6%
PID controller	medium	3.063%.
Nonlinear Carrier Control	Faster than Simple Voltage Feedback	3.733%
Fuzzy Controller with Simple Voltage Feedback	Slower than simple voltage feedback	3.65%

Input Current THD is <5% for all feedback systems except Simple Voltage feedback system and hence they are applicable for low power supply and devices.

4. HARDWARE IMPLEMENTATION

A hardware prototype was implemented using off the shelf devices.$V_{IN=}$48V (rms).Vo=12V, C=470μF, Duty ratio=0.25,

C_o=1000μF, output power = 15watt, Vout=12V. Voltage ripple =0.04, L_f=5mH, C_f=0.1μF, PWM IC: KA 3525, IRF 840 for switch, BC159 for ultrafast diodes. Switching frequency=60 kHz, Line Frequency=50Hz.Figure 11.shows the input voltage and current waveform.

Design of Magnetics were done such that core do not saturate for inductor peak current. Ferrite Core was selected. Switching frequency of IC was set to 60 kHz. The hardware implemented was having EMI susceptibility and Power Factor correction.

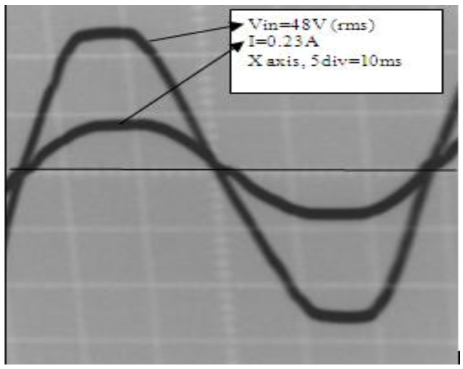

Figure 11: Experimental result of unity power factor operation

5.CONCLUSION

A Unity Power Factor rectifier with power quality enhancement has been dealt with. Total Harmonic Distortion in the input current at utility side of various feedback systems is determined from simulation results. Open loop and Closed loop systems were capable of power factor correction. When slow response can be tolerated, open loop system in discontinuous conduction mode is applicable. When fast response is required, Non linear Carrier control can be preferred .Simple feedback system provide utility with more total harmonic distortion even if power factor correction is possible. Fuzzy controller with low inrush current capability also enhances Power Quality.

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