PIEZOELECTRIC TRANSFORMER BASED CONTINUOUS-CONDUCTION-MODE VOLTAGE SOURCE CHARGE-PUMP POWER FACTOR CORRECTION ELECTRONIC BALLAST *

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Abstract

This paper presents the piezoelectric transformer (PT) based continuous-conduction-mode (CCM) voltage source (VS) charge-pump (CP) power factor correction (PFC) electronic ballast. By replacing L-C resonant tank and transformer in the conventional CCM VS CP-PFC electronic ballast with PT, the cost and volume can be reduced. The experimental results show that the electronic ballast using PT achieve high power factor and the switches can be operated under zero-voltage-switching condition.

INTRODUCTION

Although the electronic ballast has many aspects of superior performance, it has a serious problem. When the line voltage is higher than the DC bus voltage, the input current has a narrow conduction angle, which producing a very poor power factor with rich harmonic components. These rich harmonic components in the AC line cause many problems, such as voltage distortion, voltage flicking and electromagnetic interference (EMI) noise to other electronic equipments. In order to obtain high PF and low THD to meet the IEC 61000-3-2 Class C standard, the PFC stage circuit is needed in the electronic ballast. Recently, the two-stage approach is the most commonly selected in the products to achieve high PF as shown in Fig 1[1]. Since the two-stage PFC converters can achieve high power factor and can be used in wide ranges of input voltage and output power. However, it requires an additional PFC power stage and PFC controller, so the component count and total cost are increased.

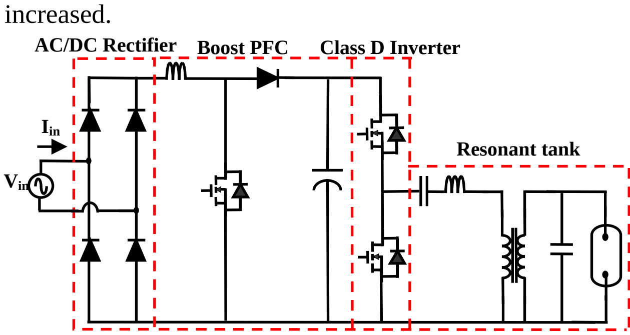


Fig 1：Two-stage PFC electronic ballast.

Presently, charge pump power factor correction (CP-PFC) techniques have become attractive. Fig 2 shows the basic AC-side continuous conduction mode (CCM) voltage source (VS) charge pump power factor correction (CP-PFC) electronic ballast [2]. The charge pump capacitor C_{in} can help the PFC inductor current achieve CCM and the input power factor nearly unity power factor.

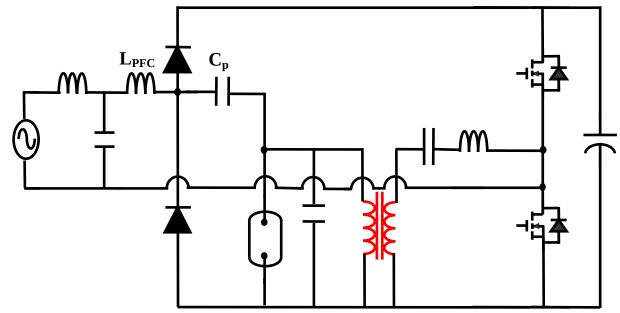


Fig 2：Conventional VS CPPFC electronic ballast.

Although the conventional AC-side CCM VS CP-PFC electronic ballast can achieve high power factor, ability to use a small input filter and reduce the component count, they have too many magnetic devices count. According to the features of the PT such as voltage gain, high power density, compact size, and no EMI, the PT based CP-PFC electronic ballast is proposed in this paper. The proposed circuit not only can achieve high PF, but also reduce the volume and the components count of the conventional VS CP-PFC electronic ballast.

CHARACTERIZATION OF THE RADIAL MODE PT SAMPLE

The radial vibration mode PT is a combination of actuator and transducer both of which operate in the in the transverse mode as shown in Fig 3. Referring to [3,4], the linear fluorescent lamp equivalent resistance is the matched load for optimal efficiency used the radial vibration mode piezoelectric transformer. Based on the efficiency consideration, the radial vibration mode PT is chosen to replace the resonant tank and transformer of the conventional CP-PFC electronic ballasts in this research.

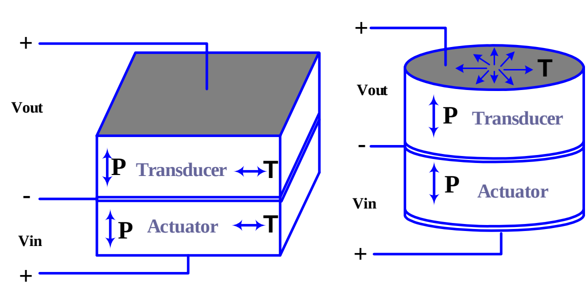


Fig 3：Radial vibration mode piezoelectric transformer.

The physics-based equivalent circuit models and characteristic equations of the radial vibration mode piezoelectric transformer have been derived in [3,4]. Based on this model, the circuit is identical to a series-parallel resonant network with an ideal transformer as shown in fig.4, which has been widely applied to a resonant converter, inverter and electronic ballast.

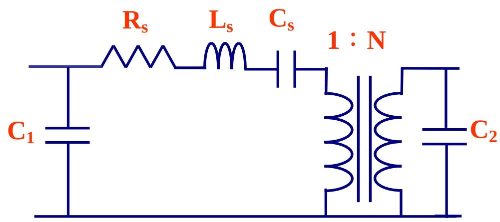


Fig 4：Equivalent circuit of the radial vibration mode PT.

Fig 5 shows the stricture of the PT sample, Iso-1, which is a multi-layer device, two layers of the primary side and single layer of the secondary side. Based on the [3,4] and Agilent 4294A, Table 1 shows the physics-based equivalent circuit models to contrast the measured result.

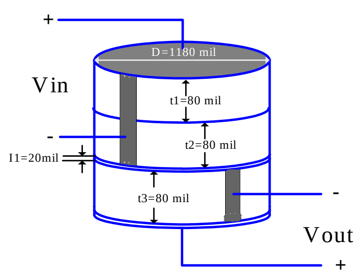


Fig 5：Structure of the PT sample Iso-1

Table1：Comparison of measured and modelled results of equivalent circuit model for sample Iso-1

		C1	Rs	Ls	Cs	C2	N	Fr
Iso-1	**Calculated**	4.81 nF	0.88 Ω	4.12 mH	1.32 nF	2.4 nF	2	70.89 kHz
	Measured	4.28 nF	5.84 Ω	5.71 mH	0.92 nF	2.1 nF	2.32	69.61 kHz

PERFORMANCE ANALYSIS OF THE RADIAL MODE PIEZOELECTRIC TRANSFORMER

Generally speaking, the piezoelectric transformer's characteristics such as voltage gain can be analyzed with a given load as shown in fig 6 [5].

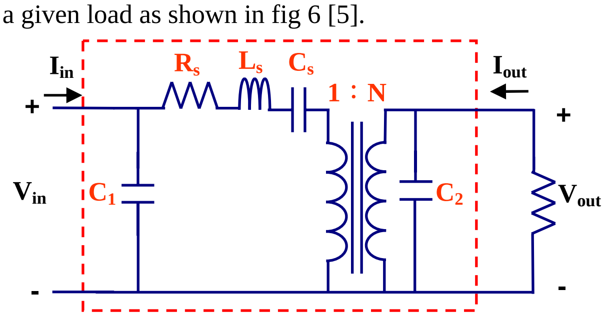


Fig 6 ：PT equivalent circuit with a given load.

The piezoelectric transformer can be characterized by a single-branch equivalent circuit model. The model can be treated as a parallel-series resonant circuit. The voltage gain curve is very important for the design of piezoelectric transformer based DC/DC converter and electronic ballast application. When analyzing the piezoelectric transformer equivalent circuit, the two-port network can be used [6].

At start up, the fluorescent lamp will be considered an open circuit, and after ionization, it will be assumed to be a resistive load at the steady state. The experimental lamp's equivalent on-resistance is 263Ω. For the 32 wattage linear fluorescent lamp, its sustain voltage must to be greater than 91Vrms. If the input voltage, V_{in}, applied to the piezoelectric transformer is 135V_{rms}, therefore, the required voltage gain to sustain lamp must to be greater than 0.67. The piezoelectric transformer sample Iso-1 was considered for this application, as shown in Figure 7, to have enough voltage gain to sustain the fluorescent lamp when the circuit is operated in a 72.3kHz switching frequency.

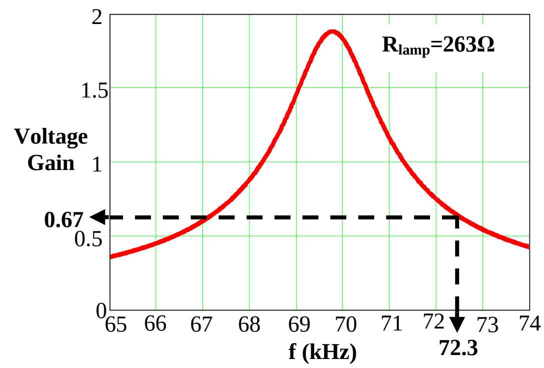


Fig 7：Voltage Gain V.S. frequency at different load condition.

CIRCUIT DERIVATION

The PT based VS CP-PFC electronic ballast is proposed as shown in Fig 8. In Fig 8, the piezoelectric transformer can be replaced the resonant inductor, DC blocking capacitor, high voltage transformer and the resonant capacitor in the Fig 2 to generate high voltage for ignite and sustain the fluorescent lamp. In addition, the input capacitance of the piezoelectric transformer works as a turn-off snubber for the power switches, which can decrease the turn-off voltage spikes and thus the turn-off losses of the switches.

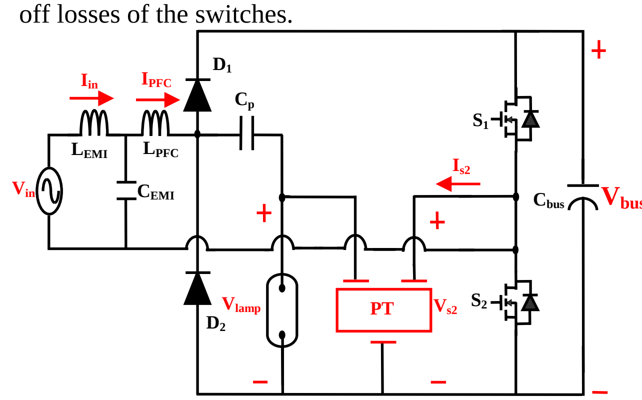


Fig 8：Proposed PT based VS CP-PFC electronic ballast.

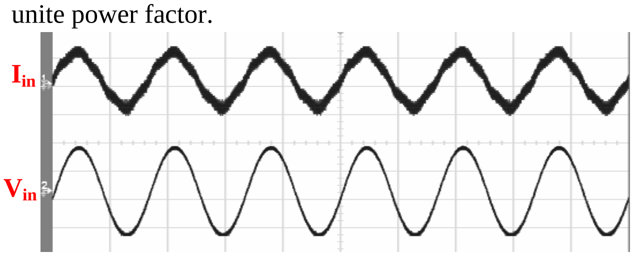
EXPERMENTAL RESULTS

The prototype circuit meets the following specifications, as shown in Table 2.

Table 2：Specifications of the PT based VS CP-PFC electronic ballast

Input voltage	110V, 60Hz
Rated power of lamp	32W
Rated voltage of lamp	90V
Equivalent resistor of lamp	263Ω
Operating frequency	72.3kHz

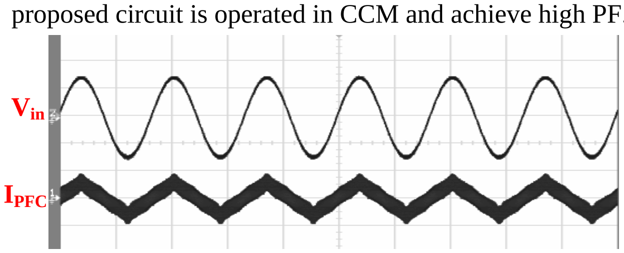
Fig 9 shows the AC input voltage supplied to the PT based VS CP-PFC electronic ballast circuit and the respective input current. As shown in the fig 13, the input current and the input voltage are nearly in phase and the PT based VS CP-PFC electronic ballast operates close to unite power factor.



I_{in}；(500mA/div)；V_{in}；(100V/div)；Time base；10ms/div

Fig 9：Measured input current and input voltage of the proposed circuit.

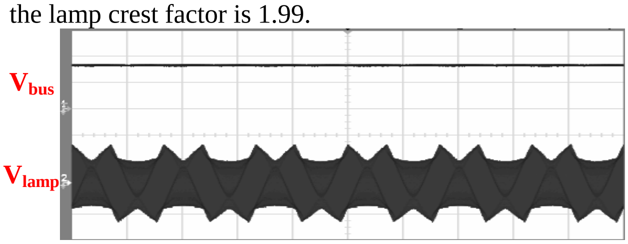
Fig 10 shows the PFC inductor current and input voltage experimental waveform. It can be seen that the proposed circuit is operated in CCM and achieve high PF.



I_{PFC}；(1A/div)；V_{in}；(100V/div)；Time base；10ms/div

Fig 10：Measured PFC inductor current and input voltage of the proposed circuit.

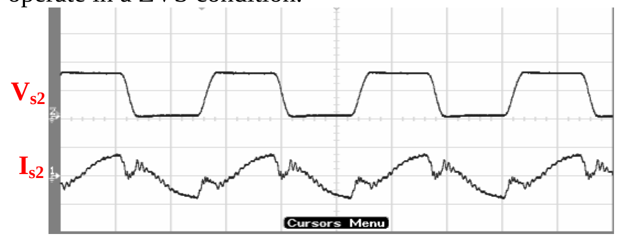
Fig 11 shows the DC bus voltage and lamp voltage, in which the peak value of the DC bus voltage is 329V and the lamp crest factor is 1.99.



V_{bus}；(200V/div)；V_{lamp}；(100V/div)；Time base；10ms/div

Fig 11：Measured DC bus voltage and lamp voltage of the proposed circuit.

Fig 12 shows the input voltage and input current waveform of the PT sample, it can be seen that switches operate in a ZVS condition.



V_{s2}；(200V/div)；I_{in}；(1A/div)；Time base；5μs/div

Fig12：Measured input voltage and input current of the PT sample.

Fig 13 shows measured current harmonics are below the required boundary, the IEC61000-3-2 Class C standard. The measured PF is 0.987 and the THD is 13.9%. The overall efficiency of the PT based VS CP-PFC electronic ballast when driving a 32 wattage linear fluorescent lamp is around 78%.

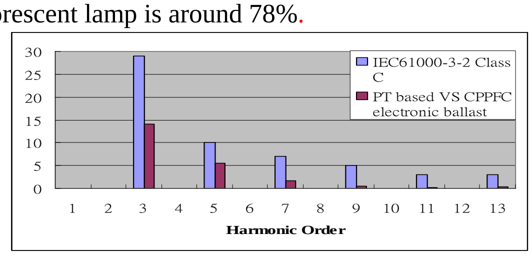


Fig 13： IEC 61000-3-2 Class C standard and measured input harmonic of the proposed circuit.

CONCLUSION

This paper presents the PT based AC-side CCM VS CP-PFC electronic ballast. The experimental results show that the electronic ballasts using PT achieved high power factor, the switches can be operated under ZVS condition, and overall 78% efficiency.

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