Power Quality Improvements Lighting System
(Fluorescent Lighting)

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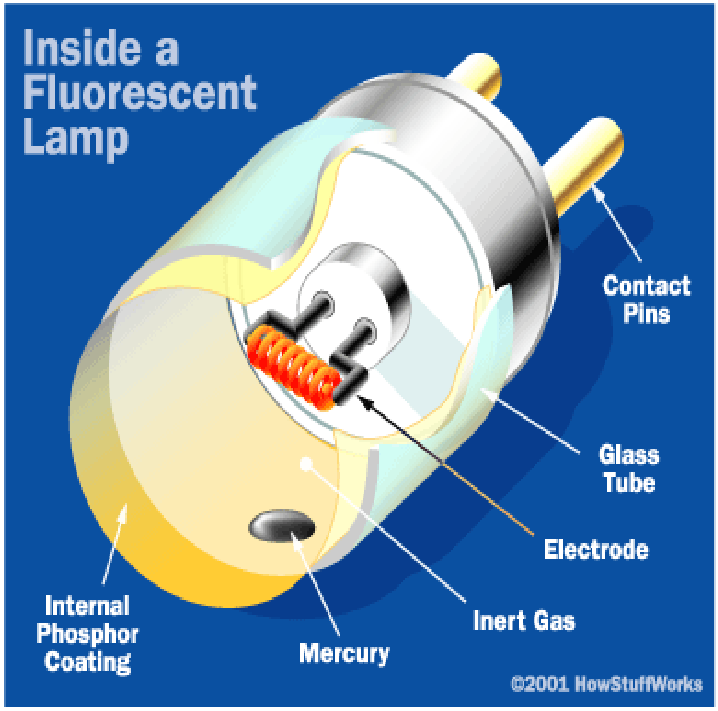
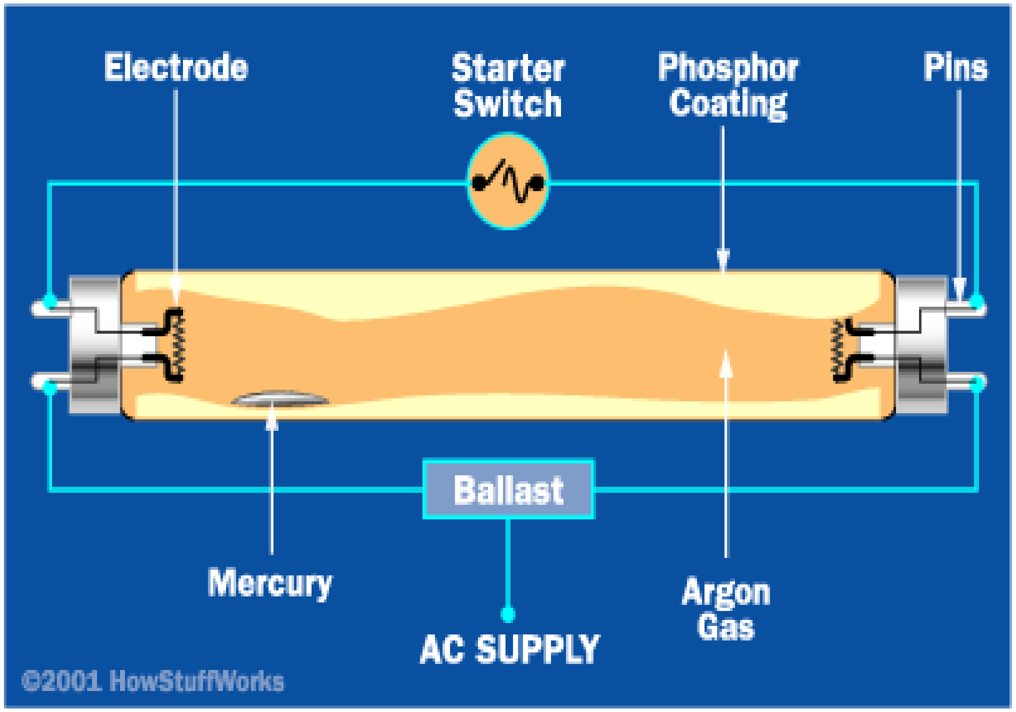
Orientation of Presentation

- Introduction
- Schematic of BCM Boost PFC Converter Based Electronic Ballast
- Design of BCM Boost PFC Converter Based Electronic Ballast
- MATLAB Model
- Simulated Performance and Results
- Experimental Performance and Results
- Conclusion

Introduction

Fluorescent Lamp:





Introduction

In Conventional High frequency Electronic Ballast

Power Quality Issues:

- Input Current THD is more than 90%.
- Input Power factor is 0.6-0.8.
- Input Current Crest factor is more than 1.7.

Introduction

Solution:

- Passive PFC Electronic ballast.
- Active PFC High Frequency Electronic Ballast.

Introduction

Drawbacks of Passive PFC Electronic Ballast

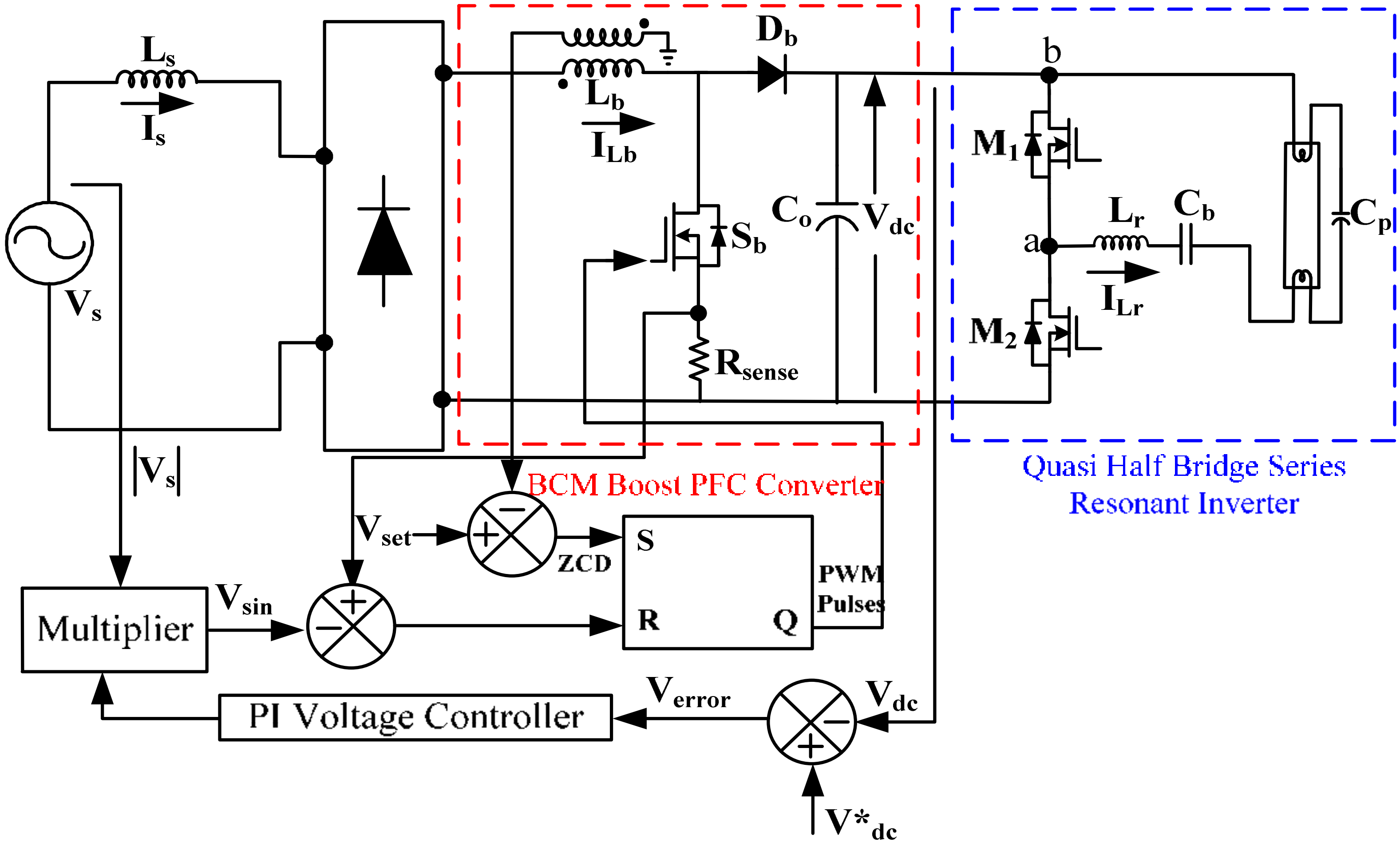
- Passive components (like inductor and capacitors) are bulky, noisy and costly.
- Input power factor can be achieved upto 0.9.

Introduction

Active PFC HF Electronic Ballast achieves

- Reduced Input Current THD at AC mains less than 10%.
- Input current CF (Crest Factor) nearly 1.41.
- Input PF (Power Factor) almost unity.
- In HF Electronic ballast, size and cost of circuit components like inductor and capacitor are reduced.

BCM Boost PFC Electronic ballast



Design of the Boost PFC Converter

The average output voltage of DBR is given as,

$$V_{in} = \frac{2\sqrt{2}V_s}{\pi}$$

For a boost converter operating in BCM (Boundary Conduction Mode), the selection of DC link voltage should be carried out such that it works for universal AC mains and it is defined as,

$$V_{dc} = \frac{V_{in}}{(1-D)}$$

Design of the Boost PFC Converter

For operating the PFC boost converter in BCM, minimum or critical value of boost inductance Lbmin is determined as,

$$L_{bmin} = \frac{V_{dc}D(1\text{-}D)}{2f_sI_o}$$

The dc link capacitor (C_o) must have enough capacitance to maintain the dc link voltage and must have to provide continuous load current at high switching frequency.
It can be calculated as,

$$C_o \geq \frac{V_{dc}}{2\omega\Delta V_{co}}$$

Design of Boost PFC Converter

For f_s = 46 kHz, I_o = 360mA, after solving earlier eqns. for universal AC mains voltage (i.e. 90V-270V), the values of minimum and maximum duty ratios are 0.1408 and 0.7136.

For input AC mains voltage of 270V rms, the peak value is 381V, so the DC link voltage must be more than this voltage for working in boost mode with universal AC mains, hence it is selected as 400V.

The calculated critical value of boost inductance is 2.46 mH (It is selected as 2.4 mH, to ensure the BCM operation).

The calculated value of bulk capacitor (C_o) is 20.47 µF for voltage ripple of 7% (It is selected as 22 µF).

Design of Resonant Circuit Parameters

The relationship between the starting resonance frequency and the resonant inverter parameters is given as,

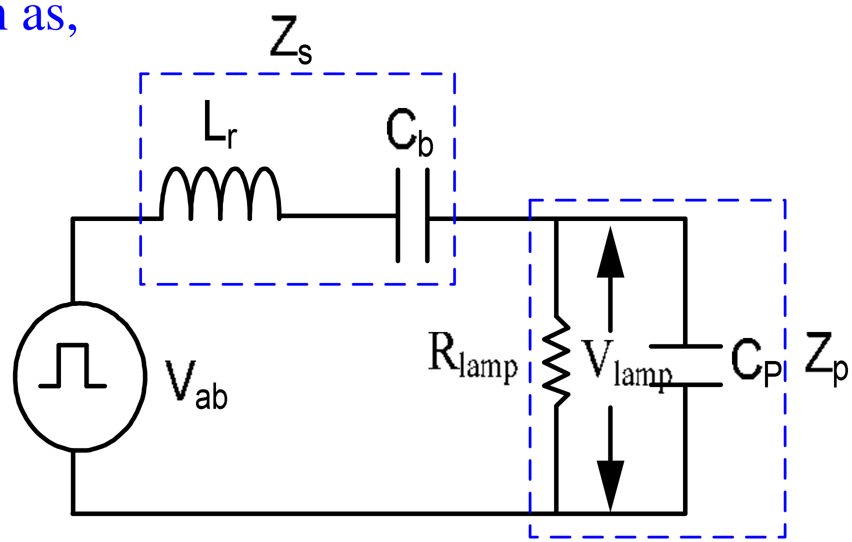
$$\omega_{starting} = \omega_{switching} = \frac{1}{\sqrt{L_r \cdot \left(\frac{C_b . C_p}{C_b + C_p} \right)}}$$

The steady-state resonance frequency is given as,

$$\omega_{running} = \frac{1}{\sqrt{L_r . C_b}}$$

For achieving zero voltage switching, Considering that

$$\omega_{switching} = 4\omega_{running}$$



Resonant Inverter Equivalent Circuit

The relationship between the rated lamp voltage and the fundamental component of the voltage source is given in the frequency domain as,

$$\left| \frac{V_{lamp}(j\omega)}{V_{ab}(j\omega)} \right| = \left| \frac{Z_p(j\omega)}{Z_s(j\omega) + Z_p(j\omega)} \right|$$

Design of Resonant Circuit Parameters

Solving the equations which are mentioned in the earlier slide;

The blocking capacitor C_b is given as,

$$C_b = 15.\left(\frac{V_{lamp}}{V_{ab}}\right)\left(\frac{1}{R_{lamp}.\omega_{switching}}\right)$$

The parallel resonant capacitor is given as,

$$C_P = \frac{C_b}{15}$$

The series resonant inductor is given as,

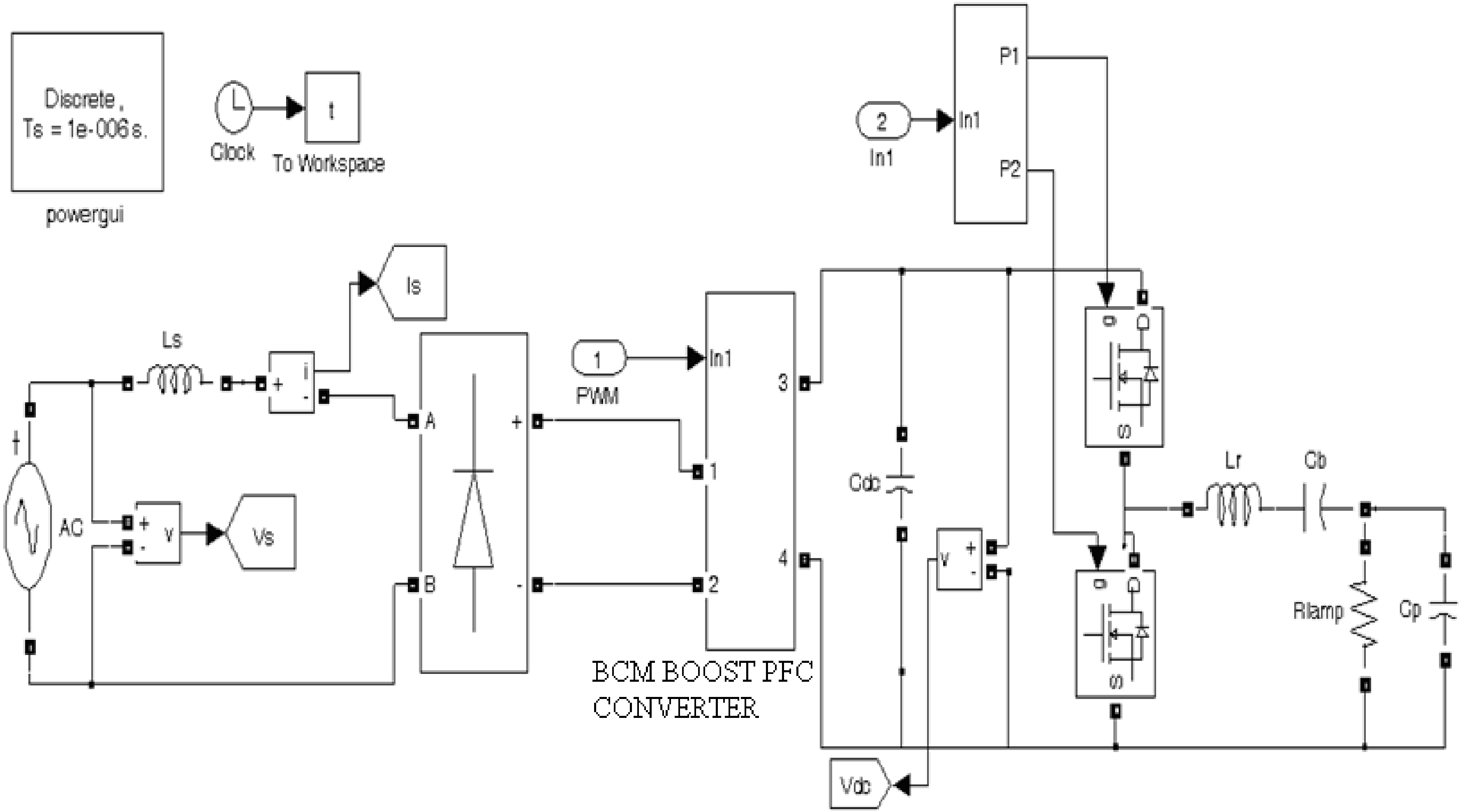
$$L_r = \frac{16}{C_b.\left(\omega_{switching}\right)^2}$$

Design of Resonant Circuit Parameters

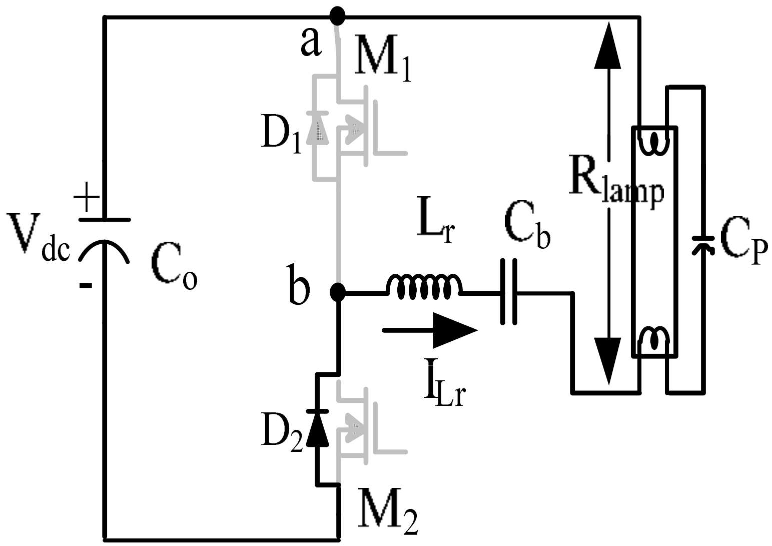
Using the equations, the calculated values of lamp resistance and different components of resonant inverter are:

R_{lamp} = 278 Ω (with 100 V as steady state lamp voltage),
L_r = 1.731 mH (selected as 1.75 mH),
C_b = 110.76 nF (selected as 100 nF),
C_p = 7.38 nF (selected as 6.8 nF).

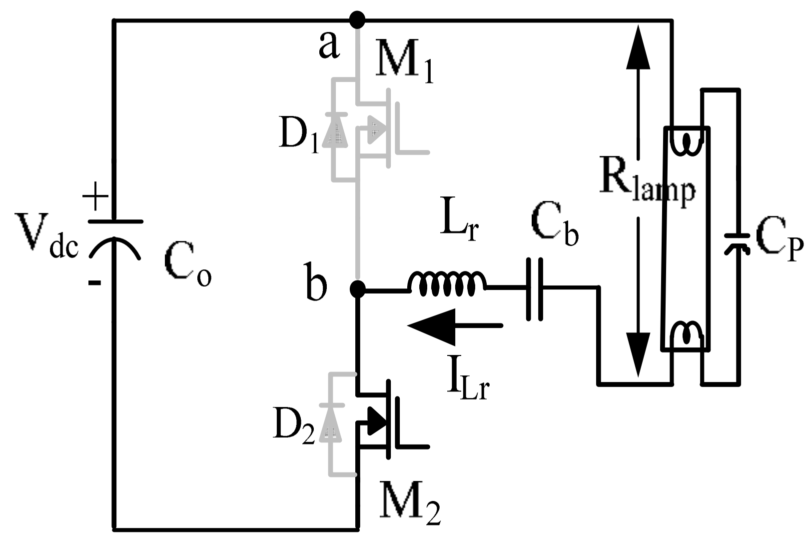
MATLAB Model of BCM Boost PFC Electronic ballast



Operating Modes of Quasi Half Bridge Series Resonant Inverter



Mode -A

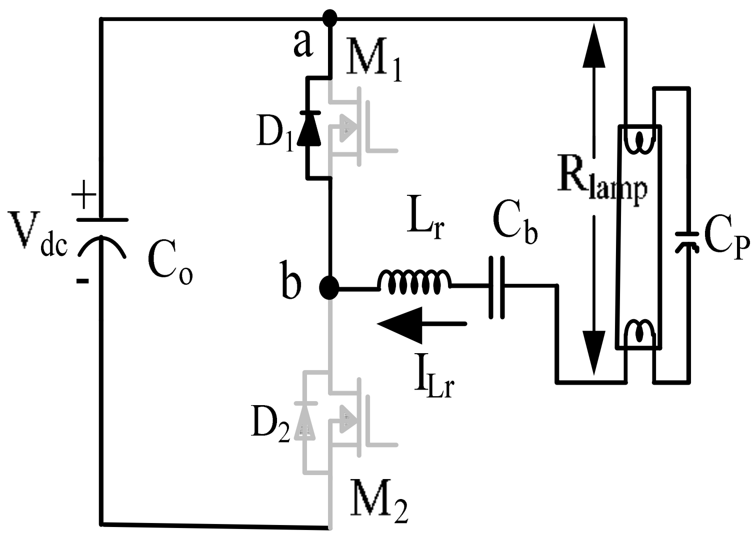


Mode -B

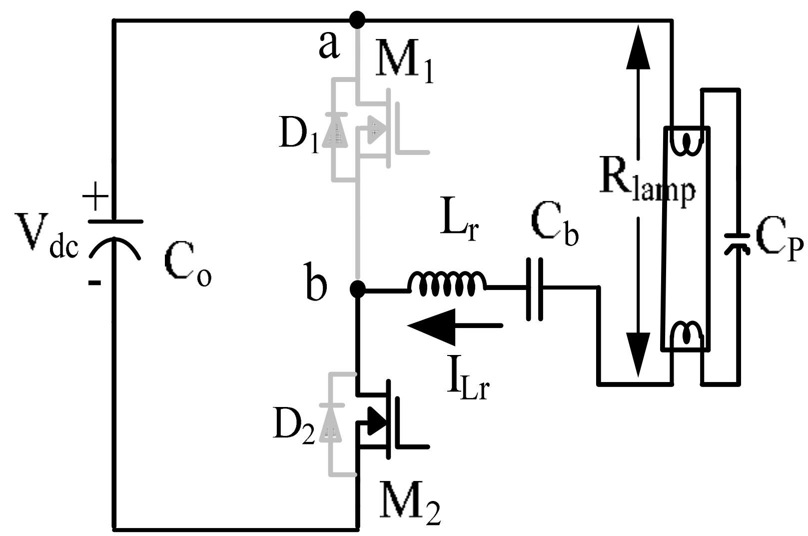
$C_o(-) \rightarrow D_2 \rightarrow L_r \rightarrow C_b \rightarrow (R_{lamp} || C_P) \rightarrow C_o(+)$

$C_o(+) \rightarrow (R_{lamp} || C_P) \rightarrow C_b \rightarrow L_r \rightarrow M_2 \rightarrow C_o(-)$

Operating Modes of Quasi Half Bridge Series Resonant Inverter



Mode -C

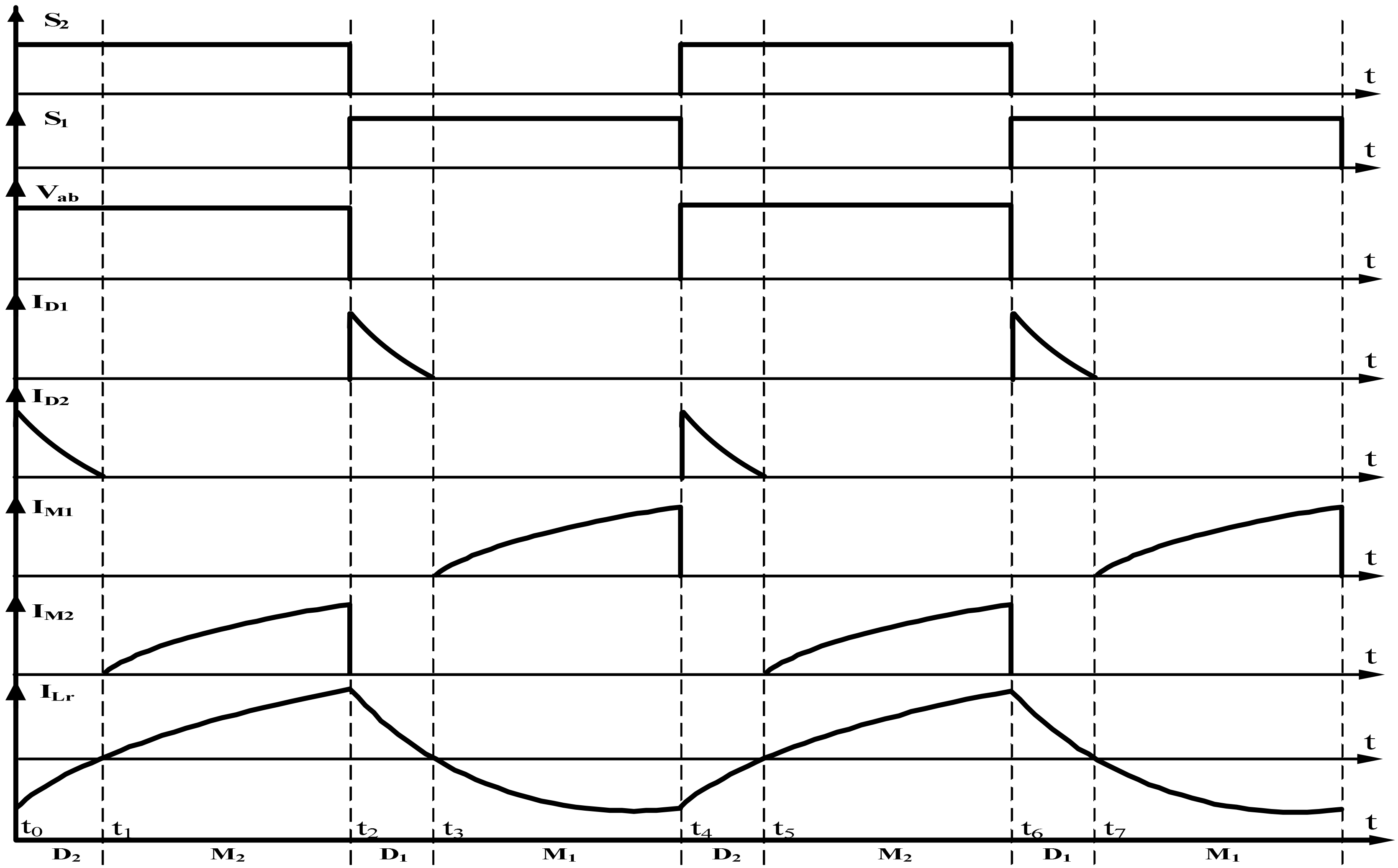


Mode -D

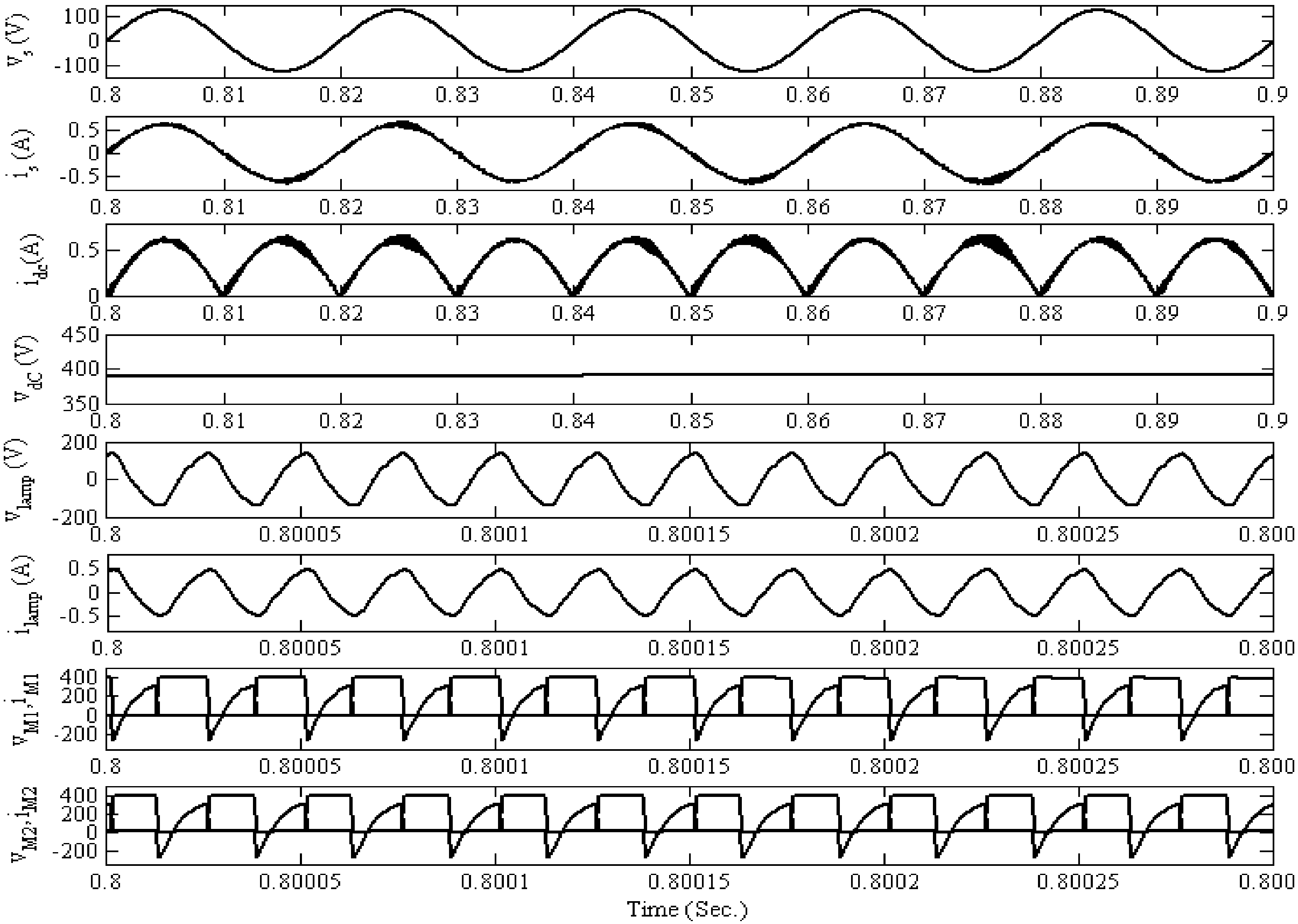
$D_1 \rightarrow (R_{lamp} || C_P) \rightarrow C_b \rightarrow L_r \rightarrow D_1$

$M_1 \rightarrow L_r \rightarrow C_b \rightarrow (R_{lamp} || C_P) \rightarrow M_1$

Theoretical Waveforms of Quasi Half Bridge Series Resonant Inverter

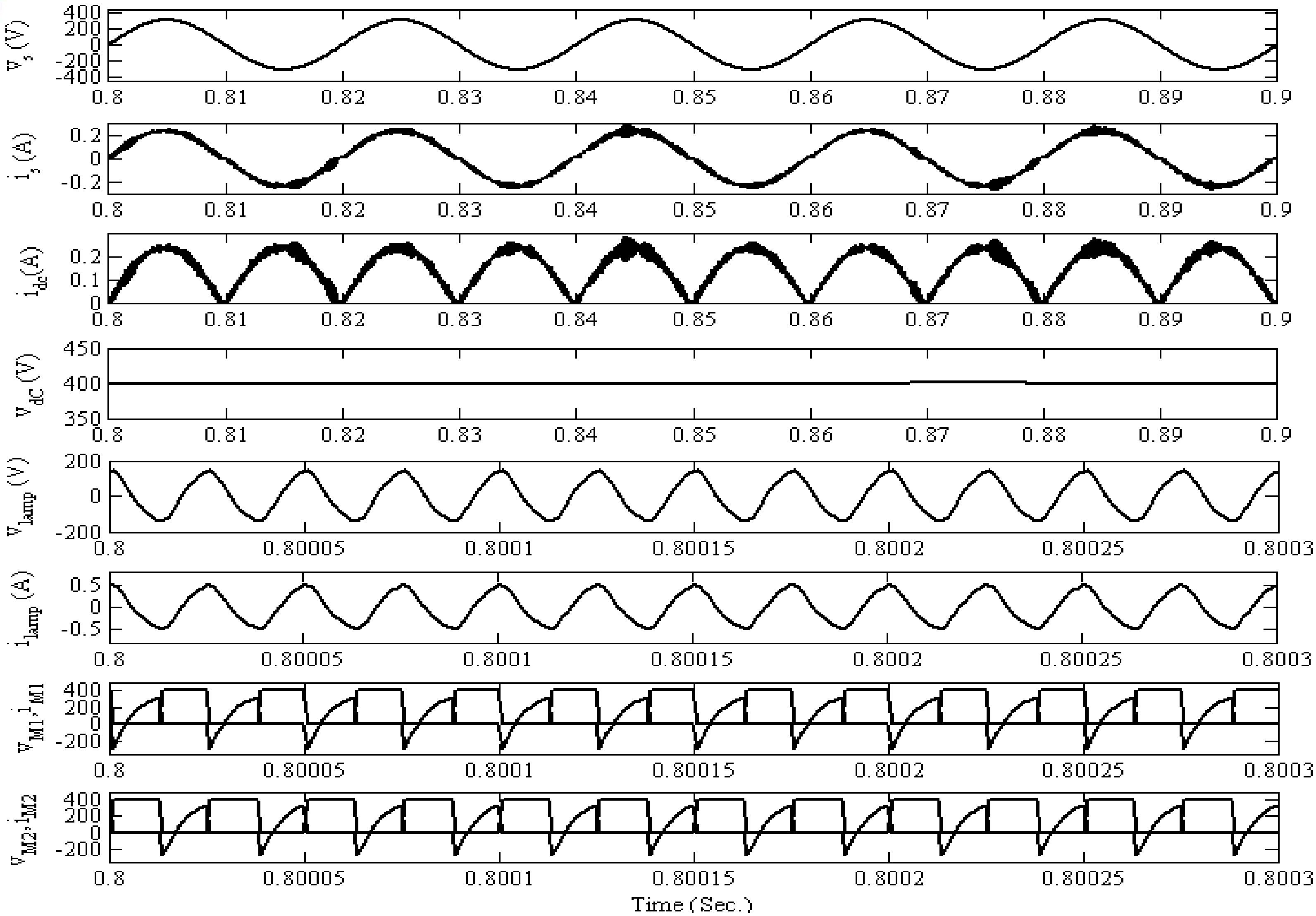


Simulated Performance and Results



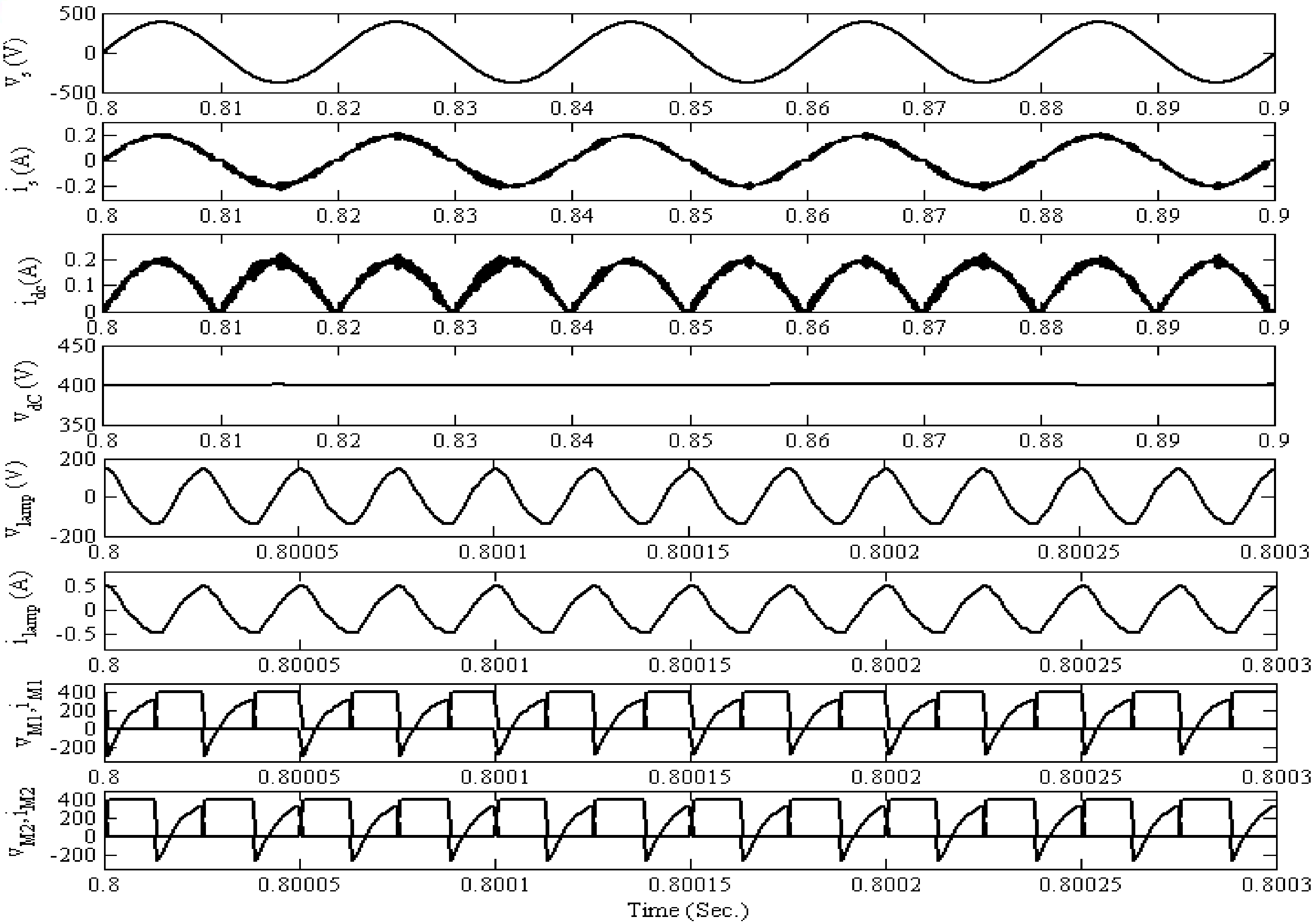
Simulated Performance of Boost PFC Electronic Ballast at AC mains voltage of 90V

Simulated Performance and Results



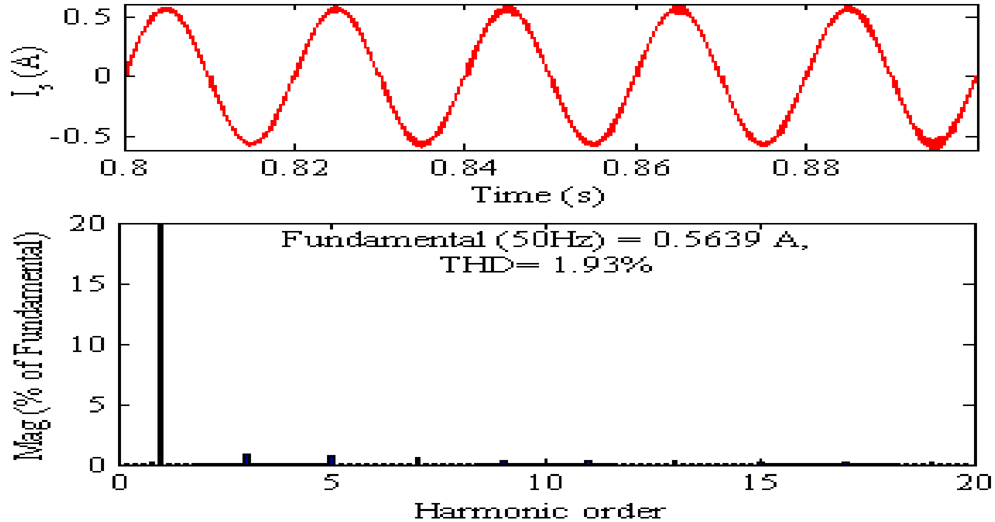
Simulated Performance of Boost PFC Electronic Ballast at AC mains voltage of 220V

Simulated Performance and Results

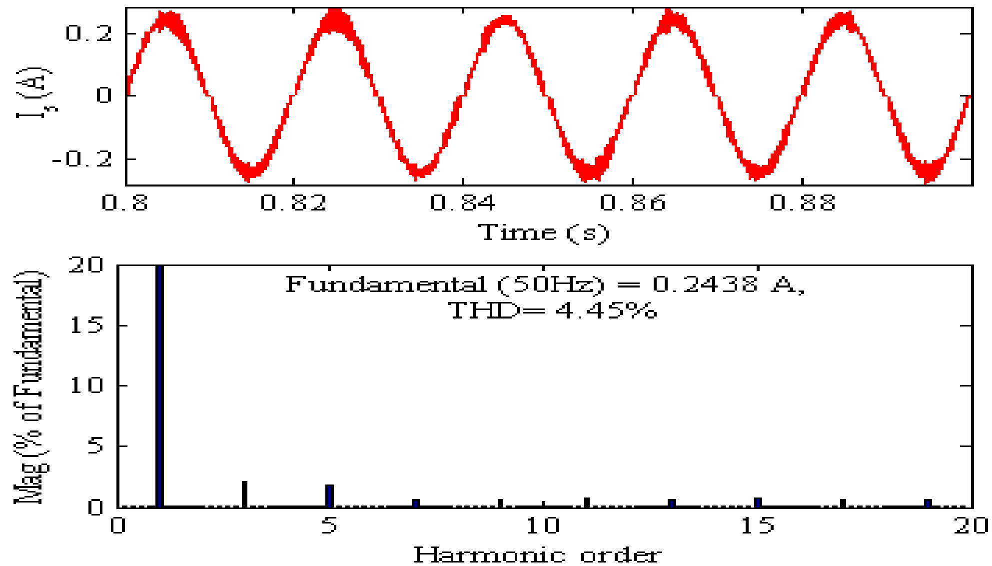


Simulated Performance of Boost PFC Electronic Ballast at AC mains voltage of 270V

Simulated Performance and Results

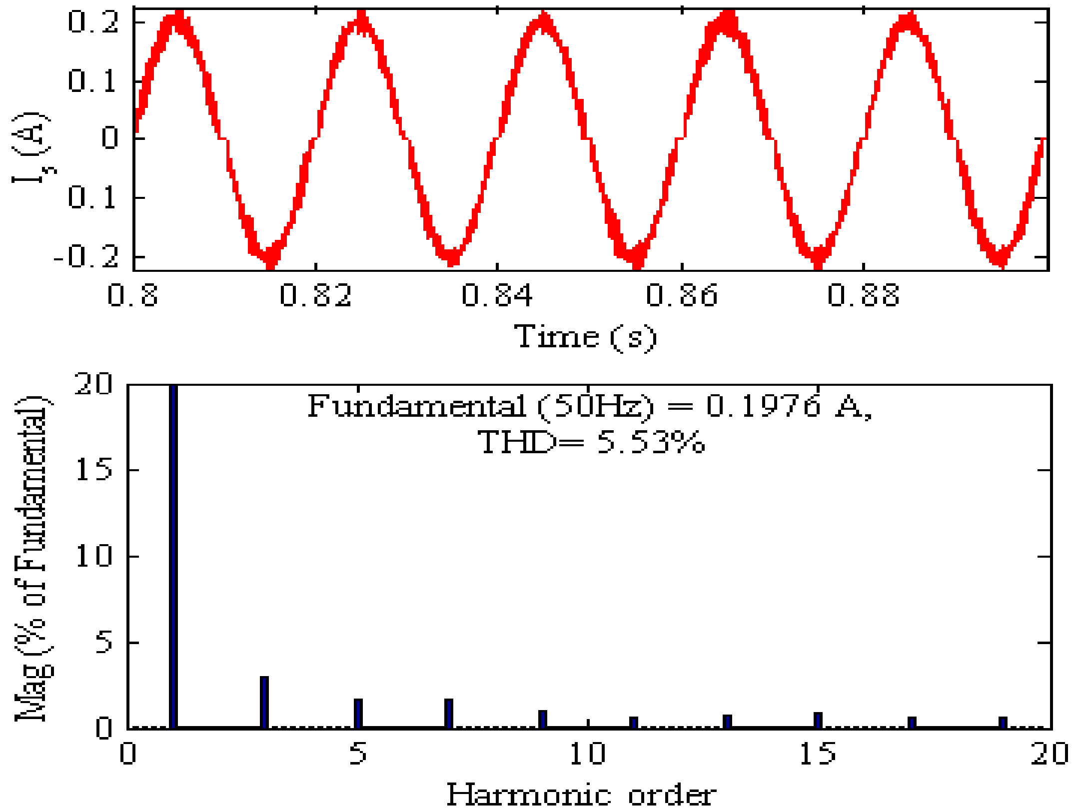


Input current waveform and its harmonic spectrum at AC mains voltage of 90V



Input current waveform and its harmonic spectrum at AC mains voltage of 220V

Simulated Performance and Results



Input current waveform and its harmonic spectra at AC mains voltage of 270V

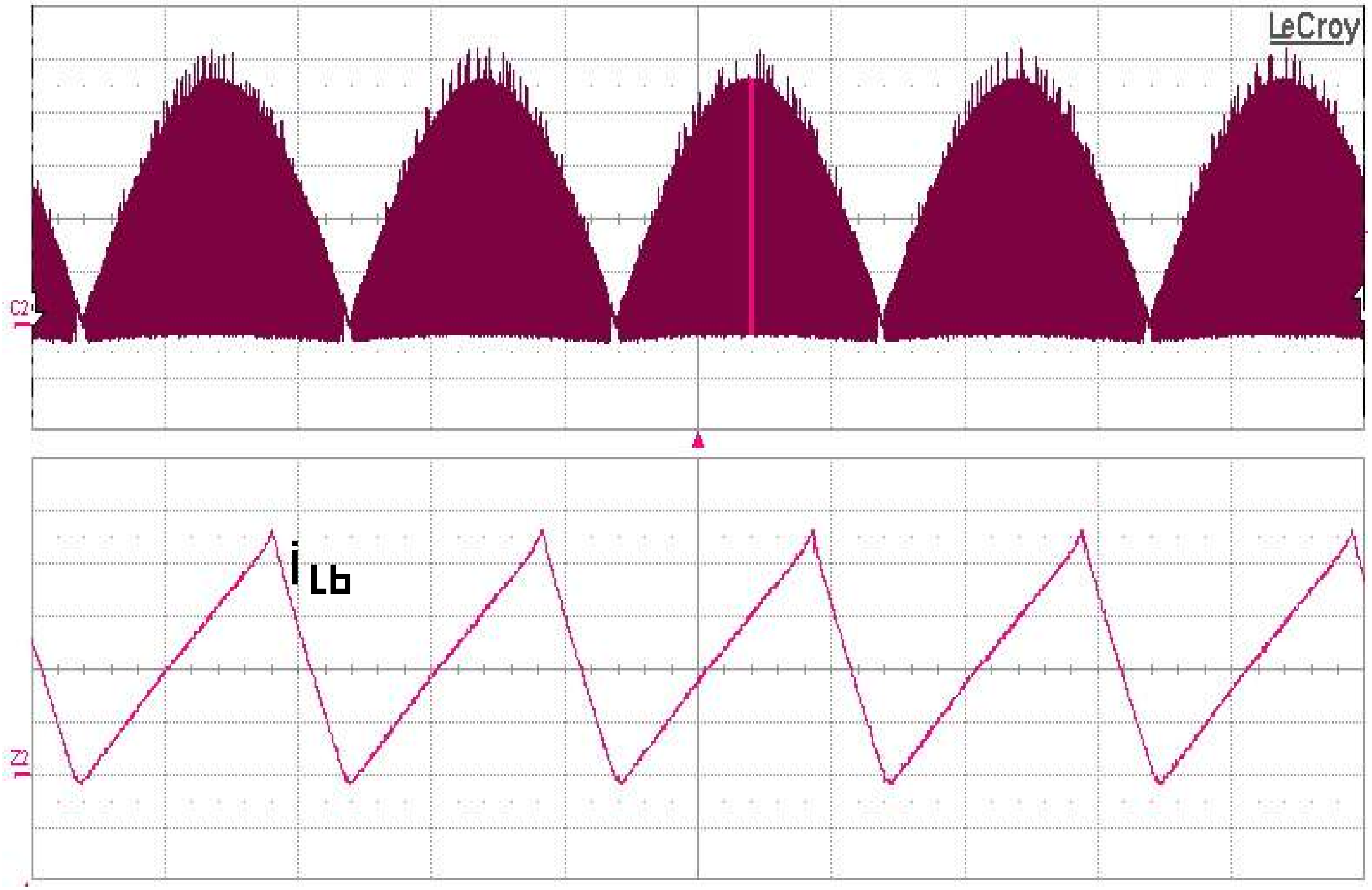
SIMULATED PERFORMANCE PARAMETERS OF BOOST PFC ELECTRONIC BALLAST

V_s (V)	I_s (A)	V_{dc} (V)	V_{lamp} (V)	I_{lamp} (A)	PF	DPF	DF	% THD_i	CF
90	447.1	391.2	93.82	360.9	0.9995	1	0.9995	1.93	1.404
100	400.3	395.3	94.81	364.6	0.9987	1	0.9987	2.30	1.408
110	361.3	397.5	95.31	366.6	0.9993	1	0.9993	1.95	1.410
120	328.4	398.6	95.58	367.6	0.9995	1	0.9992	2.15	1.411
130	301.1	399.2	95.73	368.2	0.9992	0.9999	0.9992	2.41	1.412
140	277.9	399.5	95.81	368.5	0.9990	0.9999	0.9992	2.63	1.412
150	258.2	399.7	95.85	368.6	0.9986	0.9998	0.9993	2.94	1.414
160	240.8	399.8	95.88	368.8	0.9986	0.9998	0.9982	3.31	1.412
170	225.9	399.9	95.88	368.8	0.9985	0.9998	0.9985	3.77	1.412
180	212.7	399.9	95.90	368.8	0.9987	0.9997	0.9986	3.63	1.412
190	201.1	400	95.90	368.9	0.9976	0.9996	0.9984	3.87	1.414
200	190.6	400	95.90	368.9	0.9978	0.9995	0.9976	4.26	1.413
210	181.3	400	95.91	368.9	0.9969	0.9994	0.9950	4.28	1.410
220	172.9	400	95.91	368.9	0.9967	0.9993	0.9971	4.53	1.411
230	165.0	400	95.91	368.9	0.9966	0.9992	0.9973	4.82	1.410
240	158.0	400	95.91	368.9	0.9964	0.9990	0.9968	4.59	1.410
250	151.5	400	95.91	368.9	0.9961	0.9989	0.9974	5.13	1.411
260	145.5	400	95.91	368.9	0.9959	0.9987	0.9972	5.45	1.410
270	140.2	400	95.91	368.9	0.9953	0.9985	0.9969	5.53	1.410

EXPERIMENTAL PERFORMANCE PARAMETERS OF BCM BOOST PFC ELECTRONIC BALLAST FOR A 36W, T8 FLUORESCENT LAMP

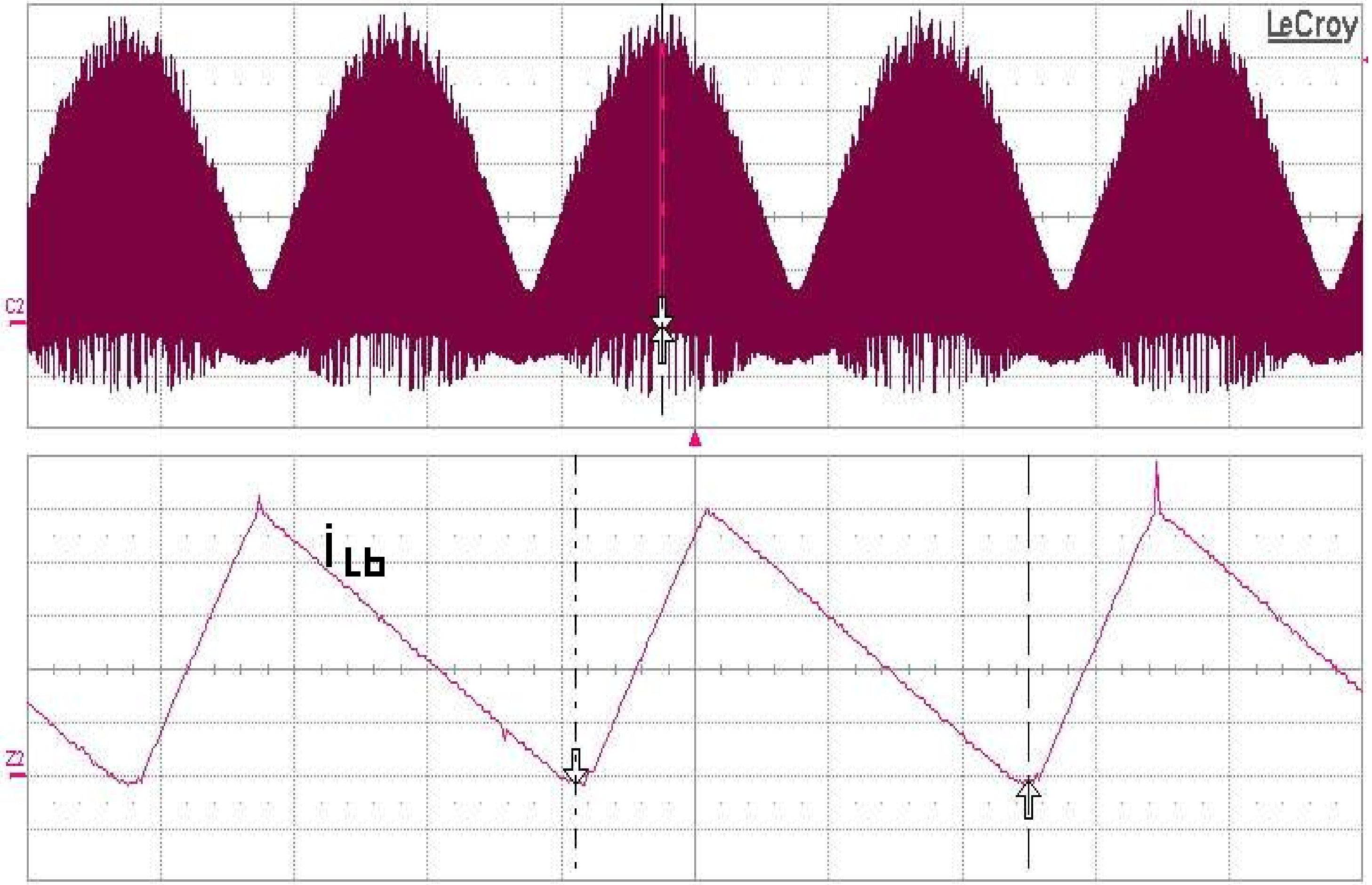
V_s (V)	I_s (A)	V_{lamp} (V)	I_{lamp} (A)	% η	PF	% THD_i	CF
90	449.42	96.8	371.2	88.83	1	1.81	1.411
130	296.20	96.4	368.4	92.32	0.999	3.03	1.442
180	212.04	96.2	366.7	92.98	0.994	4.23	1.453
220	174.49	96.3	367.1	93.58	0.984	5.67	1.467
270	145.72	95.8	361.8	91.47	0.963	6.00	1.467

Experimental Performance and Results



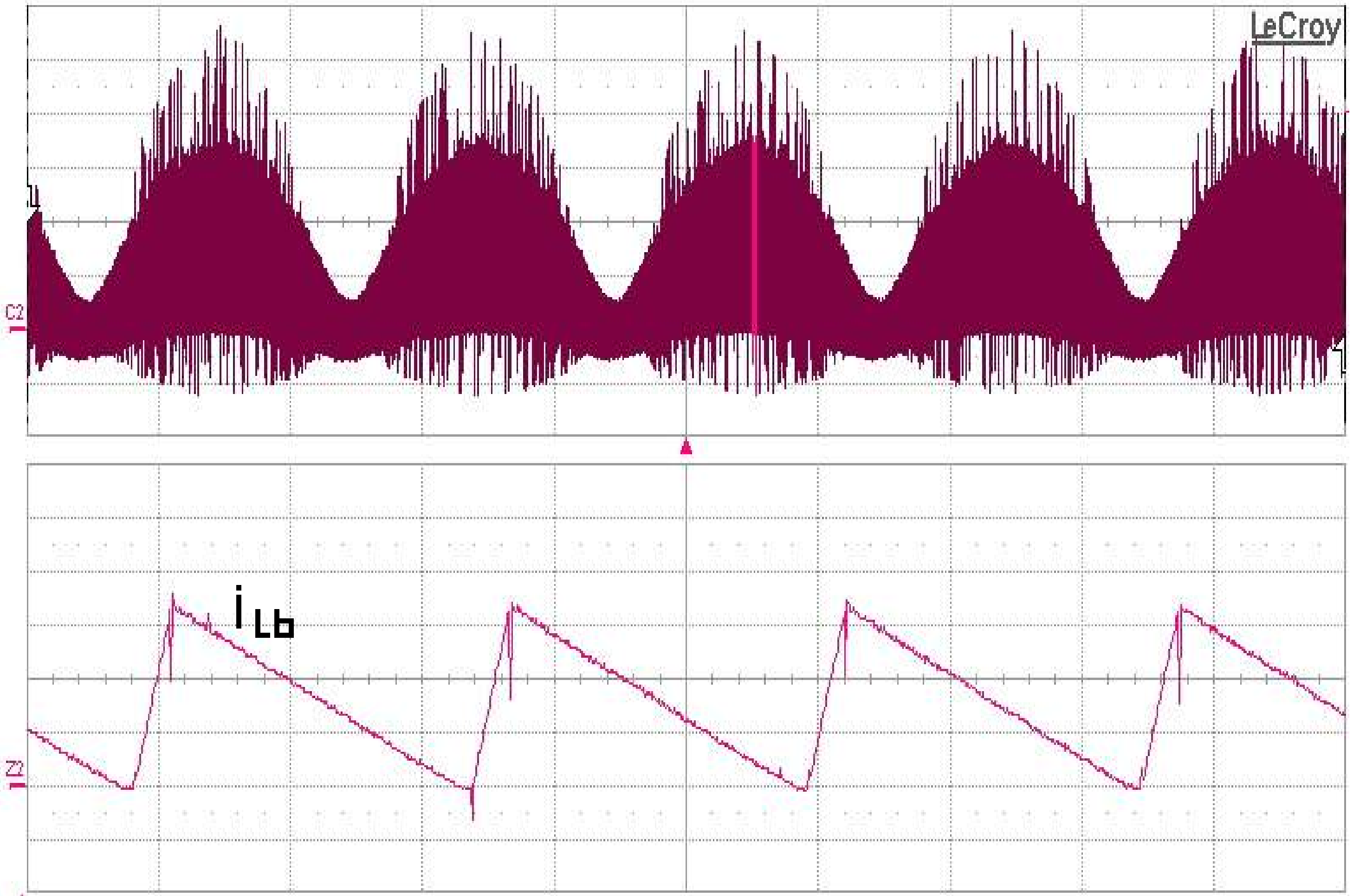
Simulated Performance of Boost PFC Electronic Ballast in terms of inductor current at AC mains voltage of 90V

Experimental Performance and Results



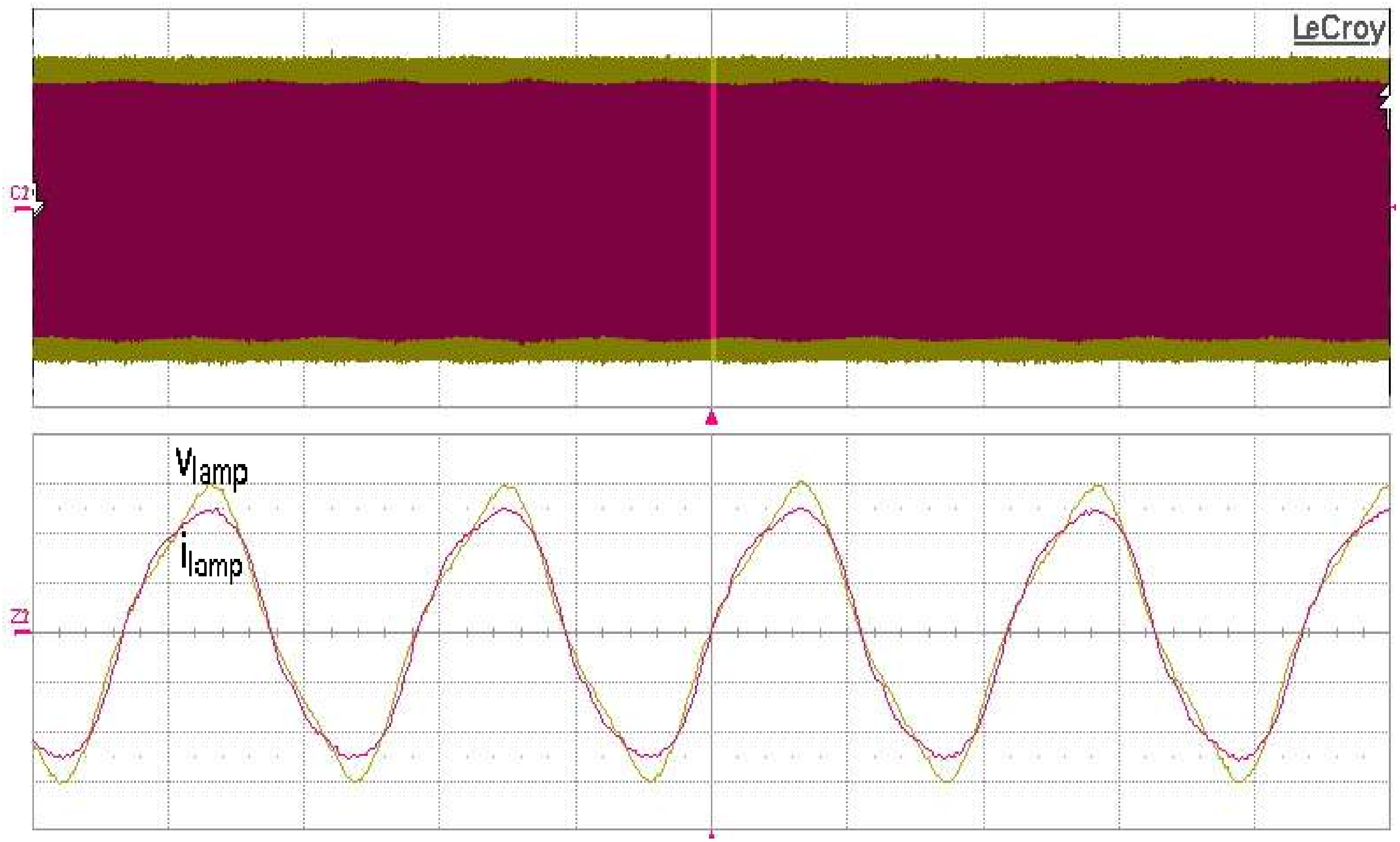
Simulated Performance of Boost PFC Electronic Ballast in terms of inductor current at AC mains voltage of 220V

Experimental Performance and Results



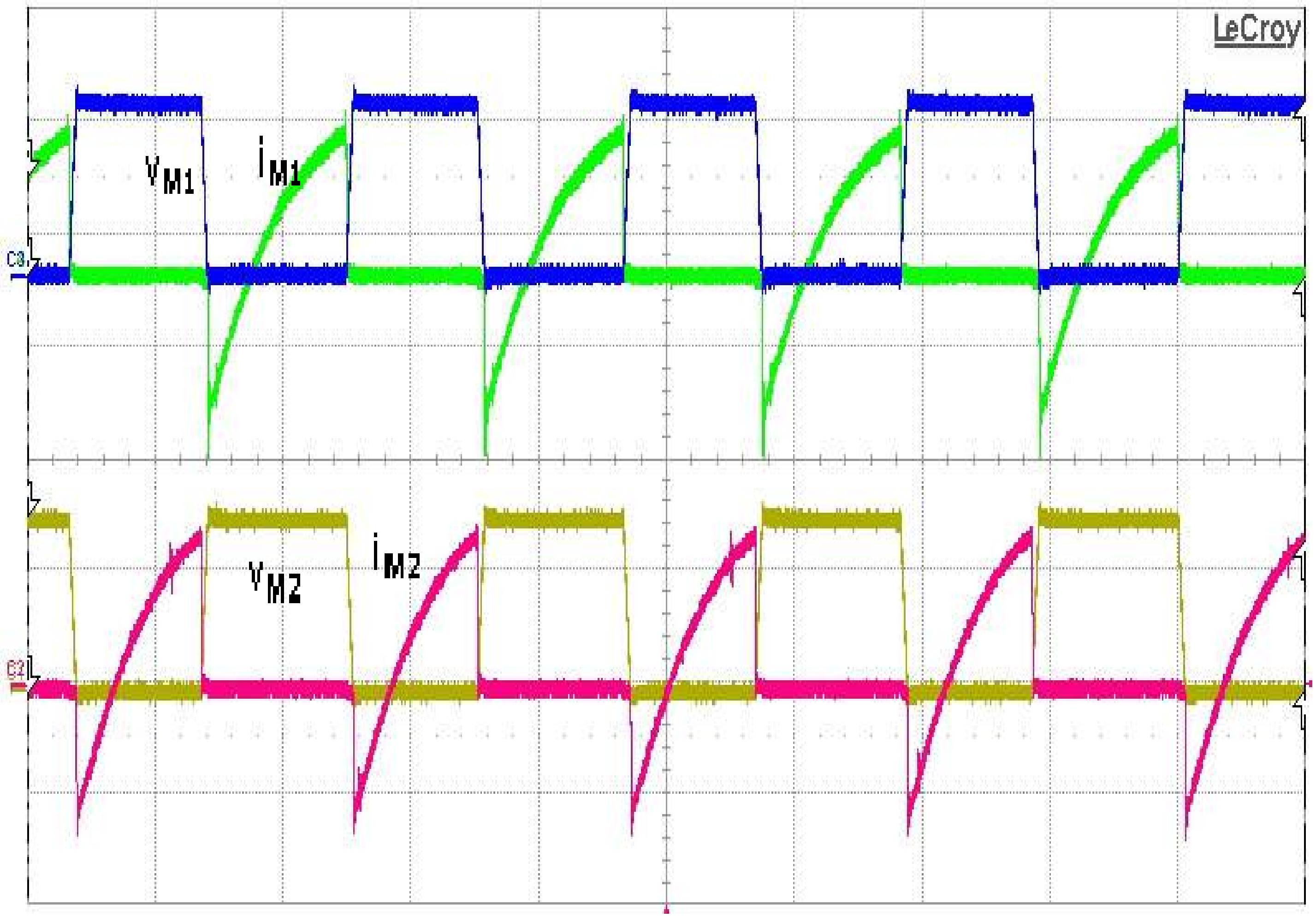
Simulated Performance of Boost PFC Electronic Ballast in terms of inductor current at AC mains voltage of 270V

Experimental Performance and Results



Simulated Performance of Boost PFC Electronic Ballast in terms of lamp voltage and lamp current at AC mains voltage of 220V

Experimental Performance and Results



Simulated Performance of Boost PFC Electronic Ballast in terms of switch voltage and switch current at AC mains voltage of 270V

Conclusion

- BCM Boost PFC converter based electronic ballast improves input power factor to almost unity.

- It has reduced THD of ac mains current under 6% for input voltage range (i.e. 90-270 V), which is as per international standard IEC-61000-3-2 (Class C) equipments.

- It achieves the crest factor of input current as 1.41 for the wide variation of AC mains voltage.

Conclusion

- Reduced Switching losses due to Zero voltage switching (ZVS) operation of active switches M_1 and M_2.

References

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3. A. Peres, D.C. Martens and I. Barbi, “ZETA converter applied in power factor correction,” in *Proc. IEEE PESC’94*, June 1994, pp. 1152-1157.
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5. Wei. Huai and I. Batarseh, “Comparison of Basic Converter Topologies for Power Factor Correction,” in *Proc. Of IEEE Southeastcon'98*, 1998, pp. 348 – 353.

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7. Jong-Lick Lin, Sung-Pei Yang and Pao-Wei Lin, "Small-signal analysis and controller design for an isolated zeta converter with high power factor correction," *Electric Power Systems Research*, Vol. 76, Issues 1-3, pp. 67-76, September 2005.

Power Quality Improvements in Compact Fluorescent Lighting

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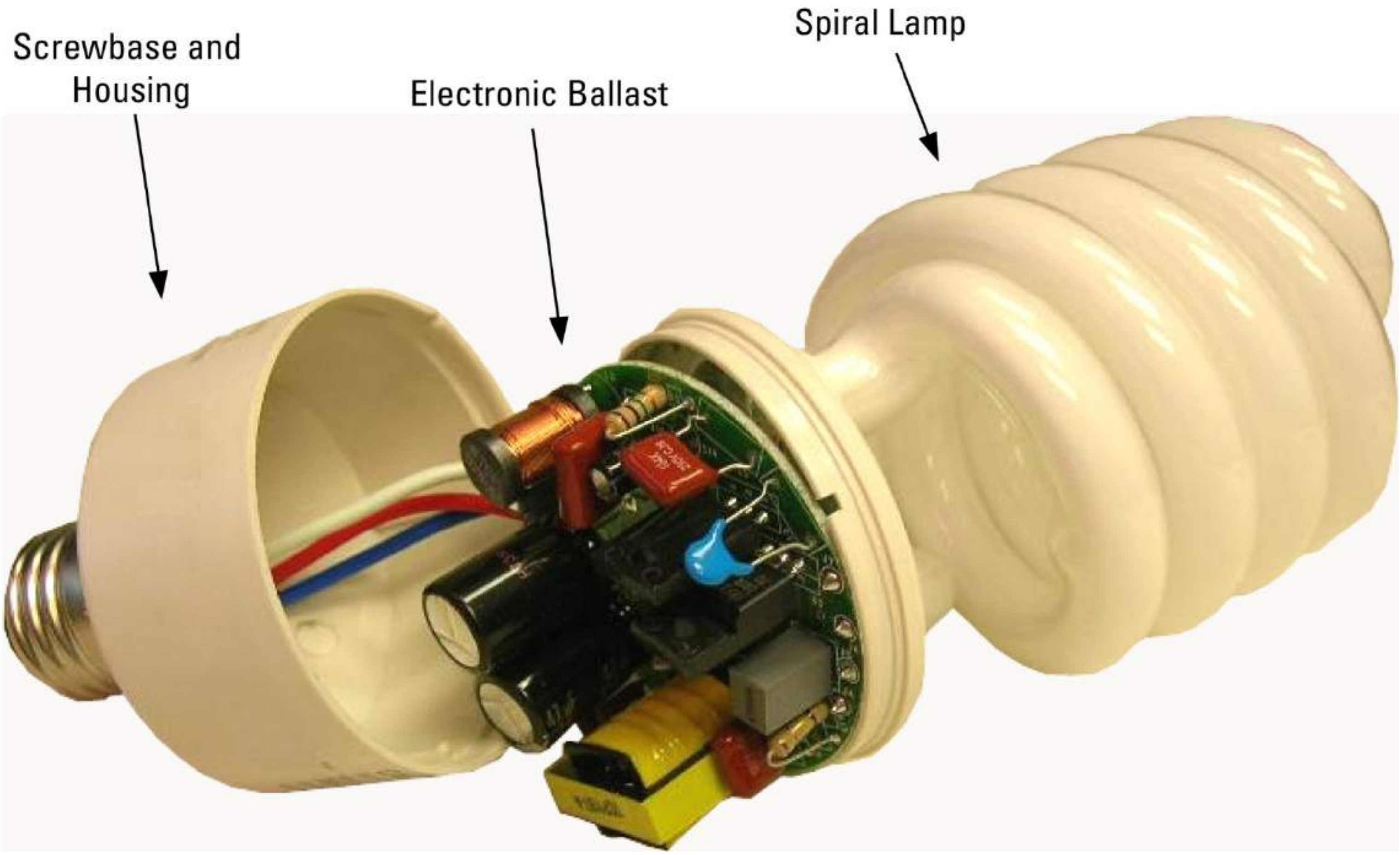
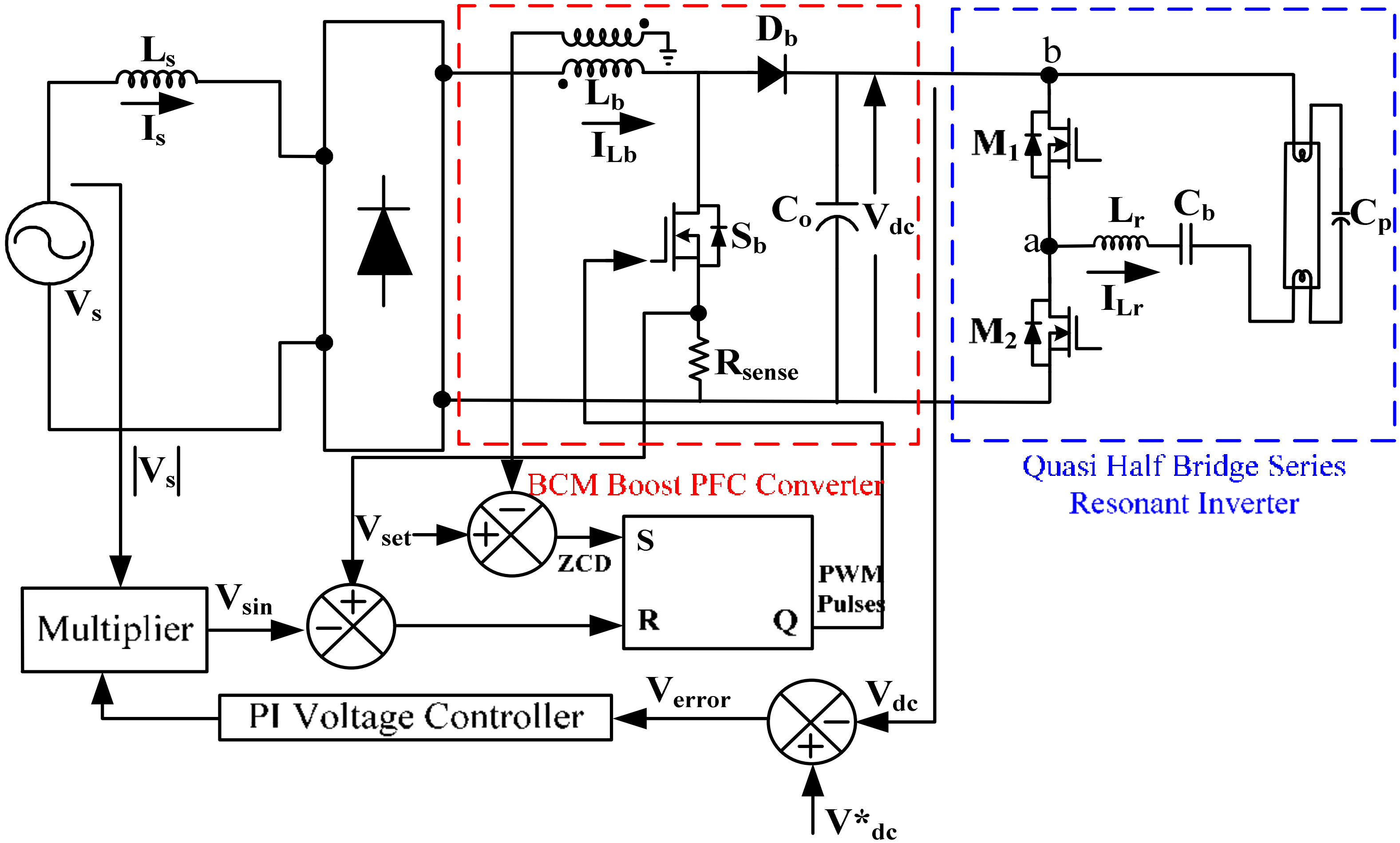
Introduction

Conventional Compact Fluorescent Lamp:



BCM Boost PFC Electronic ballast



Design of the Boost PFC Converter

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$$V_{in} = \frac{2\sqrt{2}V_s}{\pi}$$

For a boost converter operating in BCM (Boundary Conduction Mode), the selection of DC link voltage should be carried out such that it works for universal AC mains and it is defined as,

$$V_{dc} = \frac{V_{in}}{(1-D)}$$

Design of the Boost PFC Converter

For operating the PFC boost converter in BCM, minimum or critical value of boost inductance Lbmin is determined as,

$$L_{crit} = \frac{V_{dc} D(1-D)}{2 f_s I_o}$$

The output DC link capacitor (C_o) must have enough capacitance to maintain constant DC link voltage and should eliminate the second-order harmonic components present in DC link voltage. It is estimated as,

$$C_o \geq \frac{V_{dc}}{2\omega \Delta V_{co}}$$

Design of Boost PFC Converter

For f_s = 50 kHz, I_o = 210mA, after solving earlier eqns. for universal AC mains voltage (i.e. 90V-270V), the values of minimum and maximum duty ratios are 0.1408 and 0.7136.

For a boost converter operating in BCM (Boundary Conduction Mode), the DC link voltage is selected as 400V.

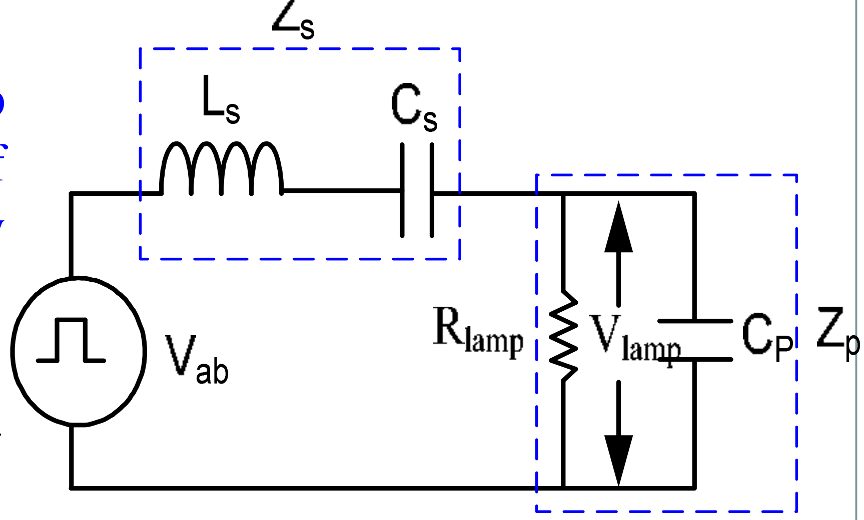
The calculated critical value of boost inductance is 3.24 mH (It is selected as 3.2 mH, to ensure the BCM operation).

The calculated value of bulk capacitor (C_o) is 10.44 µF for voltage ripple of 8% (It is selected as 10 µF).

Design of Resonant Circuit Parameters

The relationship between the rated lamp voltage and the fundamental component of the voltage source is given in the frequency domain as,

$$\frac{V_{lamp}(j\omega)}{V_{ab}(j\omega)} = \frac{1}{\left[1+\left(C_P/C_s\right)-\omega^2 L_s C_p + j\left(\omega L_s/R\right)-\left(j/\omega CR\right)\right]}$$



Resonant Inverter Equivalent Circuit

Now after substituting quality factor $Q_s = \left(\omega_s L_s / R_{lamp}\right)$, the frequency ratio $x = \left(\omega_r / \omega_s\right)$ and resonance frequency $f_r = \left(1/\sqrt{L_s C_s}\right)$ after ignition in the above equation, then the result will be given as,

$$\left|\frac{V_{lamp}}{V_{ab}}\right| = \frac{1}{\sqrt{\left[1+\left(C_P/C_s\right)\left(1-x^2\right)^2 + Q_s\left(x-\frac{1}{x}\right)^2\right]}}$$

Design of Resonant Circuit Parameters

The parallel resonant capacitor is given as,

$$C_p = \frac{C_s}{(1/x)^2 - 1}$$

The series resonant inductor is given as,

$$L_s = \frac{1}{\left(\frac{C_s C_p}{C_s + C_p}\right)\omega_s^2}$$

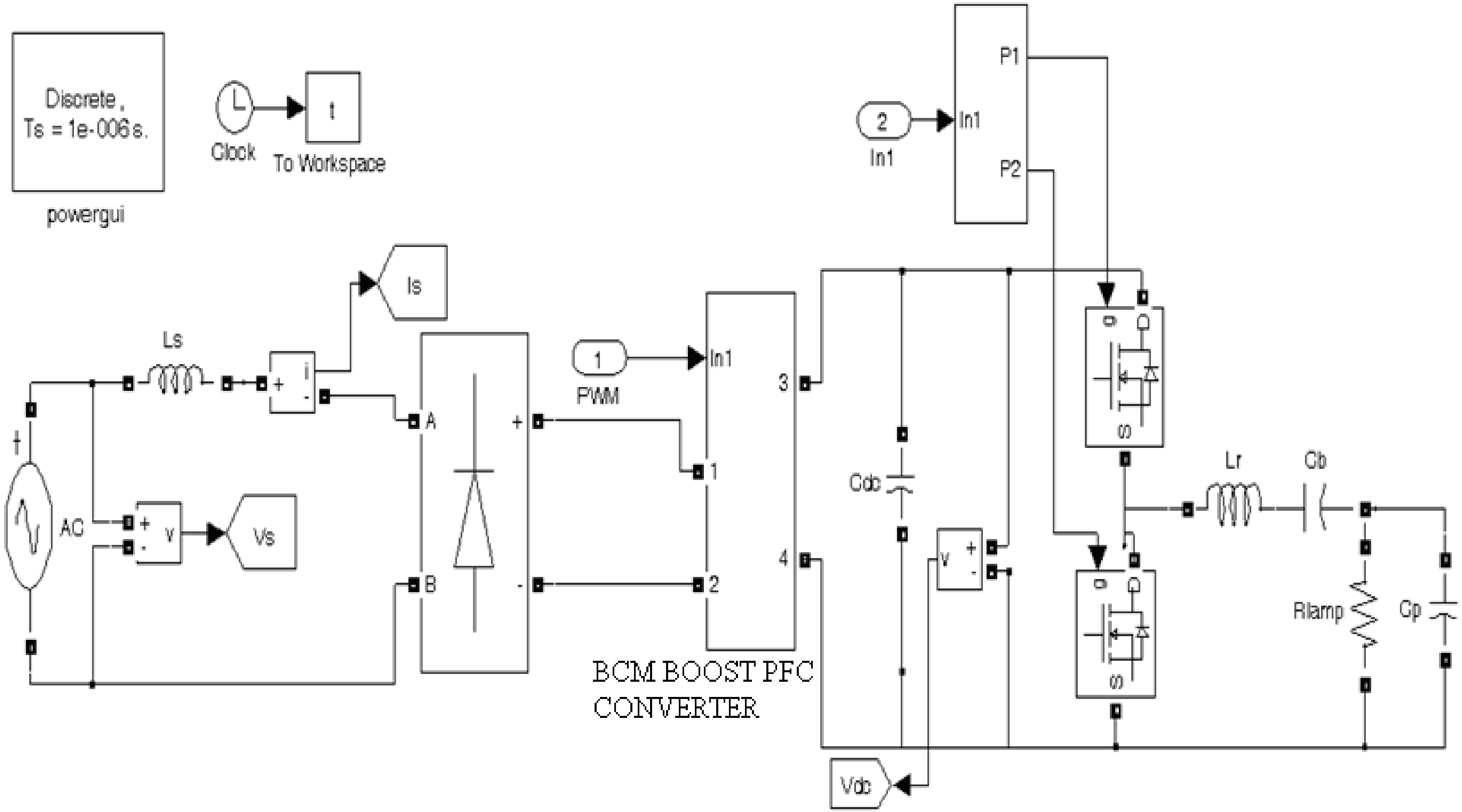
Under steady state condition, the resistance of fluorescent lamp is given as,

$$R_{lamp} = V_{lamp}^2 / P_{lamp}$$

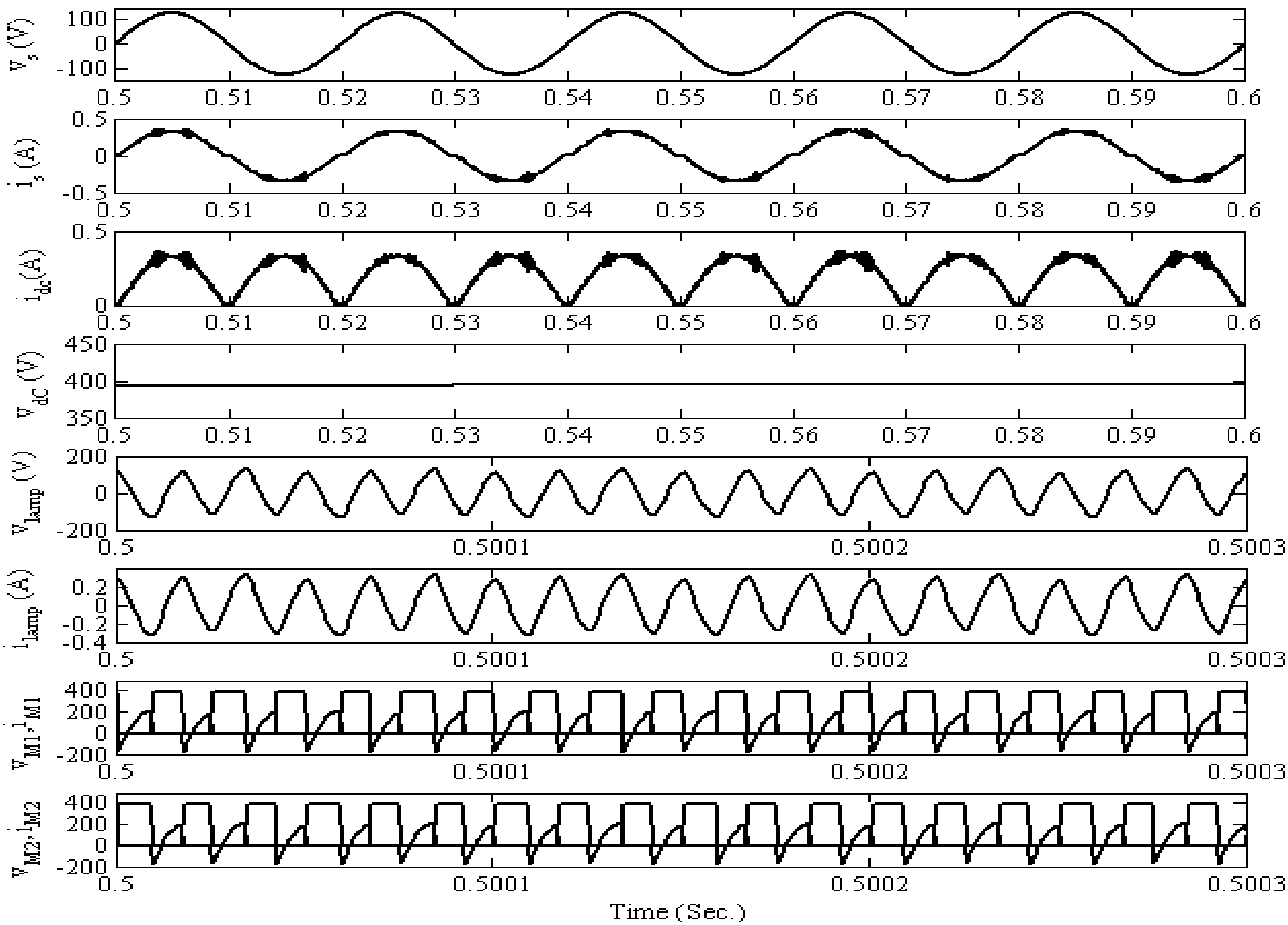
To ensure ZVS operation of both the active switches of series resonant inverter (SRI), frequency ratio (x) is selected as 0.25 and for proper ignition at the time of starting, Q_s is selected as 1.8. By solving above equations, the following results have been achieved.

R_{lamp} = 392 Ω (for rated power of 18W and lamp voltage of 84V), L_s = 3.21 mH (selected as 3 mH), C_s = 67.61 nF (selected as 100 nF), C_p = 6.8 nF.

MATLAB Model of BCM Boost PFC Electronic ballast

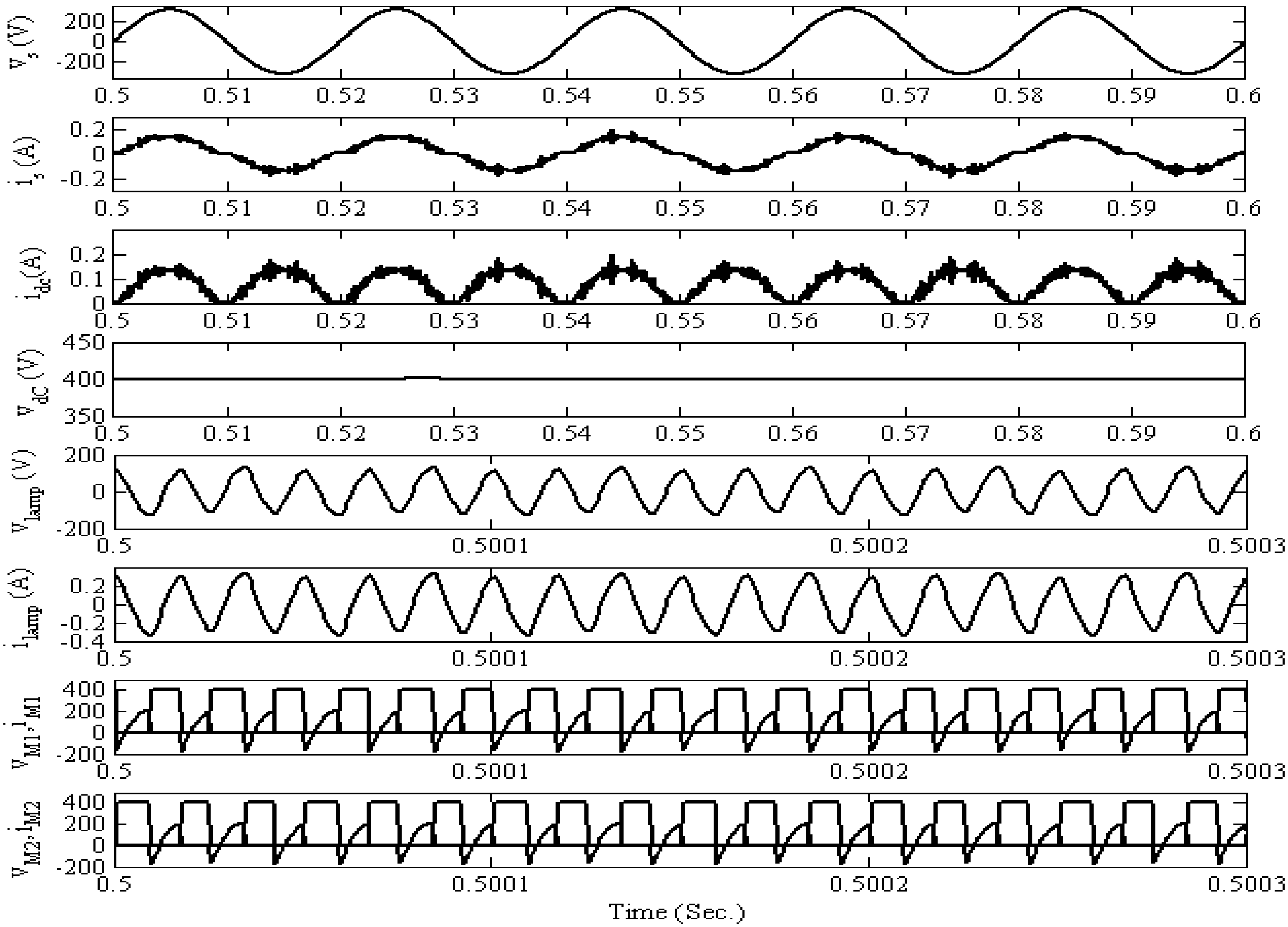


Simulated Performance and Results



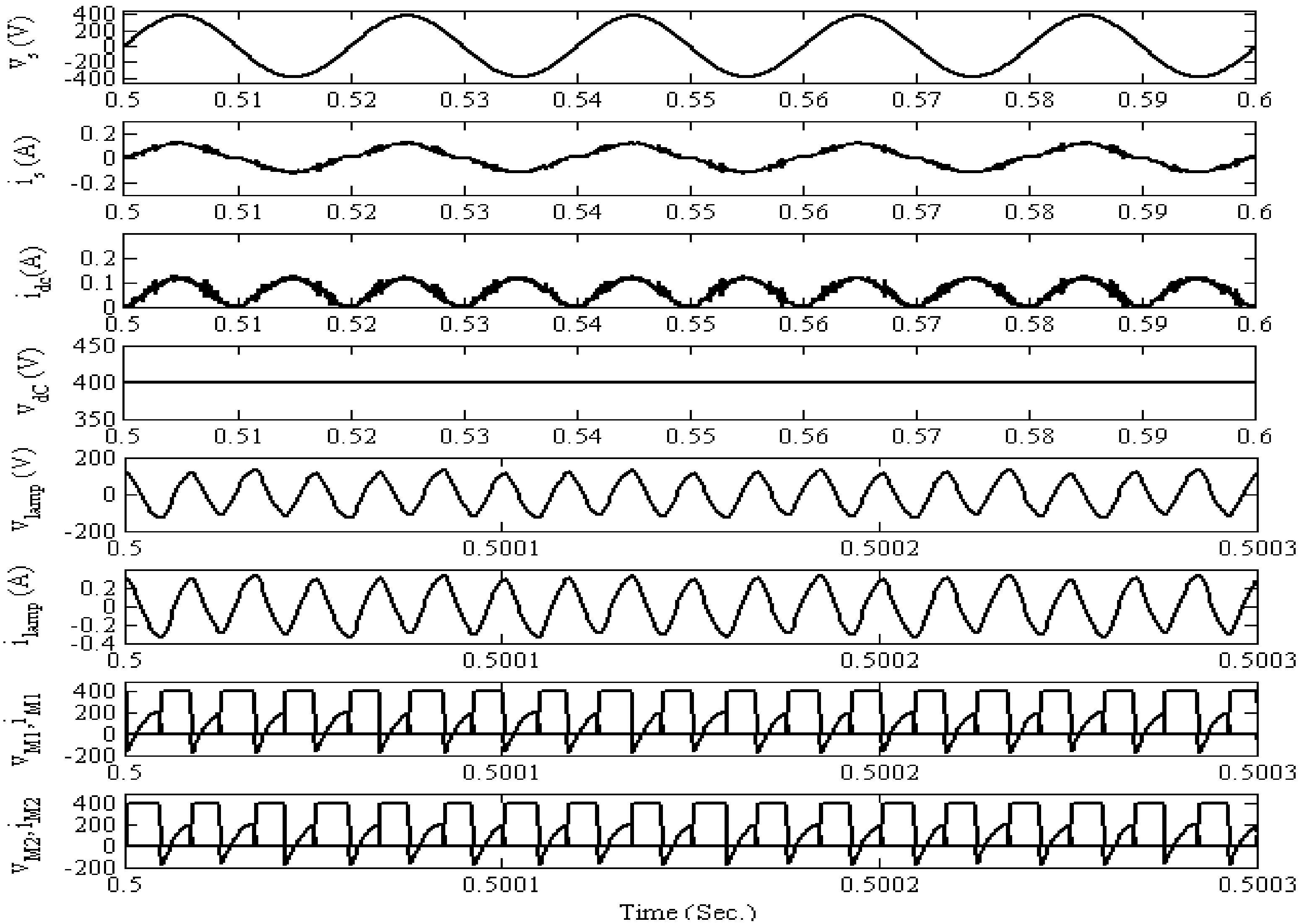
Simulated Performance of Boost PFC Electronic Ballast at AC mains voltage of 90V

Simulated Performance and Results



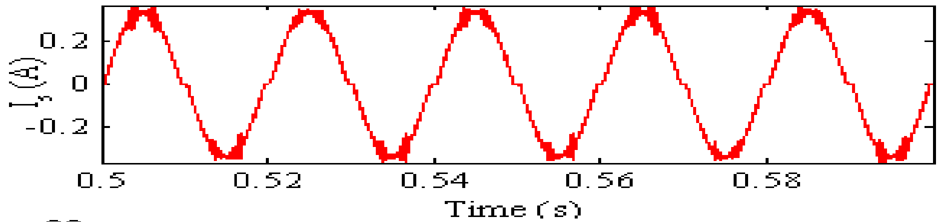
Simulated Performance of Boost PFC Electronic Ballast at AC mains voltage of 220V

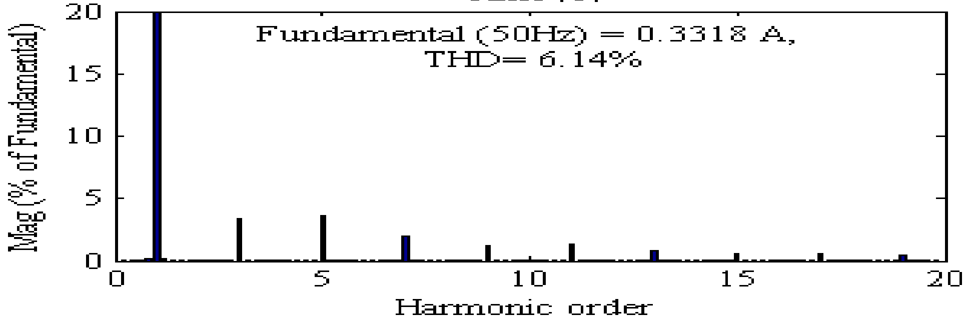
Simulated Performance and Results



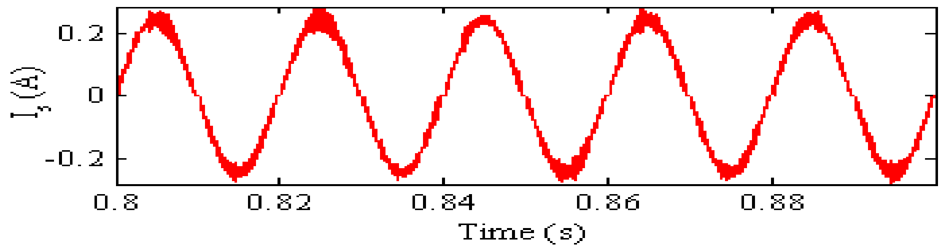
Simulated Performance of Boost PFC Electronic Ballast at AC mains voltage of 270V

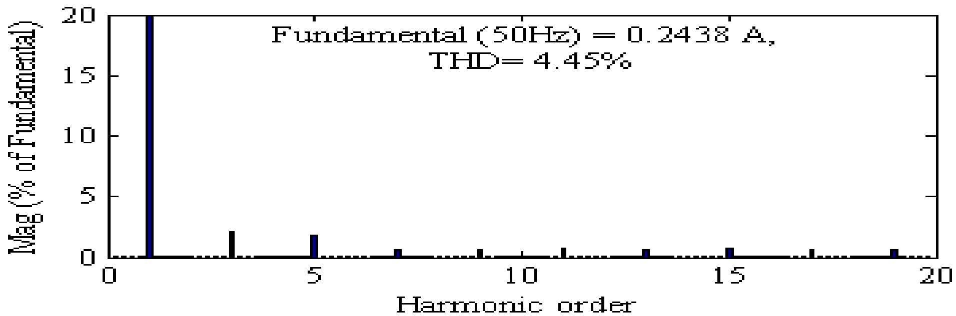
Simulated Performance and Results





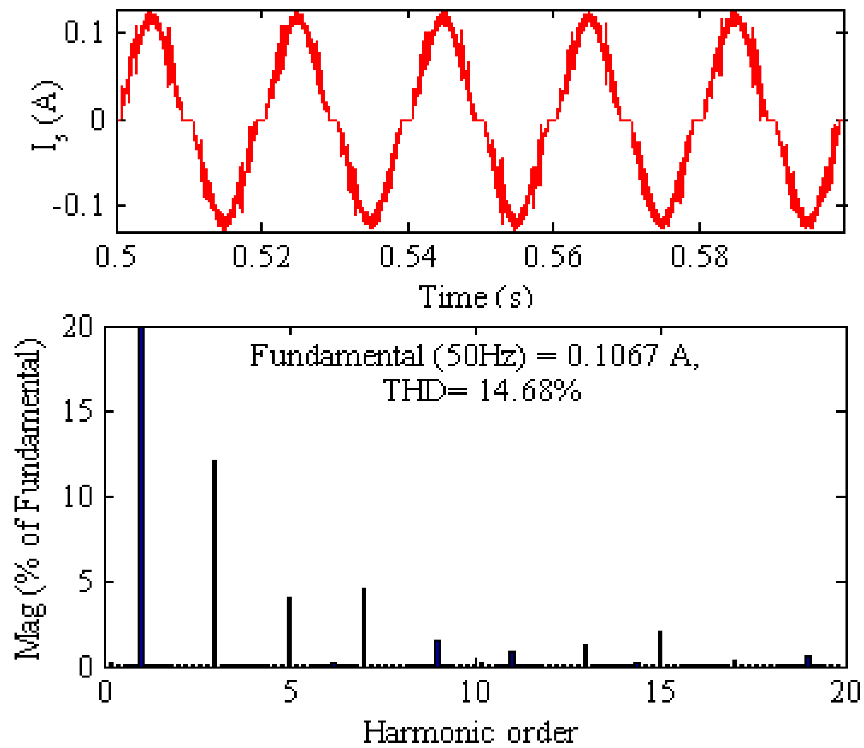
Input current waveform and its harmonic spectrum at AC mains voltage of 90V





Input current waveform and its harmonic spectrum at AC mains voltage of 220V

Simulated Performance and Results



Input current waveform and its harmonic spectra at AC mains voltage of 270V

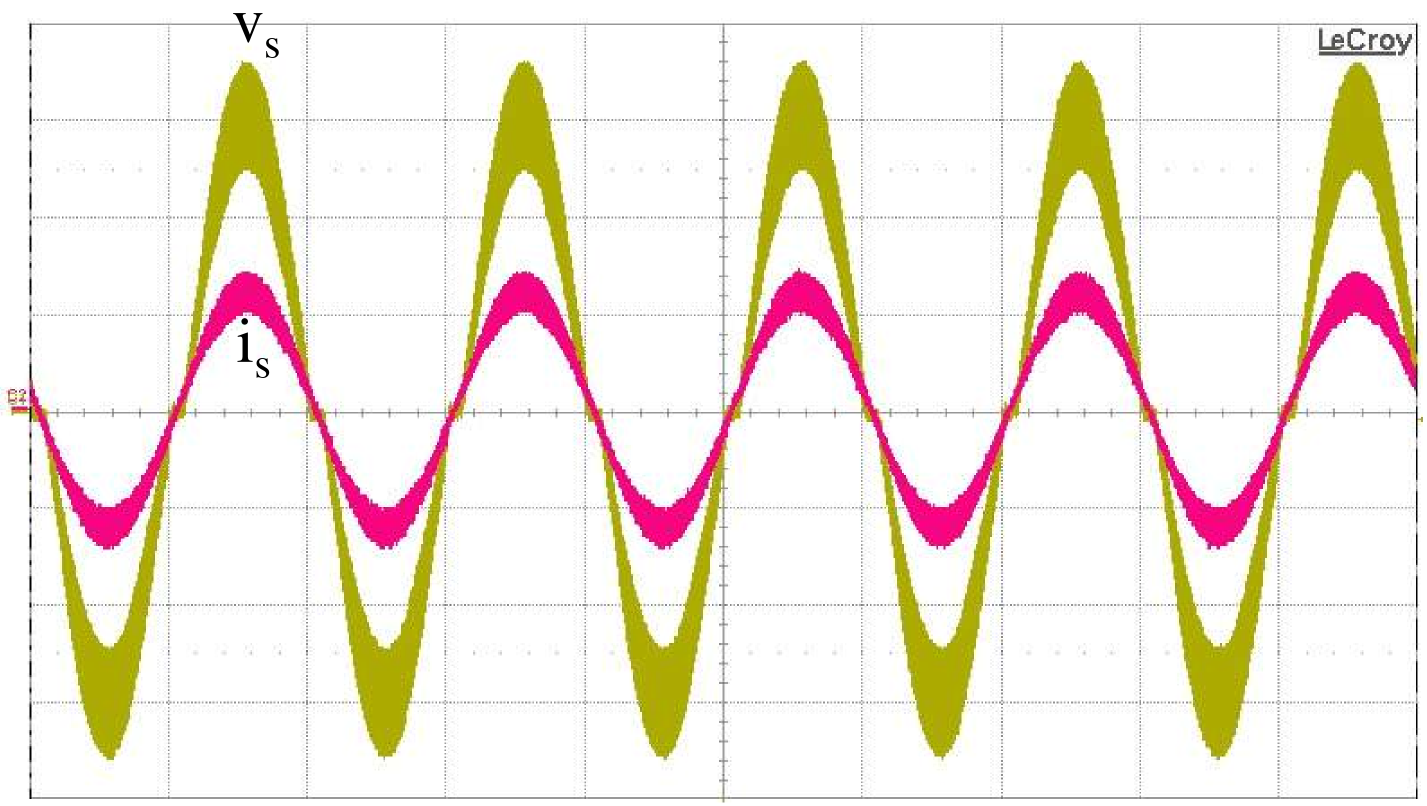
SIMULATED PERFORMANCE PARAMETERS OF BCM BOOST PFC ELECTRONIC BALLAST

V_s (V)	I_s (A)	V_{dc} (V)	V_{lamp} (V)	I_{lamp} (A)	PF	DPF	% THD_i	CF
90	241.7	395.1	82.78	212.2	0.9971	1	6.14	1.408
100	216.6	397.5	83.25	212.6	0.9967	1	6.55	1.406
110	195.6	398.7	83.47	213.1	0.9968	1	6.94	1.408
120	178.5	399	83.56	213.4	0.9967	1	7.37	1.409
130	160.4	399.4	83.44	213.9	0.9956	0.9999	7.82	1.407
140	148.7	399.7	83.49	214.1	0.9950	0.9999	8.64	1.406
150	138.4	399.8	83.51	214.1	0.9932	0.9998	9.88	1.406
160	129.4	399.9	83.52	214.2	0.9925	0.9998	10.24	10407
170	122.0	400	83.53	214.2	0.9920	0.9997	10.99	1.401
180	114.8	400	83.52	214.2	0.9904	0.9997	12.01	1.403
190	108.9	400	83.54	214.2	0.9897	0.9997	12.69	1.401
200	103.5	400	83.53	214.2	0.9881	0.9996	13.32	1.403
210	98.87	400	83.54	214.2	0.9812	0.9995	14.16	1.401
220	94.09	400	83.53	214.2	0.9861	0.9996	13.53	1.395
230	88.12	400	83.52	214.2	0.9857	0.9995	13.68	1.402
240	84.03	400	83.53	214.2	0.9856	0.9994	13.97	1.405
250	81.21	400	83.53	214.2	0.9854	0.9992	14.36	1.402
260	78.23	400	83.53	214.2	0.9851	0.9991	14.59	1.402
270	76.54	400	83.52	214.2	0.9852	0.9991	14.68	1.401

EXPERIMENTAL PERFORMANCE PARAMETERS OF BCM BOOST PFC ELECTRONIC BALLAST FOR AN 18W COMPACT FLUORESCENT LAMP (CFL)

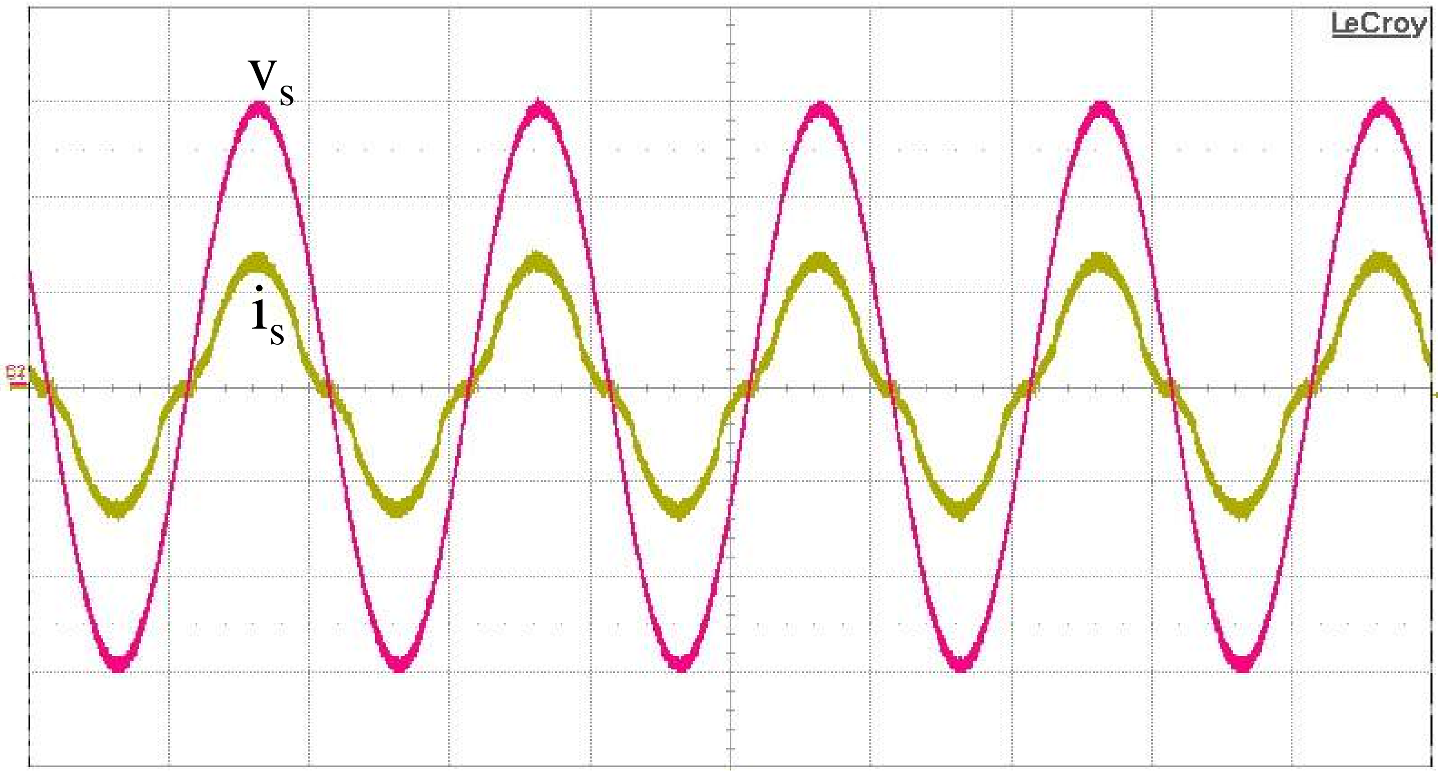
V_s (V)	I_s (A)	V_{lamp} (V)	I_{lamp} (A)	% η	PF	% THD_i	CF
90	228.20	84.1	210.5	86.54	0.996	9.33	1.493
130	161.57	83.8	211.2	84.77	0.994	3.03	1.508
180	117.92	83.6	212.6	84.58	0.990	4.23	1.528
220	96.29	83.4	215.7	86.12	0.986	15.64	1.548
270	79.42	83.2	214.3	84.75	0.981	17.66	1.572

Experimental Performance and Results



Experimental Performance of Boost PFC Electronic Ballast in terms of AC mains voltage and AC mains current at 90V

Experimental Performance and Results

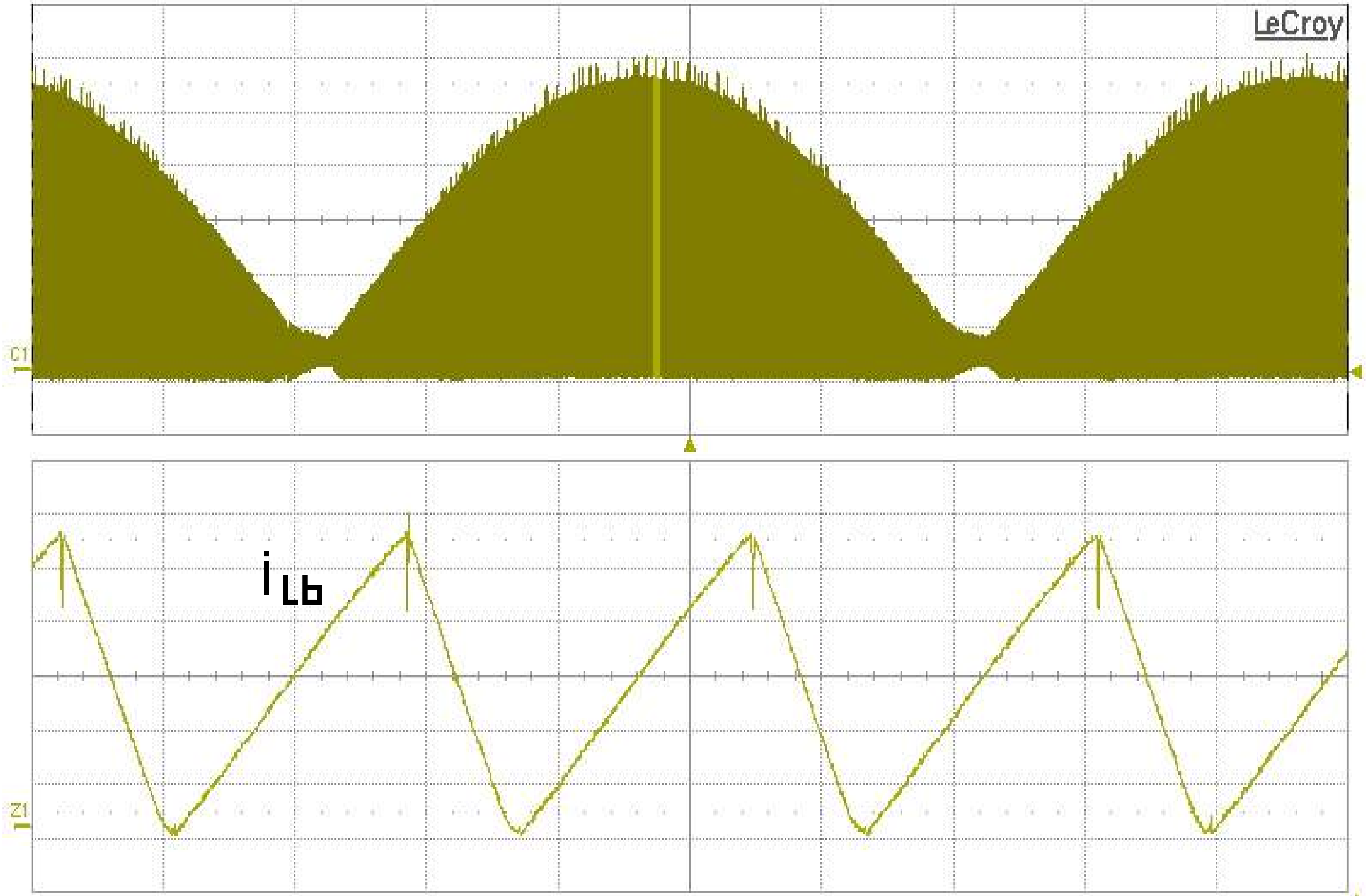


Experimental Performance of Boost PFC Electronic Ballast in terms of AC mains voltage and AC mains current at 220V

Experimental Performance and Results

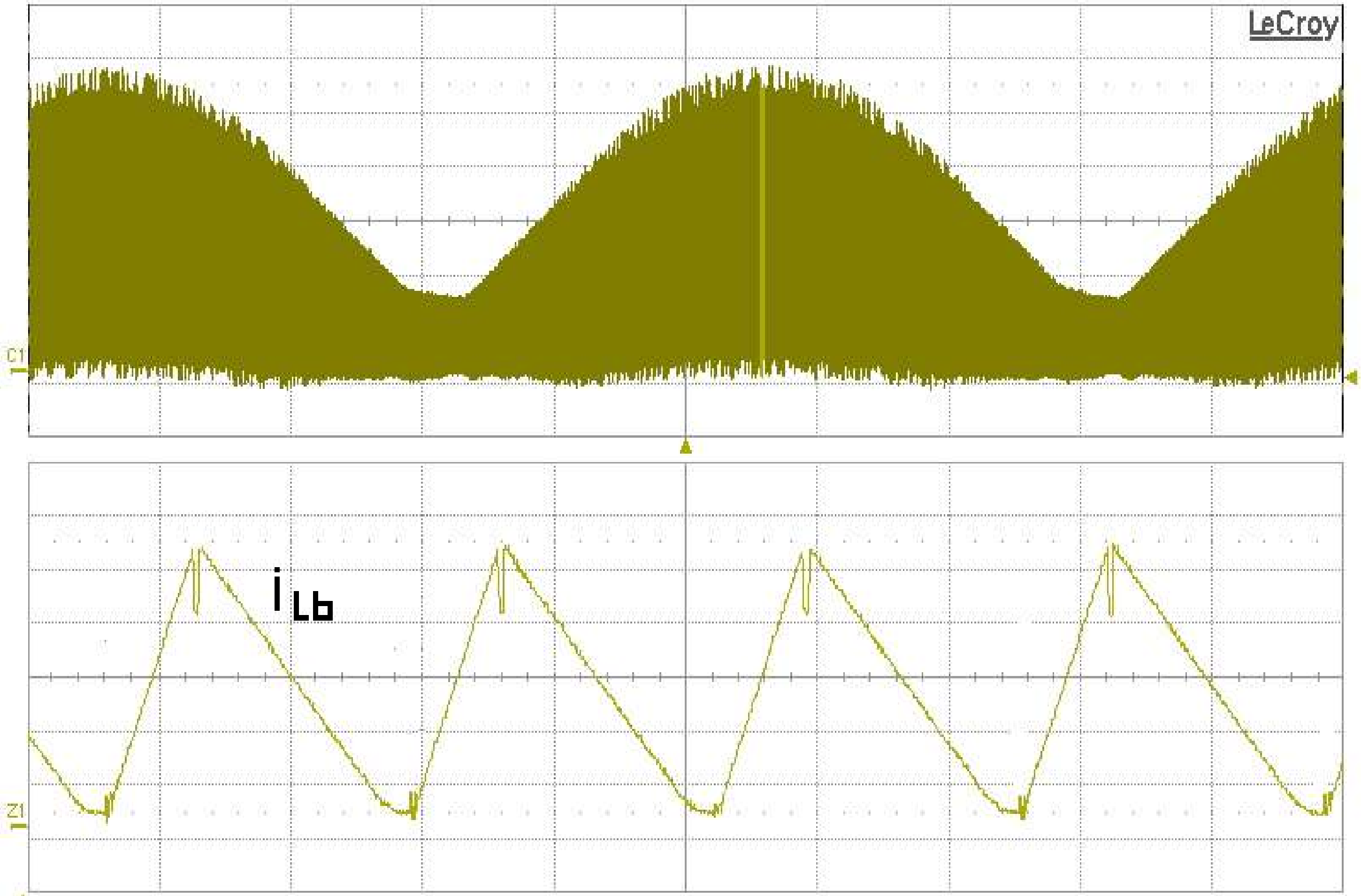
Experimental Performance of Boost PFC Electronic Ballast in terms of AC mains voltage and AC mains current at 270V

Experimental Performance and Results



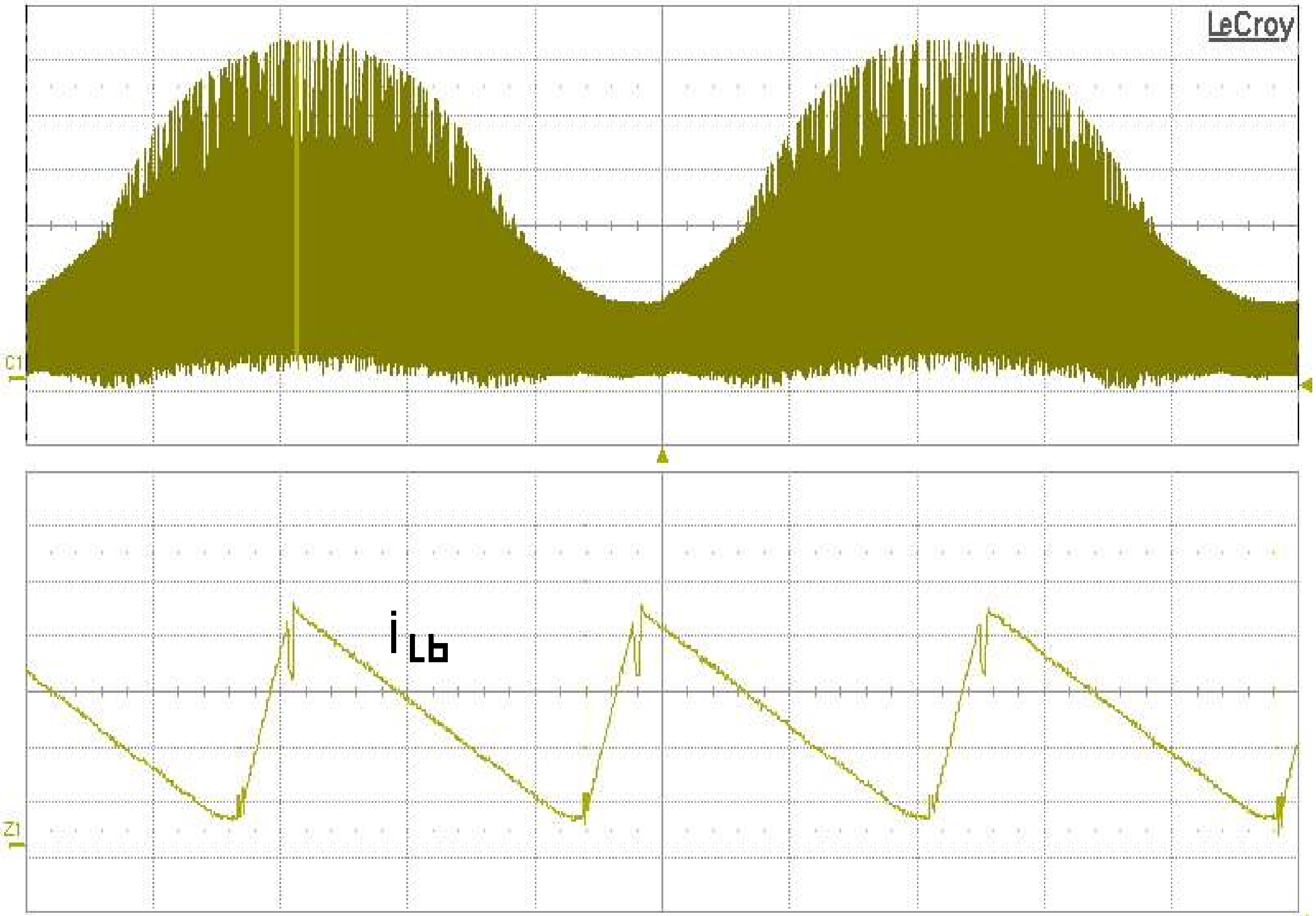
Simulated Performance of Boost PFC Electronic Ballast in terms of inductor current at AC mains voltage of 90V

Experimental Performance and Results



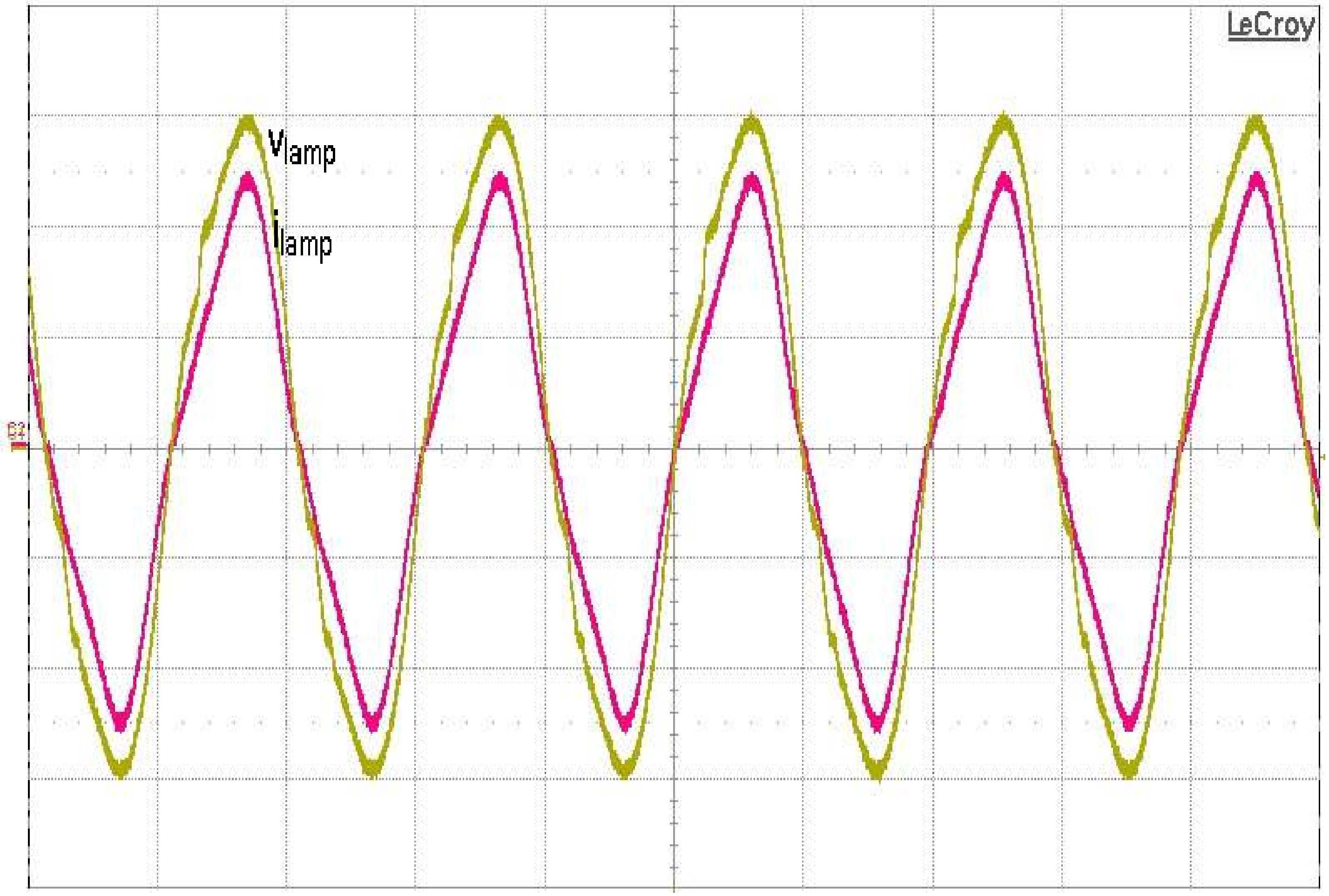
Simulated Performance of Boost PFC Electronic Ballast in terms of inductor current at AC mains voltage of 220V

Experimental Performance and Results



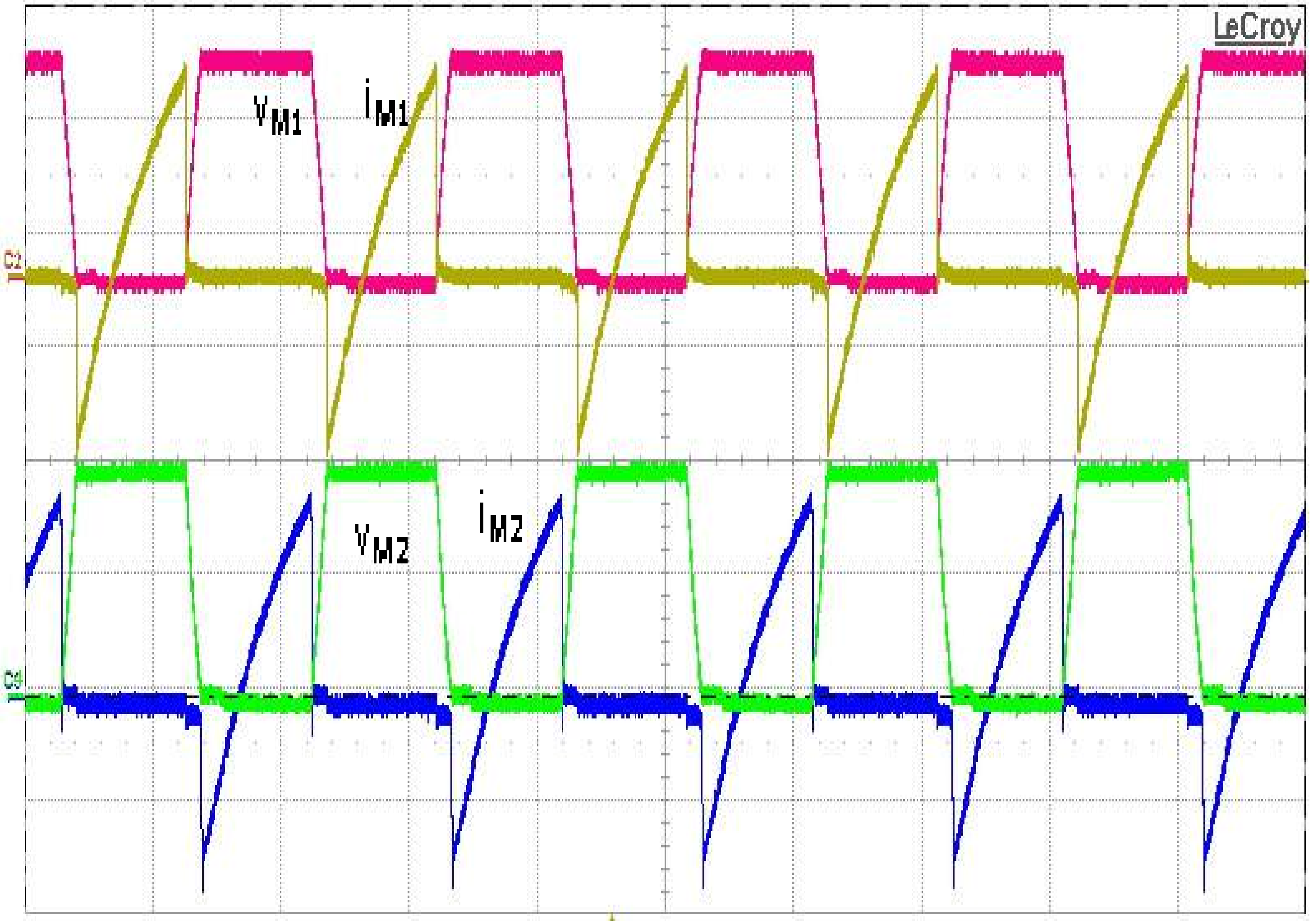
Simulated Performance of Boost PFC Electronic Ballast in terms of inductor current at AC mains voltage of 270V

Experimental Performance and Results



Simulated Performance of Boost PFC Electronic Ballast in terms of lamp voltage and lamp current at AC mains voltage of 220V

Experimental Performance and Results



Simulated Performance of Boost PFC Electronic Ballast in terms of switch voltage and switch current at AC mains voltage of 270V

Conclusion

- BCM Boost PFC electronic ballast improves input power factor to almost unity.
- It has reduced THD of ac mains current under 18% for universal input voltage range (i.e. 90-270 V), which is as per international standard IEC-61000-3-2 (Class C) equipments.
- It achieves the crest factor of input current as 1.4 for the wide variation of AC mains voltage.
- Zero voltage switching (ZVS) reduces the switching losses, hence improves the overall efficiency.

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Power Quality Improvements in High Brightness LED Lighting

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Introduction

Advantages of High Brightness LED lamp over Other Discharge lamp

- High luminous efficacy (lumens/watt),
- Flicker less start,
- Easily dimmable,
- Long life,
- Low maintenance,
- Robust and shock resistance,
- More environmental friendly due to the absence of mercury content.

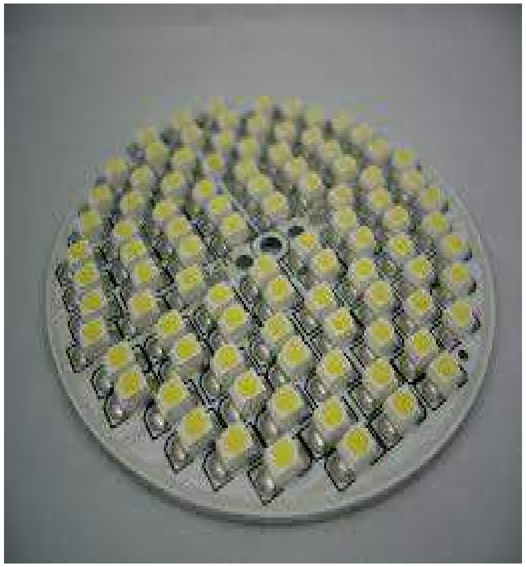
Introduction

Disdvantages of High Brightness LED lamp over Discharge lamp

- Higher cost,
- Larger heat sink requirement, since most of the power is converted into heat,
- Available in 1W, 3W and 5W ratings, hence for higher wattage applications more series-parallel strings need to be connected.

Introduction

LED lamp:



Introduction

Applications:

Car Lighting

Street Lighting

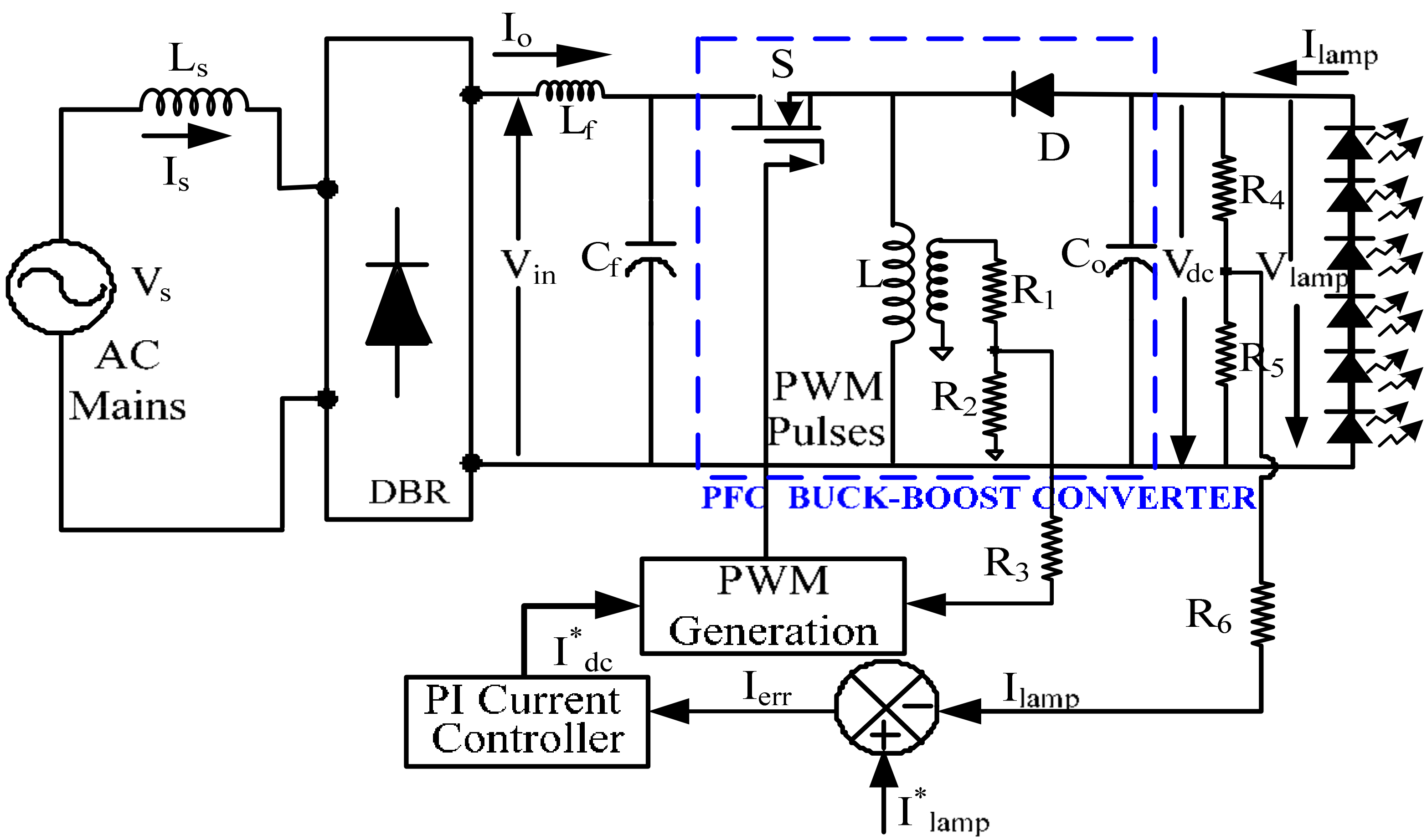
Introduction

Applications:

Domestic Lighting

Commercial Lighting

Buck-Boost PFC LED Lamp Driver



Design of Buck-Boost PFC Converter

The design procedure includes calculations of the component values of PFC buck-boost AC-DC converter is as follows:

The duty cycle of a buck-boost converter operating in continuous conduction mode (CCM) is defined as,

The calculated minimum and maximum duty cycle are 0.1019 and 0.2539 for the input voltages of 270V and 90V respectively.

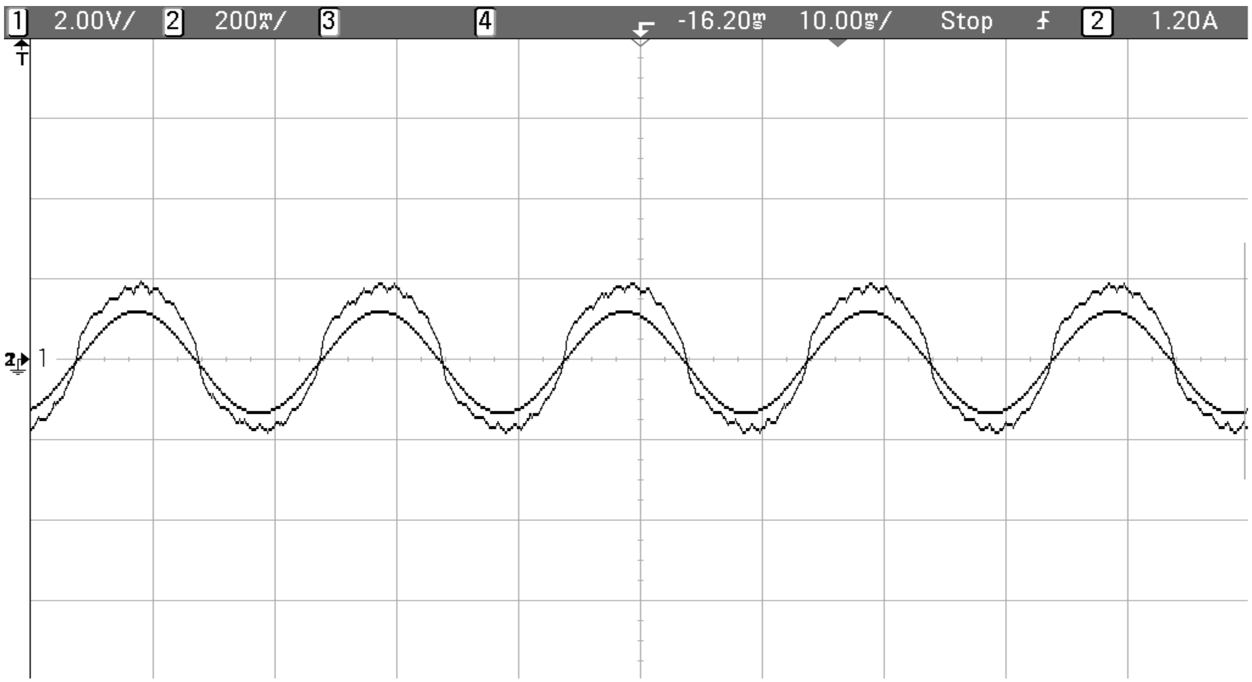
Simulated Performance parameters of Buck-Boost PFC LED Lamp Driver

V_s (V)	I_s (mA)	V_{lamp} (V)	I_{lamp} (mA)	PF	% THD_i	CF
90	158.1	40.78	318.2	0.997	8.80	1.367
130	117.9	41.26	320.1	0.996	13.90	1.382
180	80.20	41.74	323.9	0.9882	16.14	1.374
220	66.81	41.80	324.4	0.9729	18.62	1.376
270	56.48	41.62	322.9	0.9712	19.21	1.389

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver

V_s (V)	I_s (mA)	V_{lamp} (V)	I_{lamp} (mA)	P_o (W)	P_{in} (W)	η (%)	PF	% THD_i	CF
90	170.51	40.553	304.3	12.34	15.27	80.81	0.992	12.24	1.398
130	121.14	40.543	317.7	12.88	15.60	82.56	0.987	15.93	1.384
180	87.55	40.411	319.8	12.92	15.48	83.46	0.982	18.82	1.402
220	70.56	40.265	314.7	12.67	15.19	83.41	0.978	19.96	1.415
270	58.71	40.195	307.8	12.37	14.87	83.18	0.973	20.46	1.428

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of AC mains voltage and AC mains current at 90V

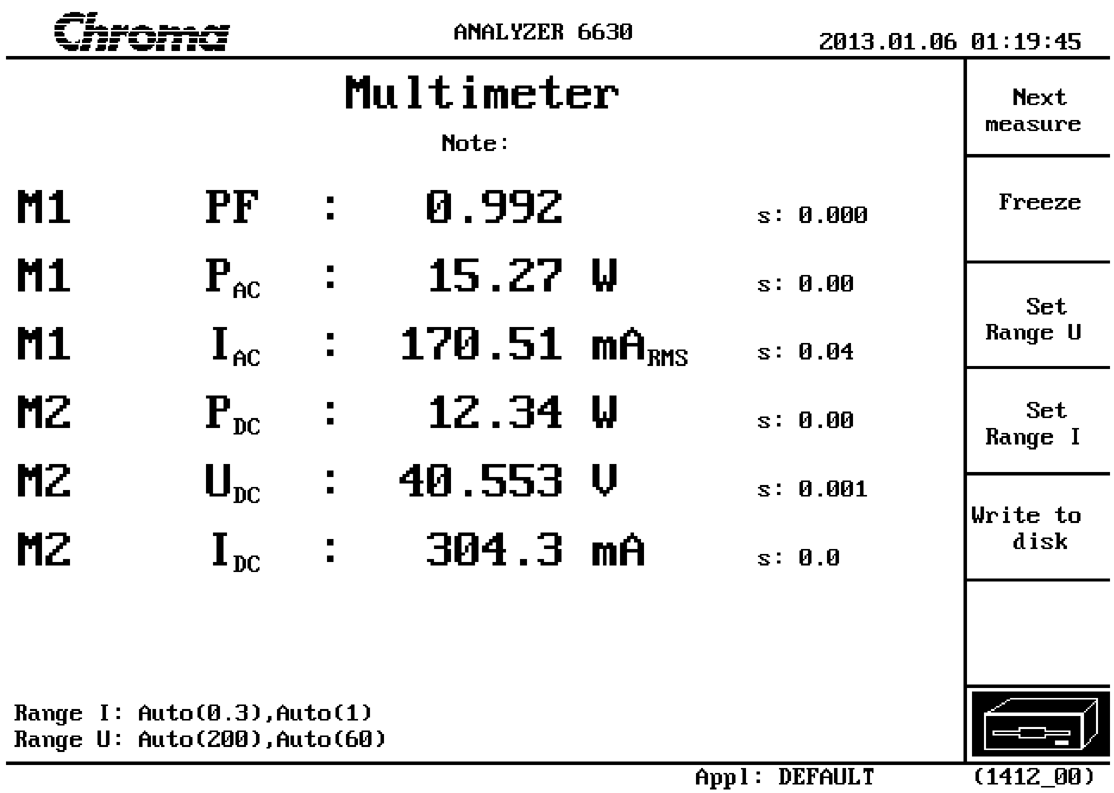
Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver

Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of AC mains voltage and AC mains current at 220V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver

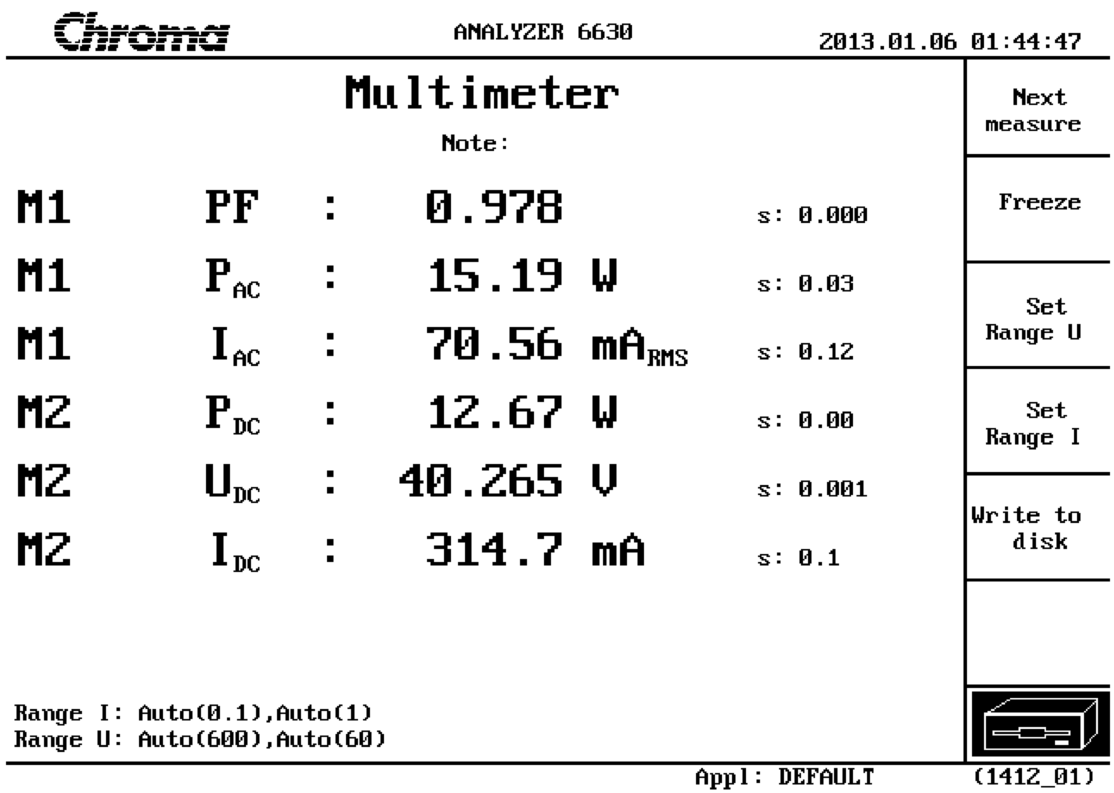
Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of AC mains voltage and AC mains current at 270V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



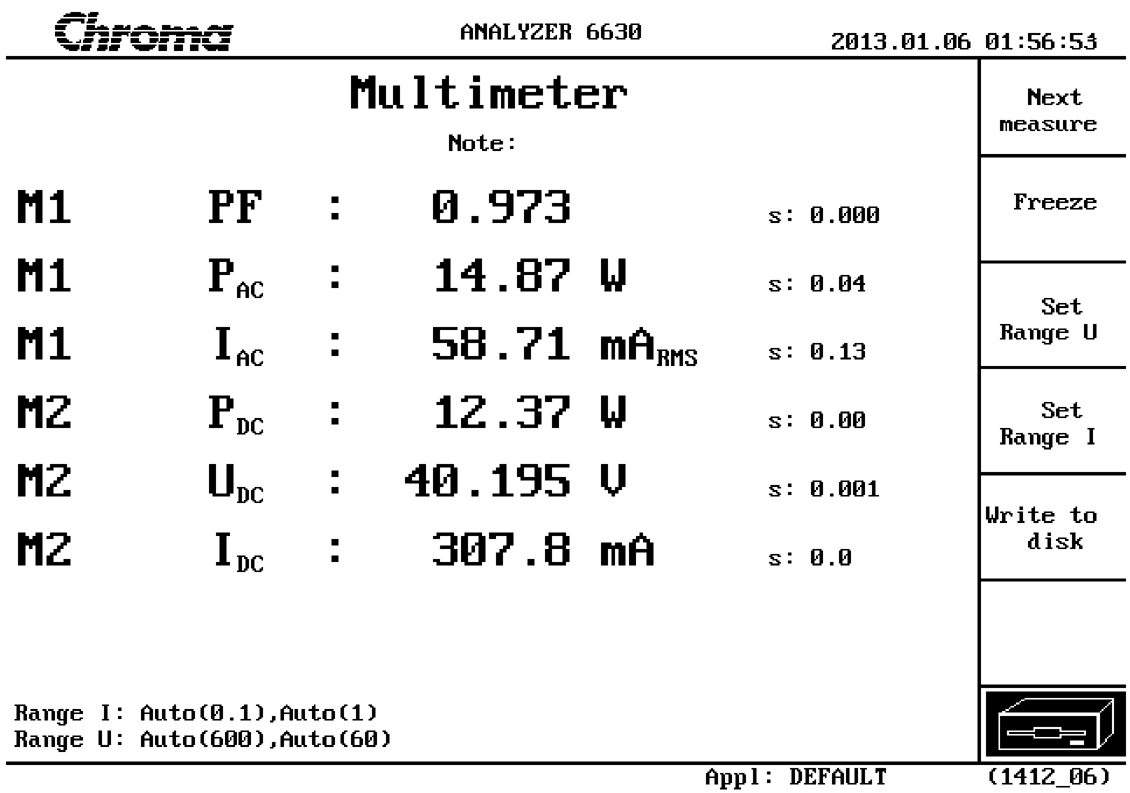
Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of multimeter reading at AC mains voltage 90V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



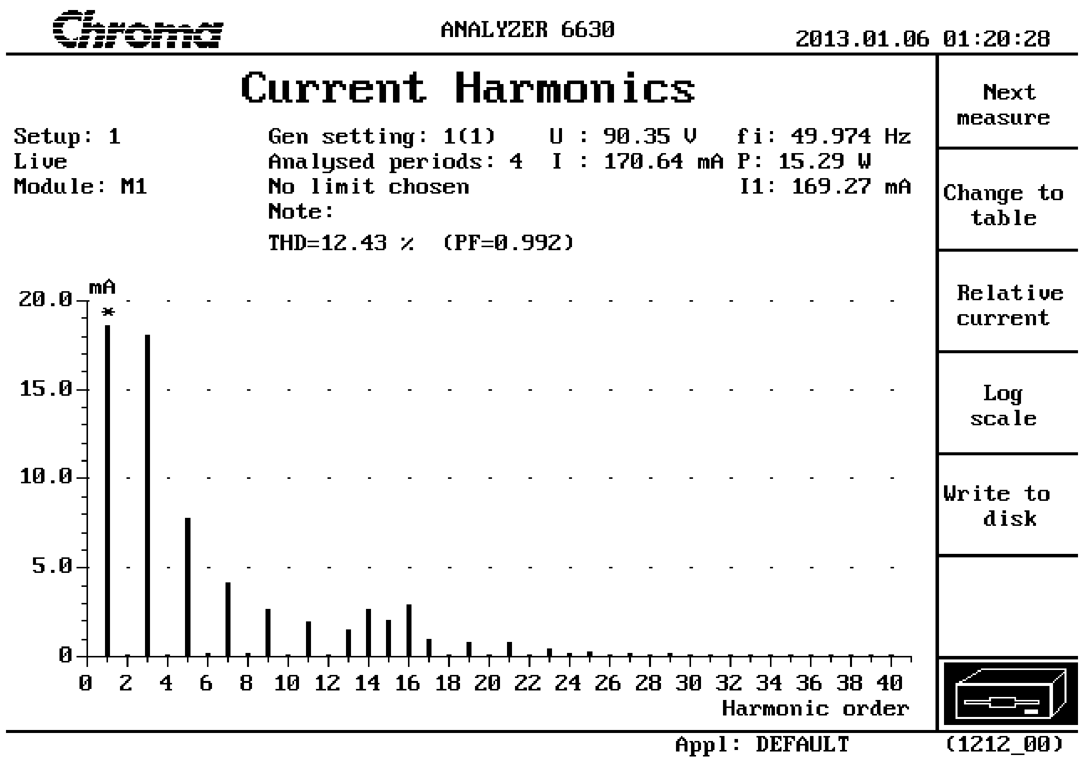
Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of multimeter reading at AC mains voltage 220V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



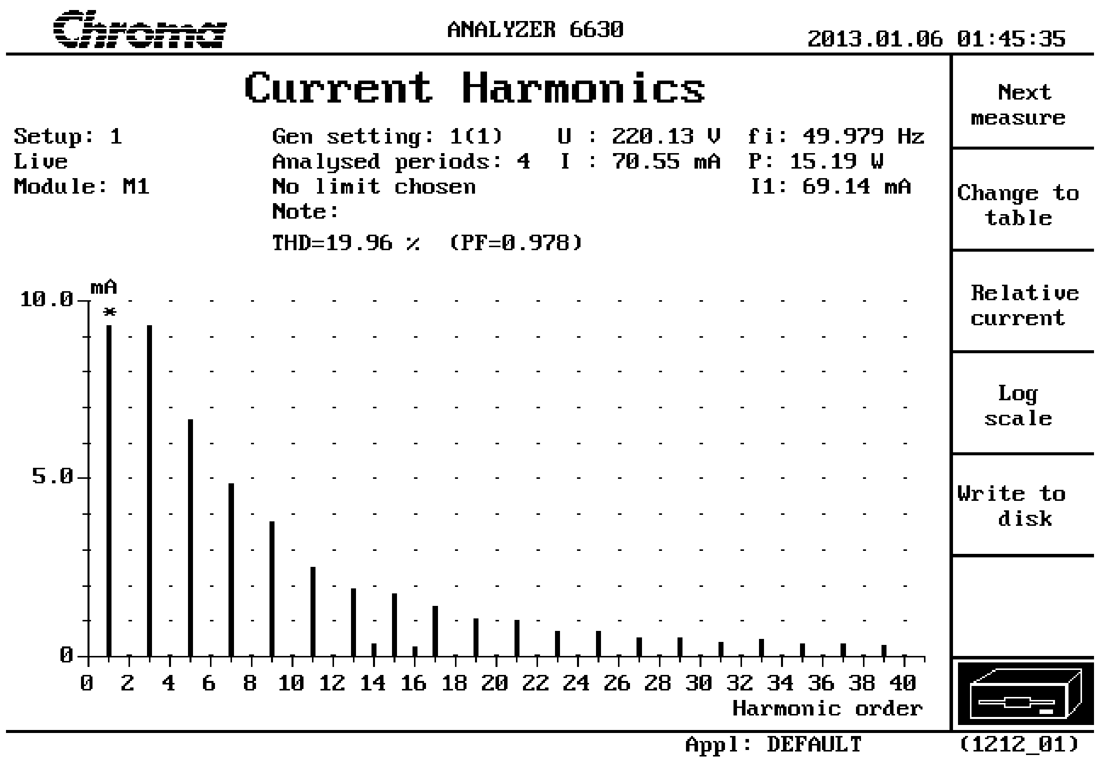
Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of multimeter reading at AC mains voltage 270V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



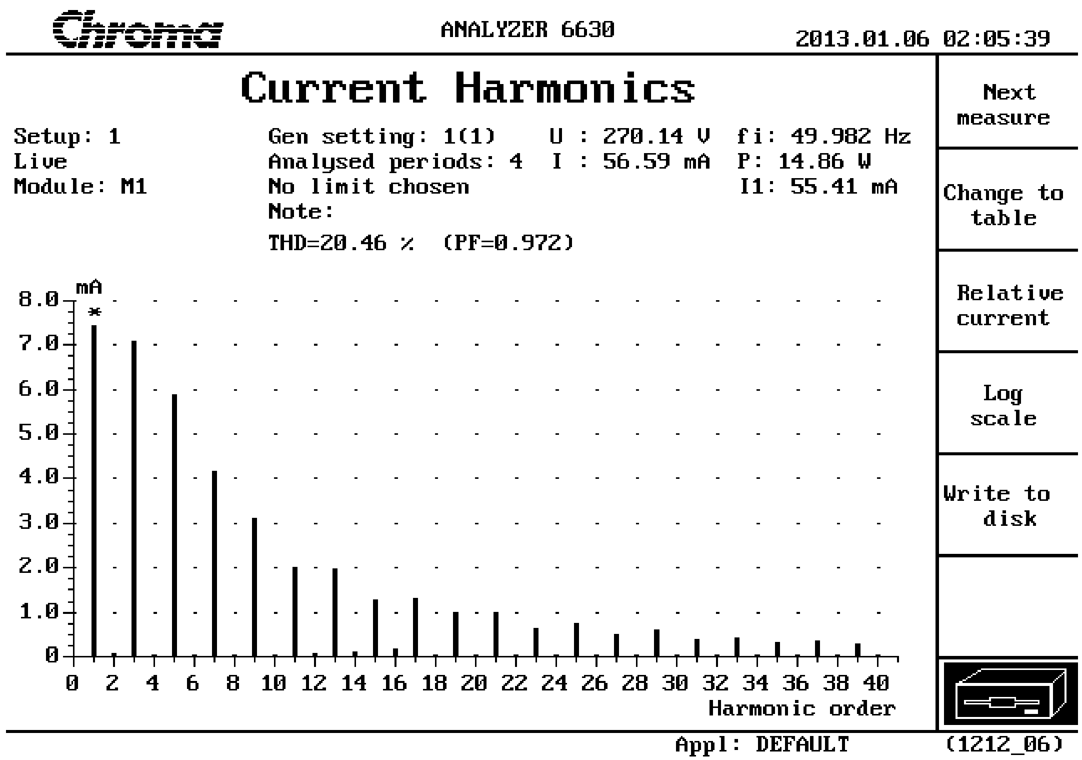
Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of Current Harmonics at AC mains voltage 90V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



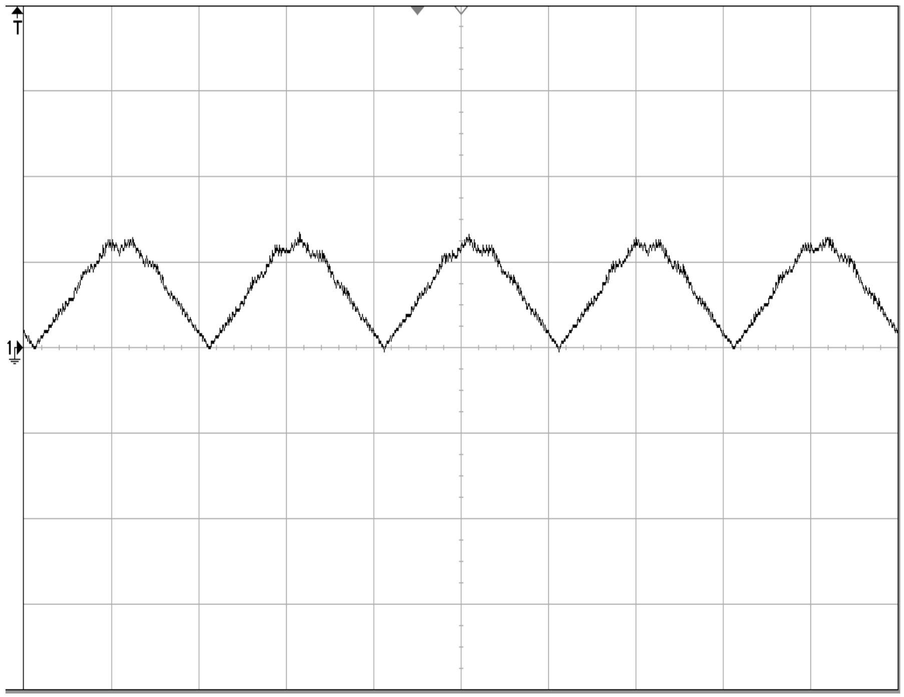
Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of Current Harmonics at AC mains voltage 220V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



Experimental Performance of Buck-Boost PFC LED Lamp Driver in Current Harmonics at AC mains voltage 270V

Experimental Performance Parameters of Buck-Boost PFC LED Lamp Driver



Experimental Performance of Buck-Boost PFC LED Lamp Driver in terms of inductor current at AC mains voltage 220V

Conclusion

- High input power factor has been achieved with universal Input.
- THD of AC mains current is under 20% for universal mains, which is as per international standards IEC-61000-3-2 for class C equipments (i.e. lighting).
- Crest factor of input mains current is obtained close to 1.41, which is of sine waveform.
- Constant lamp voltage and lamp current has been achieved with universal AC mains.

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