Performance Analysis Of High Power PF Corrector By Co-Simulation Using PSIM And Matlab/Simulink

P.A. Kharade, Dr. M.D. Uplane

Abstract: Presently, circuit simulation in power electronics has become ever more demanding in both speed and accuracy. At the same time, as almost every simulator has its own pros and cons, co-simulations are becoming more prevalent. In this paper, an efficient high power AC to DC converter with power factor correction is analyzed based on co-simulation using PSIM and Matlab/Simulink Software. For the performance comparison, firstly a 5KW PFC converter and its control is realized with Boost and Interleaved Boost topology using PSIM software. In second phase, power circuit is realized using PSIM software, and the control circuit is implemented with Matlab/Simulink. Boost and Interleaved Boost topology PF converters are tested and analyzed using both the platforms and results are shown for comparison purposes. In order to regulate the output voltage and to improve input P F, a cascade controller is used, which is structured with a control toolbox in Matlab/Simulink, and validated through co-simulation with Sim-Coupler Module.

Index Terms: High power PFC converter, Boost, Interleaved Boost topology, PSIM, Matlab, Sim-Coupler Module, Co-Simulation

1 INTRODUCTION

In the present time, a large portion of the electronic devices uses DC power. Transformation of AC to DC is generally utilized in numerous applications, for example, Switched Mode Power Supplies, battery chargers, power supplies to communication systems, washing machines, air-conditioners, servers, and so on. Because of the presence of diodes, traditional rectifiers followed by large size capacitors for energy storage, goes about as a nonlinear burden to the power line, and the power factor of such circuits is exceptionally low, even lower than 0.7 [1]. Ordinary rectifiers have unpredictable and non-sinusoidal line currents infusing enormous measure of harmonic flow in line and polluting the power supplies. These low order line current harmonics distorts the voltage at the point of common coupling. Notwithstanding voltage mutilations, it likewise expands current evaluations of line, because of enormous flows warming of the types of the equipment, low efficiency, large size line filtering requirement are a portion of the downsides. Therefore to keep away from every one of these results and to improve power quality according to the universal IEC Standards, an appropriate power factor corrector must be utilized [5]. In this paper, two fundamental converter topologies, boost, and interleaved boost are investigated and compared for improving PF, THD and efficiency in single-phase power supply. The two topologies are operated at switching frequency 100 KHz with 5KW output power and 400V output DC voltage to give THDi under 5%, efficiency more prominent than 98% and PF near to unity [6],[11]. The number of active and passive circuits was utilized by numerous analysts/researchers to address this issue [2], [3].

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The least complex methodology is to utilize passive PFCs, which improves power factor to some degree satisfactory level. Out of the solutions available in literature, passive PFCs are effective for low power applications most noteworthy up-to 200W. Hindrances/drawbacks of passive PFCs are huge in size, critical reliance of average output voltage on load change, and are all the more exorbitant/costly. To resolve/determine this issue active/dynamic PFCs were recommended by many researchers [4], [12], [14]. In general, a power electronics system comprises of the power circuit and a suitable control system. For the modeling of electronic circuits, a variety of software packages such as a PSpice, PSIM and SABER, etc. are available. However, these packages are not appropriate for demonstrating complex controllers. On the other hand, Matlab/Simulink is a very powerful program for control framework configuration however, isn't appropriate for precise modeling of power electronics circuit behavior. Along these lines, to simulate the complete/entire power electronic system, the simulation environments should be interfaced together to obtain simulation results as close as possible to the actual system behavior, in this manner empowering the designer to quickly identify and correct undesirable interactions between the power circuit and the control system, resulting more accurate results in a shorter settling time. The co-simulation tool is a very important tendency in power electronics simulation that allows relying on the merits of two powerful environments in a complementary way to improve the efficiency of a stand-alone PFC converter system. Simulink as a powerful environment for system modeling- simulation and PSIM as a widely used software in many areas, and it is characterized by a friendly simulation environment and powerful waveform processing [21]. The rest of the paper is organized as follows: Section 2 presents a circuit parameters and its design, and covers theory of boost dc-dc converter of the PFC system. Section 3 discusses on PSIM simulation and Co-Simulation in term of their structures and improvements. Simulation work including the results is discussed in Section 4. Finally, a simple conclusion is given in Section 5.

2 CIRCUIT PARAMETERS AND ITS DESIGN

2.1 PFC Converter:

The block diagram of the PFC converter is shown in Fig.1. Power converter uses a diode rectifier followed by a bulk capacitor to convert AC voltage to DC voltage, followed by a boost converter that acts as an active PF corrector. For controlling the output voltage and correcting the input power factor, the DC output voltage, input AC current, and input ac voltage are given as a feedback signals to the controller. The controller has its own reference levels and according to the error it manipulates the actuating signals and provides the gate signals to the active device MOSFETs to control the output voltage and input power factor.

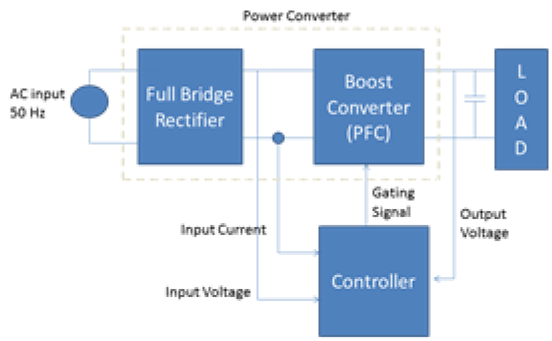

Fig.1 Block Diagram of PFC Converter

The key circuit parameters and specifications:
Vin(t) = 180V～265VACrms
Vo = 400VDC ± 5%
Po = 5000W, Fs = 100KHz
Lin = 520μH, Co = 1410μF

where Vin(t) is the Universal AC input-rms voltage, Vo is the regulated output DC voltage, Po is the desired output power, Fs is the switching frequency of the active devices, Lin is the boost inductor, Co is the output capacitor.

2.2 Controller :

CONTROL STRATEGY FOR PROPOSED BOOST TOPOLOGY: The proposed boost PFC converter embraces/adopts average current control, and use the voltage control loop and current control loop, as shown in Fig.2. There are different current mode control techniques like variable frequency Peak current control, Hysteresis control, and average current control. Out of which average current control shows better outcomes. It is more desired than other control methodologies since line current can be approximated by the average of current per switching cycle [7],[14]. For regulation of output voltage and simultaneously correction of power factor here, cascade control is utilized. The utmost aim of the controller is to force the inductor current, i.e. input current of the boost converter to follow accurately a given reference current. Cascade control comprises of the outer loop, and a inner loop. Outer voltage loop keeps up the output voltage steady and inner current loop plays the role for power factor correction by continuously comparing input i.e., inductor current IL with reference current Iref. By the use of PI controller along with PWM technique, gate signals are generated, which actually controls the duty cycle of the active devices. The design of boost inductor is important/ crucial for PFC converter; inductor is designed at a minimum input voltage of the circuit and for minimum ripple current in the input. The output capacitor for the converter is selected as per the requirement of hold up time i.e. energy storage capacity of it, lower and higher limits of output voltage, and the load power [8], [9],[10].

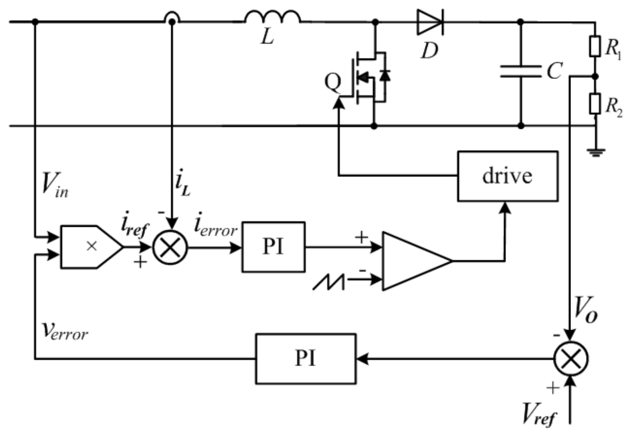

Fig.2: Average current control Strategy for Boost Converter.

3 PSIM SIMULATION:

Table : I PSIM Simulation Results: Boost L = 520uH, Co =1410uF

$V_{in\ AC}$ V_{rms}	$I_{in\ AC}$ (A)	P_{in} (W)	R_L (Ω)	V_{out} DC (V)	I_{out} DC (A)	P_{out} (W)	P.F.	THD %	Effi %
230	32.43	5014	32	397.89	12.4	4965	0.9956	8.08	99.03
230	25.61	4019	40	399.2	9.98	3985	0.9966	8.01	99.15
230	20.33	3225	50	400.12	8	3191	0.9965	8.19	98.93
230	16.81	2691	60	400.33	6.67	2661	0.9961	8.32	98.87
230	12.56	2021	80	400.39	5	1998	0.9949	8.44	98.86
230	9.97	1616	100	400.44	4	1597	0.9935	8.8	98.82
230	7.42	1228	133	400.37	3	1201	0.9912	9.17	97.8
230	4.92	822	200	400.00	2	798	0.9862	10.3	97.1
230	3.3	561	300	399.3	1.33	530	0.9791	12.3	94.46
230	2.47	434	400	397.32	0.99	393	0.9735	15.2	90.58

To assess /evaluate and compare the performance of the boost and IBC type PFC converters, 5000W models are simulated using PSIM software and with PI current control method [17], [18].PFC by Average Current Control using simple Boost Topology

3.1. SIMULATION RESULTS:

PSIM Simulation Model of Boost Converter is shown in Fig.3.The AC input voltage-current waveforms and DC output voltage-current waveforms of boost converter are shown in Fig. 4. And the waveforms of Fast Fourier Transform (FFT) of ripple current in a boost converter are shown in Fig. 5. The rectified AC input is boosted using a boost converter. For closed-loop operation in real-time implementation input voltage, inductor current and output voltage will be sensed using current transformer and potential transformer. The converters are operated/ worked at 100 kHz switching frequency, 5000W output power with the reference voltage of 400V, and the load resistor RL is varied from 400ohms to 32 ohms by keeping the AC input voltage 230Vrms constant. Simulation results of the Boost topology with PSIM are shown in Table I.

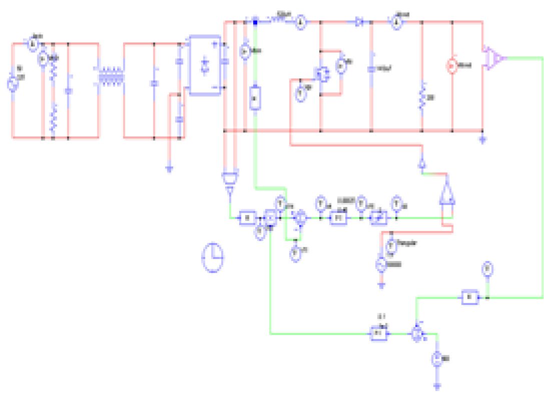

Fig.3: *PSIM Simulation Model of Boost Converter.*

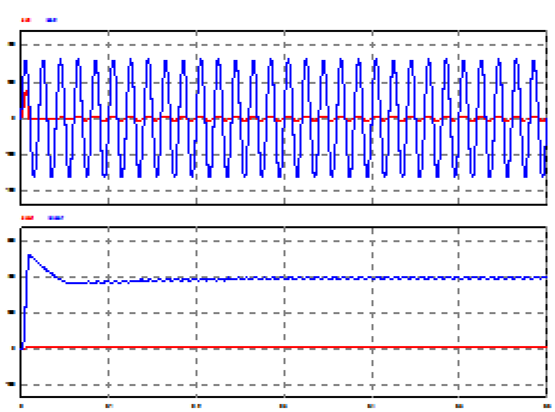

Fig.4. *Input-Output Waveforms of Boost Converter*

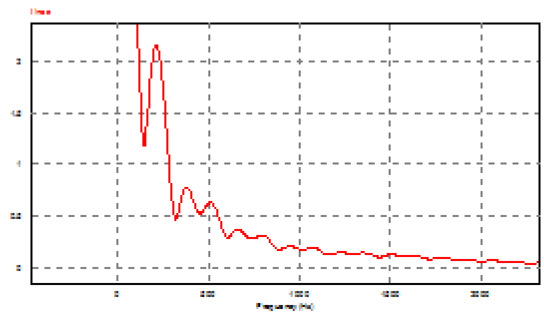

Fig. 5. *FFT Analysis of ripple current in Boost Converter*

PFC by Average Current Control using Interleaved Boost Topology:

In ordinary boost topology, the volume of inductor is enormous and a ripple current cancellation is not possible. These limitations can be overpowered by the usage of interleaved boost converter (IBC). IBC contains of two boost converters connected in parallel, operating at 180° phase shift. The input current is the addition of two inductor currents. As the ripple currents flowing in two inductors are out of phase, they tend to cancel each other, and so total harmonics in the input side is reduced. At 50% duty cycle, the cancellation of ripple current is the most ideal [15]. Fig.6 shows the PSIM simulation model of the IBC converter. The results of simulation using PSIM are given in Table II. The AC input voltage-current waveforms and DC output voltage-current waveforms of interleaved boost converter are shown in Fig.7. And the waveforms of Fast Fourier Transform (FFT) of ripple current in a boost converter are shown in Fig. 8. The reduction in THD, and improvement in power factor, and improvement in overall efficiency is shown in Fig.9a, Fig 9b and Fig. 9c respectively.

Table : II PSIM Simulation Results: IBC Interleaved Boost L1 =L2= 520uH, Co = 1410uF

V_{inAC} V_{rms}	$I_{in\,AC}$ (A)	P_{in} (W)	R_L (Ω)	$V_{out\,DC}$ (V)	$I_{out\,DC}$ (A)	P_{out} (W)	P.F.	THD %	Effi %
230	31.57	5064	32	397.16	12.4	5003	0.9937	1.87	98.79
230	25.25	4052	40	398.33	9.95	4000	0.997	2.12	98.72
230	20.27	3239	50	399	7.98	3199	0.9986	2.48	98.74
230	16.93	2682	60	398.35	6.66	2664	0.9993	2.76	99.34
230	12.77	2032	80	399.41	4.99	1996	0.9993	3.46	98.23
230	10.18	1630	100	399.2	3.99	1593	0.9984	4.62	97.72
230	7.7	1233	133	398.21	2.99	1192	0.9965	6.12	96.63
230	5.25	845	200	393.68	1.97	775	0.9917	9.97	91.75
230	3.52	568	300	398.66	1.32	530	0.9815	11.9	93.05
230	2.9	427	400	400	1	399	0.9812	16.3	93.5

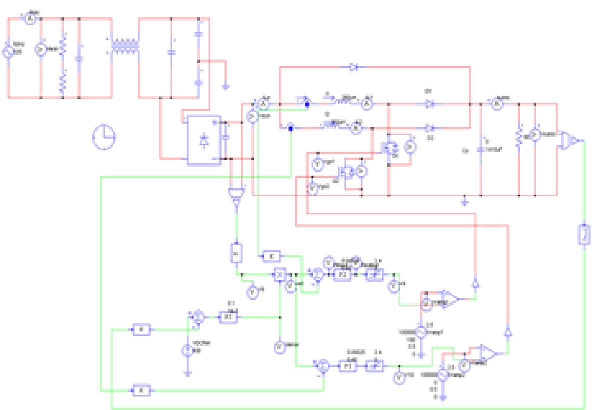

***Fig.6**. PSIM Simulation Model of IBC Converter.*

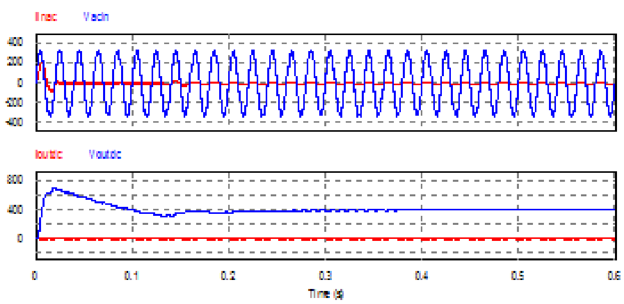

***Fig. 7**. Input-output waveforms of IBC Converter*

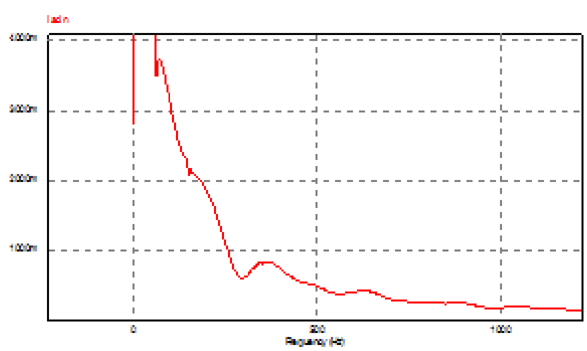

***Fig.8**. FFT Analysis of ripple current in IBC Converter*

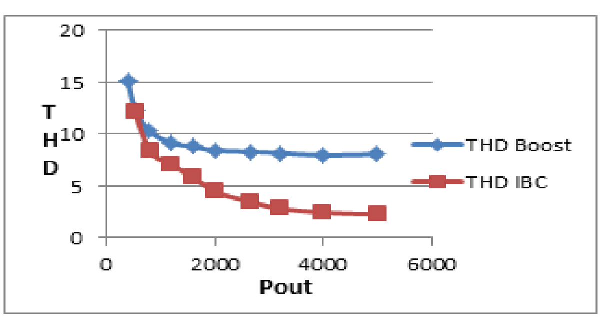

***Fig.9a**. THD versus output power for Boost and IBC (PSIM Simulation)*

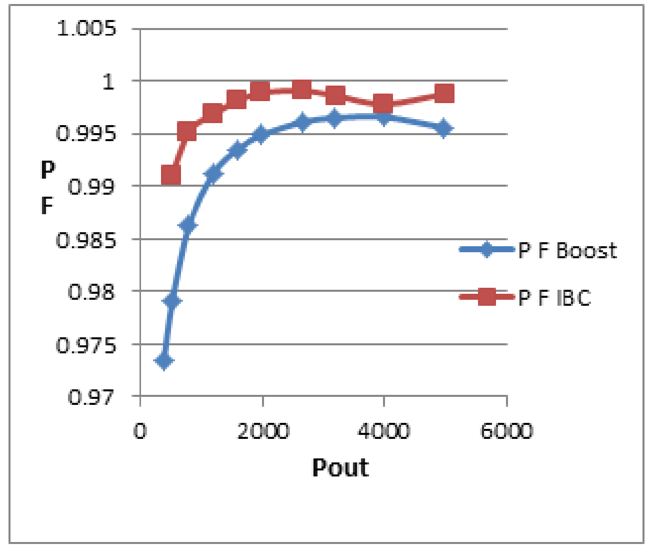

***Fig.9b.** PF versus output power for Boost and IBC (PSIM Simulation)*

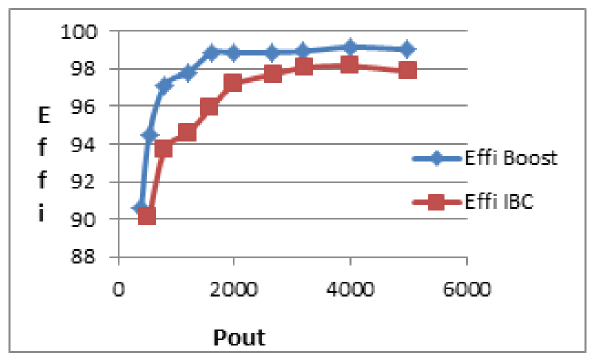

***Fig.9c.** Efficiency versus output power for Boost and IBC (PSIM Simulation)*

4 CO-SIMULATION USING PSIM AND Matlab/Simulink :

Here, a new additional model of the PSIM software called SimCoupler is used, which permits the link between PSIM and Matlab/Simulink [15]. This is the simplest module to use and gives a quick simulation and displays waveforms in both PSIM and Matlab [19].

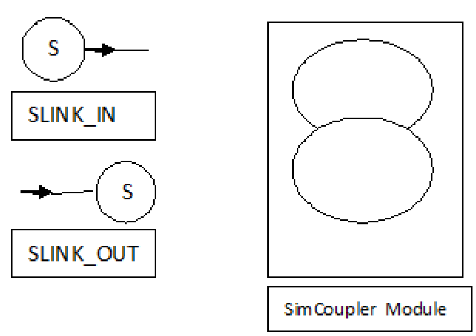

***Fig. 10** SimCoupler Model Block.*

To accomplish /achieve this co-simulation, SimCoupler has three modules as shown in Fig .10. SimCoupler model block, SLINK_IN, and SLINK_OUT. SLINK_IN is input port gets signals from Simulink, SLINK_OUT is output port yields/gives signals to Simulink and the SimCoupler model block, interconnects with the other part through input and output port. Fig.11. Shows the co-simulation of the boost converter. So we are using the capabilities of the two powerful soft-wares in a complementary way [20]. Observations and results of the co-simulations of both the converters are compiled in Table III and Table IV.

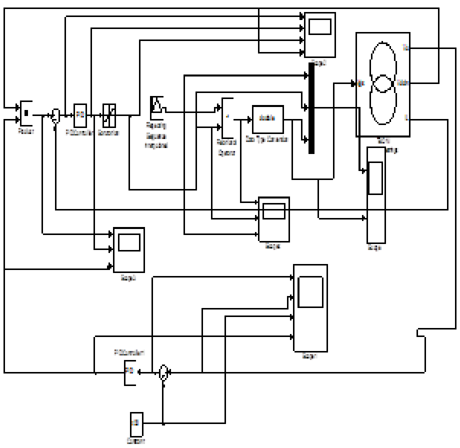

Fig. 11a: *Control Circuit for Co-simulation of Boost with PSIM and Matlab.*

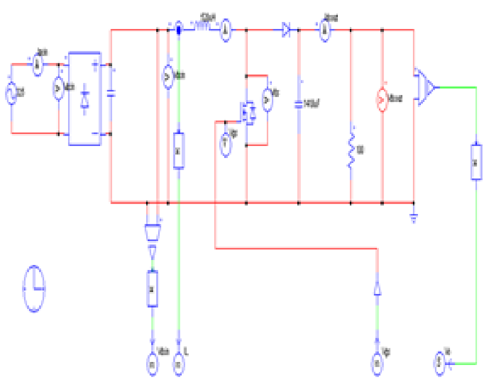

Fig. 11b: *Power circuit for Co-simulation of Boost with PSIM.*

Table : III Co- Simulation Results: Boost
L = 520uH, Co = 1410uF

V_{inAC} V_{rms}	$I_{in\ AC}$ (A)	P_{in} (W)	R_L (Ω)	$V_{out\ DC}$ (V)	$I_{out\ DC}$ (A)	P_{out} (W)	P.F.	THD %	Effi %
230	29.69	4996	32	399.06	12.5	4892	0.9922	9	98.05
230	22.68	3768	40	390.91	9.77	3754	0.9915	9.2	99.61
230	20.12	3219	50	399.91	7.99	3166	0.9914	9.3	98.36
230	16.26	2705	60	401.17	6.69	2667	0.9908	9.58	98.59
230	12.69	2033	80	400.68	5	1994	0.9894	10.5	98.07
230	9.4	1605	100	401.27	3.99	1589	0.9875	11.5	97.65
230	6.99	1237	133	401.49	3.01	1206	0.984	13.4	97.52
230	5.19	828	200	401.25	2	803	0.9748	18.2	96.98
230	3.33	560	300	406.4	1.35	551	0.9552	26.7	98.93
230	1.84	425	400	410.1	1.02	411	0.9332	35.4	98.37

The co-simulation of Interleaved Boost Converter (IBC) with PSIM and Matlab/Simulink by the use of SimCoupler block is as shown in Fig.12a and Fig.12b. The results of co-simulation are given in Table 4. The reduction in THD, improvement in power factor, and improvement in the overall efficiency of the IBC converter is given Fig.13a, Fig.13b and Fig.13c, respectively.

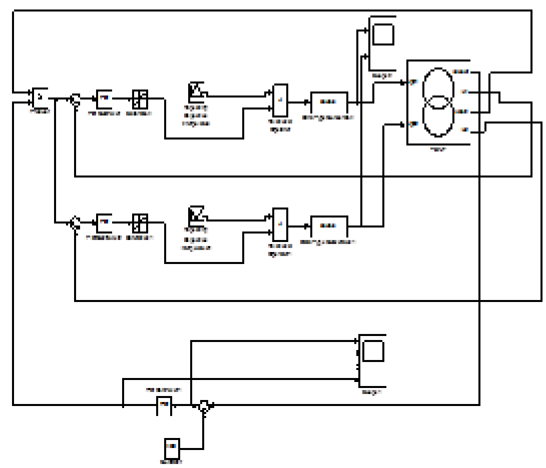

Fig. 12a: *Control Circuit for Co-simulation of IBC with PSIM and Matlab.*

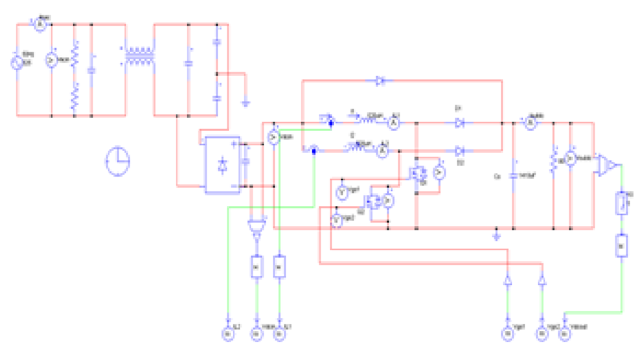

Fig.12b. *Power circuit for Co-simulation of Interleaved Boost with PSIM.*

Table No.IV Co- Simulation Results: IBC Interleaved Boost
L1 =L2= 520uH, Co = 1410uF

V_{inAC} V_{rms}	$I_{in\ AC}$ (A)	P_{in} (W)	R_L (Ω)	$V_{out\ DC}$ (V)	$I_{out\ DC}$ (A)	P_{out} (W)	P.F.	THD %	Effi %
230	31.21	5048	32	396.68	12.4	4985	0.9943	3.67	99.76
230	25.14	4031	40	398.32	9.97	4008	0.9968	4	99.43
230	20.2	3238	50	400.6	8.02	3222	0.9982	4.25	99.52
230	16.82	2694	60	400.69	6.67	2681	0.9987	4.4	99.52
230	12.61	2030	80	400.83	5.02	2020	0.9988	4.76	99.46
230	10.03	1616	100	400.36	4	1602	0.9982	5.05	99.09
230	7.55	1218	133	400.22	3	1203	0.9968	6.17	98.71
230	5.49	852	200	399.98	1.99	799	0.9952	8.38	97.69
230	3.97	586	300	398.33	1.33	528	0.9911	12.1	95.07
230	2.96	447	400	399.9	0.999	403	0.9867	19.9	93.58

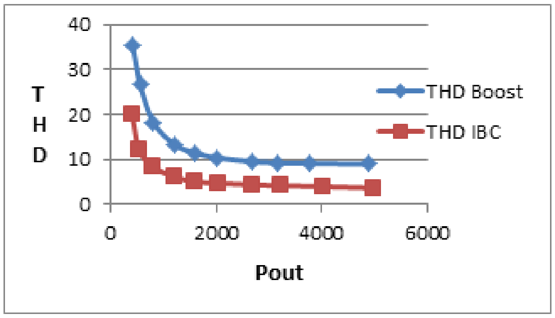

Fig.13a. *THD versus output power for Boost and IBC (PSIM-Matlab Co-Simulation)*

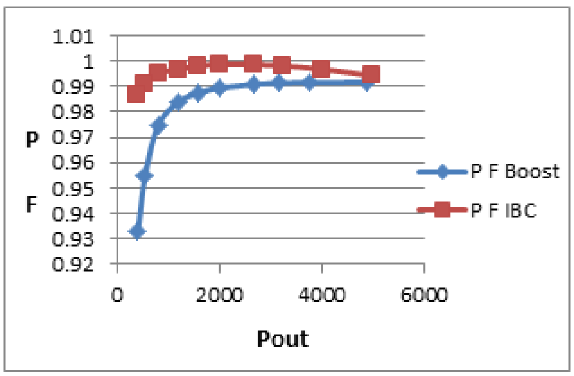

Fig.13b. *PF versus output power for Boost and IBC (PSIM-Matlab Co-Simulation)*

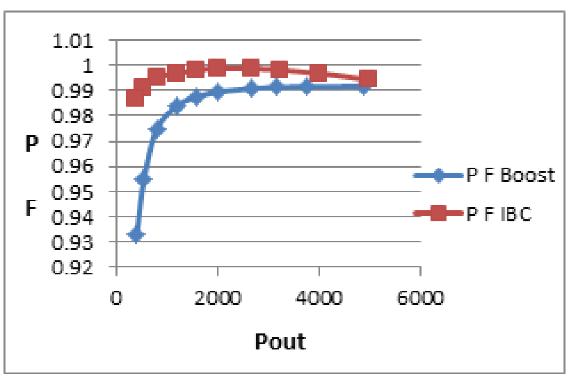

Fig.13c. *Efficiency versus output power for Boost and IBC (PSIM-Matlab Co-Simulation)*

5 CONCLUSION

In this paper, high power 5KW PFC converters with Boost and Interleaved Boost topology are modeled using PSIM and Matlab/Simulink. Two platforms are interfaced using SimCoupler Module. The performance of the converter by purely PSIM simulation and by co-simulation, using PSIM and Matlab/Simulink are examined to demonstrate their advantages and disadvantages. From co-simulation it is clear that the power circuit can be easily simulated in a PSIM environment, whereas Matlab/Simulink is very much suitable for Controller implementation. It is observed that, compared to boost topology, THD in interleaved boost topology converter is less and acceptable as per IEC-61000-3-2 standards. Even though the implementation of the controller using Matlab/Simulink is convenient, but co-simulation takes more time to settle down the output voltage. By analyzing the results, we can conclude that the IBC topology gives PF nearer to unity with a reduction in THD.

6 ACKNOWLEDGMENT

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