Comparative Analysis of Boost and Buck-Boost Derived Topologies Used As Power Factor Correction

T. Rajesh Reddy[1], V. Ananthalakshmi[2]

[1](PG *Student Department of Electrical & Electronics Engineering, G.Pullareddy Engineering College, Andhrapradesh, India*
[2](*Assistant professor, Department of Electrical & Electronics Engineering, G.Pullareddy Engineering College, Andhrapradesh, India*

ABSTRACT
AC/DC converters are extensively used in various applications. The electronics equipment uses as input stage a rectifier with capacitor as a filter. A major problem associated with these loads is the harmonic currents injected into the power supply and low power factor. The undesirable effects of harmonics distortion and low power factor are well documented [l]. Therefore, it is highly desirable to include power factor correction schemes in the electronics equipment. Boost converter in continuous conduction mode using the multiplier approach is commonly used as a power factor correction topology due to its excellent performance in medium power. Recently power factor correction topologies derived from Buck-Boost converter have been proposed, mainly because they emulate a natural resistor when operating in discontinuous conduction mode, using a single control loop. Topologies derived from Buck-Boost converters, are an attractive solution in power factor correction applications in relative low power range. This paper presents a comparative analysis between Boost converter in continuous conduction mode and Sepic and Cuk converters in discontinuous conduction mode in order to study their performance in terms of PF, THD Efficiency, semiconductors stress, volume, etc.

I. INTRODUCTION

In order to obtain values of power factor (PP) close to unity, total harmonic distortion (THD) lower than 10 %, to reduce the size of filtering devices and to accomplish energy saving, active filters have been developed. A circuit performing this function is often called "resistor emulador" (RE) [l]. Boost converter using a multiplier control technique approach [2] operating in continuous conduction mode (CCM), is the most commonly used topology for power factor correction (PFC), due to it is excellent results in low and medium power applications. In recent years, some topologies derived from Buck-Boost converters working in discontinuous conduction mode (DCM) have been developed **[3, 4].** In this operation mode the input current is proportional to the input voltage, which means that they emulate a resistive load requering a single voltage loop. On the other hand, as a consequence of the DCM, these topologies present higher semiconductor stress and an input ripple, besides the extra magnetic component required in this solution unlike to the Boost topology. Therefore, a comparative analysis between Boost (CCM) and derived from Buck-Boost topologies (DCM) could be interesting for PF applications in low power range (< 300 watts) in order to evaluate efficiency, cost, PF, THD and volume topics. Finally, experimental results are presented to assess the theoretical comparative analysis.

II. DC/DC CONVERTERS FOR POWER FACTOR CORRECTION APPLICATIONS

The Boost topology (Fig. 1) is a suitable alternative for PFC in medium power applications **[SI.** However, it is interesting to know its operation in relative low power cases. Advantages and disadvantages of this topology are well known; the most relevant one can be summarized as follows: The not pulsating input current reduces the EM1 requirements. The inductor location d e s easier to implement the current mode control. Isolation cannot be easily implemented. Difficult to include short circuit and in-rush current protection. An experimental prototype of a Boost converter working with peak current control was implemented. The design specifications are: switching frequency f, = 100 KHz, output voltage VO=240V**,** output power Po=50 watts and input voltage **V**in **=** 120Vrms, the input voltage and current waveforms under full load conditions are shown in fig. 2. The results obtained are: PF = 96 % and THD = 4 %.

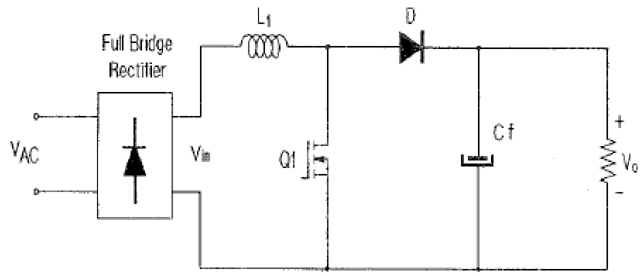


Fig. I **Boost** converter

On the other hand, the Sepic and Cuk topologies working in
DCM (see figs. 3a y b), with a single voltage-follower control [3,4], perform as a natural emulator resistor. Under this situation, the input current is proportional to the input voltage, which means that if the input voltage is a rectified sinusoidal waveform, then the input current will follow this reference. In these topologies, it is important to guarantee the DCM in all the operation range. The study of the boundaries between both conduction modes can be easily obtained from reference ***[6].*** Fig. 4 shows the maximum duty cycle for DCM as function of the conversion ratio and the parameter &, which is a critical aspect in the design of this converter. In this figure, we can see the zone in that the converter works in both modes (Mixed Operation Mode MOM). So, depending of the ***wt*** values the converter would be operating in DCM or CCM ***[6].***

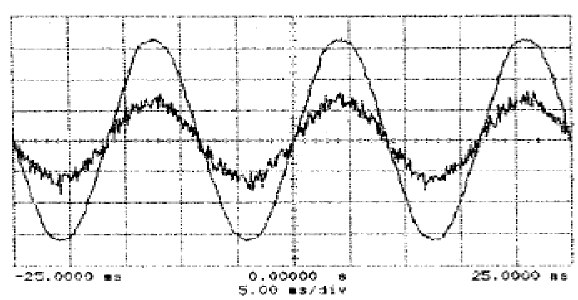
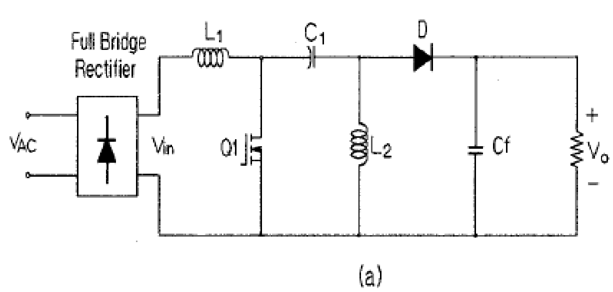


Fig. 2 Input current and voltage waveform for Boost converter.



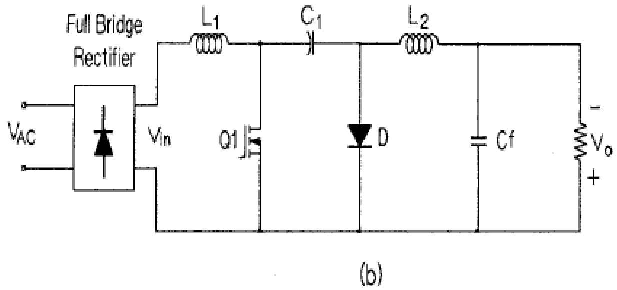


Fig. 3 Converters (a) Sepic and (b) **Cuk**.

The equations 1 and 2 determine these limit conditions ***[6]:***

$K_a > K_{critmax}(wt)$ CCM ……………………………… (1)

$K_a < K_{critmin}(wt)$ DCM ……………………………... (2)

$K_{critmax}(wt) < K_a < K_{critmin}(wt)$ MOM ………… (3)

Where: $K_a = \frac{2L_e}{RT_s}$

being **Ka** a dimensionless parameter, **Le** the equivalent inductance, R the load and Ts switching period.

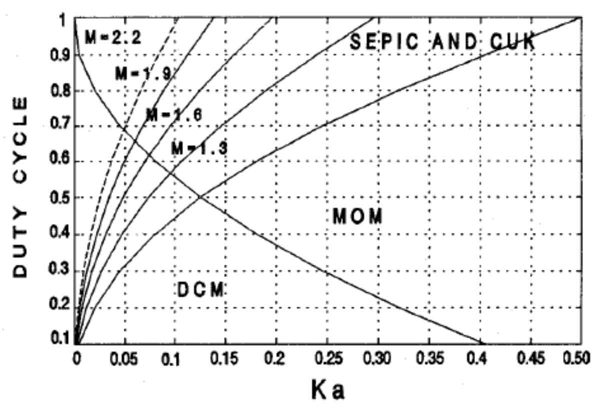


Fig. 4 Boundaries between DCM and CCM for Cuk and Sepic converters.

As a consequence of DCM in the Cuk and Sepic converters, the semiconductors stress is very high [3]. Therefore, this is the first important point to consider in the comparative analysis. The transistor and diode stress in the Boost CCM, Cuk and Sepic DCM topologies are shown in table 1.

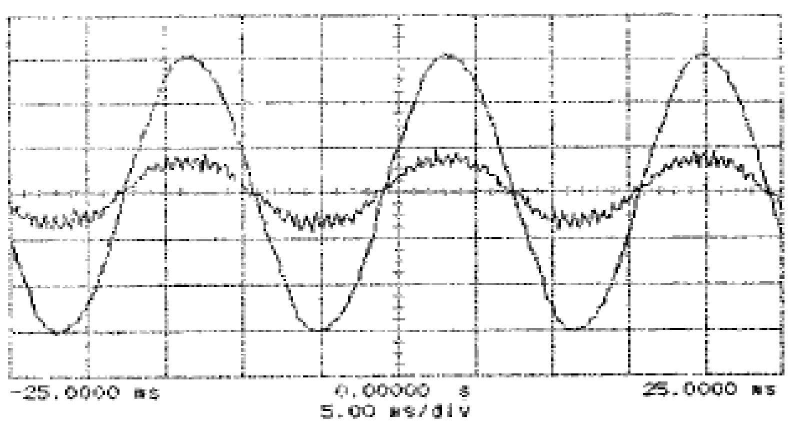
Table 1 Semiconductors stress for the analized topologies.

Semiconductors Stress	Topologies	
	Boost (CCM)	CUK,SEPIC (DCM)
V_{Tmax}	V_o	$V_{in} + V_o$
i_{Tmax}	$(i_{in} M) / 4$	$(V_{in} t_{on}) / L_{eq}$
V_{Dmax}	V_{in}	$V_{in} + V_o$
i_{Dmax}	i_{in} / M	$(V_{in} t_{on}) / L_{eq}$

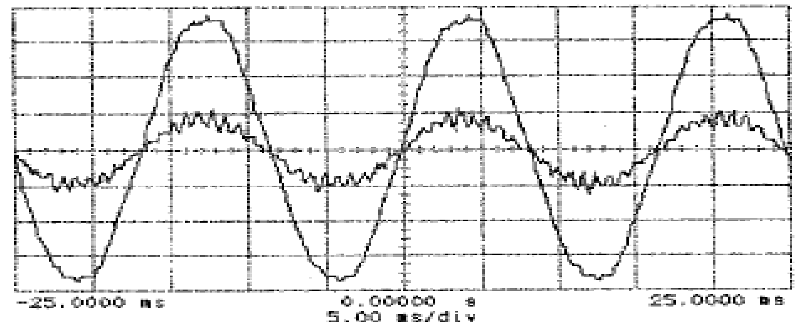
In order to carry out comparative evaluation between the converters above mentioned, experimental prototype of Cuk and Sepic converters with a voltage-follower approach, have been built. The design specifications are: switching frequency fs = 100 kHz**,** output voltage V0=240V, output power Po = 50 watts, input voltage Vac =120 Vrms, with this specification, the magnetic components are: Cuk topology L1= 900 μH and L2 = 492 μH***;*** for the Sepic topology L1= 900 μH and L2= 670 μH**.** The input voltage and current waveforms under full load conditions, for Cuk and Sepic converters, are shown in fig. 5.The values obtained are: for the Cuk topology PF = 92.10%, THD = 8.3%.and an efficiency = 89.15 %; the for the Sepic topology a PF = 91.83 %, THD = 9.98% and an efficiency = 88% (was considered 16th harmonics). To reduce the switching ripple in the input current an additional filter capacitor is needed.

III. CONSIDERATIONS THE COMPARATIVE ANALYSIS

In order to carry out the comparative analysis, it is necessary to take in account some considerations.



(a)



(b)

Fig. 5 Input current and voltage input waveforms for (a)Cuk, (b) Sepic converters.

In order to maintain the same conditions of comparison (e.g., the same percent of inductor current and output capacitor voltage ripple), it is necessary to optimize the power stage for each one of measurement intervals. Therefore it is necessary to make many experimental prototypes. On the other hand, as the Cuk and Sepic converters have the property of emulate a resistor in a natural way, then we can simulate their performance concerning PF, THD and efficiency, (considering the duty cycle constant during a line half cycle) [***3***].

Keeping in mind the two aspects mentioned before, computer simulations for the Sepic and Cuk converters under open loop considerations were developed *[7]*, and we only considered to build experimental prototype for Boost converters to different output power range. It is important to remark that the of main objective of this computer programmers is to evaluate the PF and THD evolution of the topologies analizd. Theoretical and experimental results show good agreement as shown **figs.** 6 and 7. The following section presents the comparative analysis up to ***300*** watts.

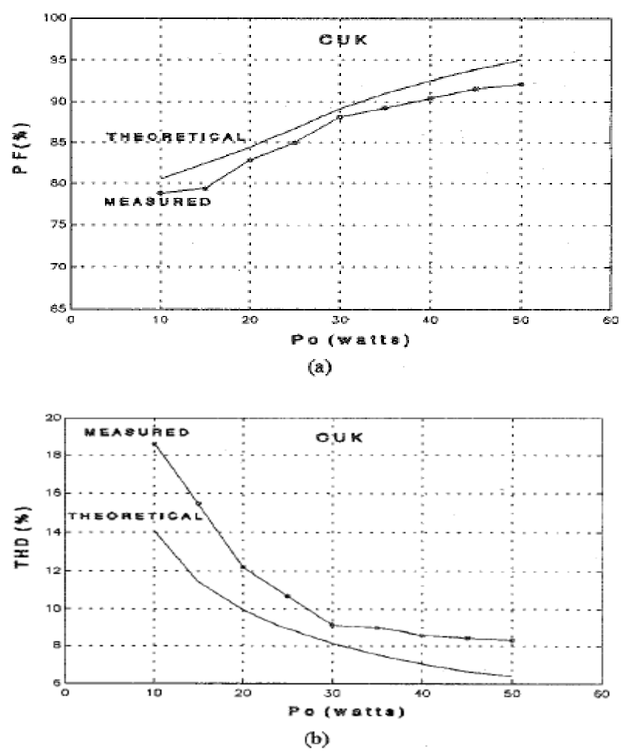


Fig. *6* (a) PF, (b) THD, experimental and theoretical results vs output power for the Cuk topology.

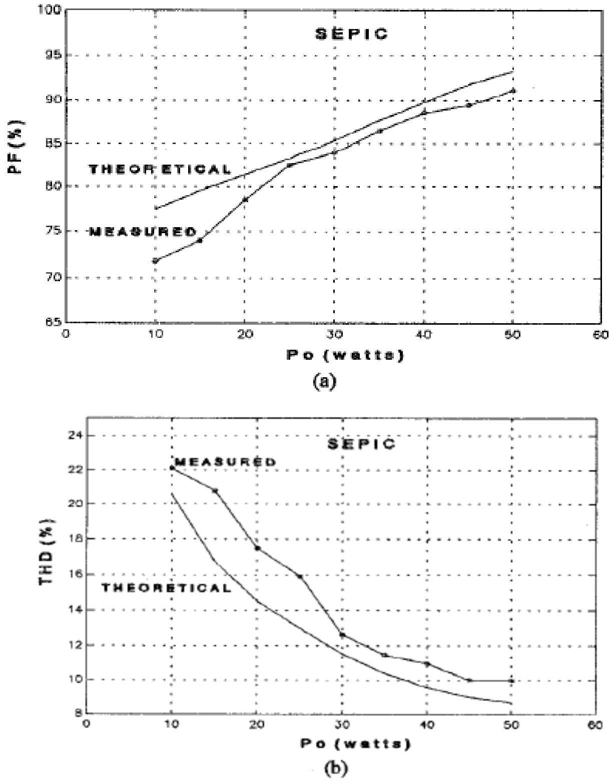
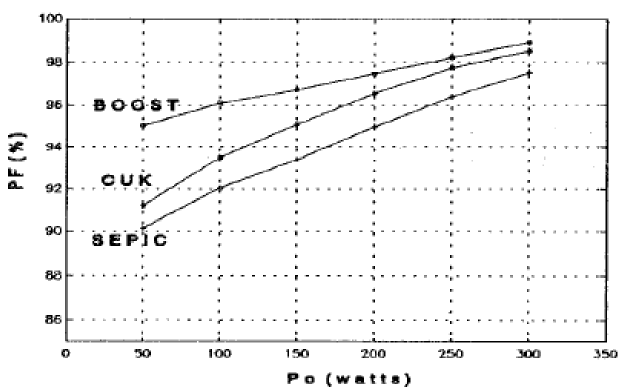


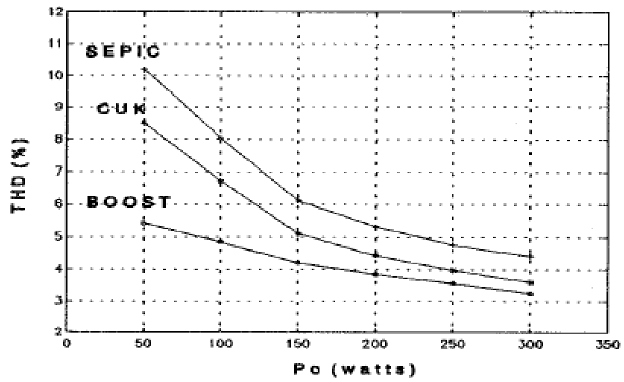
Fig .7 (a) PF, (b) THD, experimental and theoretical results vs output power for the Sepic topology.

IV. COMPARATIVE ANALYSIS

We must remember that the semiconductors stresses are high when the Sepic and Cuk topologies are working in DCM and the efficiency is lower than the Boost CCM converter. Therefore, this study is limited to below 300 watts. It is very important **to** remark that the comparative study presented here is limited to PWM topologies and it does not include, in this moment, ZCS solutions in which is needed only a single voltage follower approach **[8].** PF, THD and efficiency results for Boost, Sepic and Cuk converters are shown in fig. 8 a, b and c up **to** 300 watts. Through this results, we can observe that the Boost topology has a better performance than Sepic and Cuk topologies. Moreover, this topology has a good performance in terms of PF and THD. Nevertheless, the Cuk converter presents a good PF and THD values, showing decrement in the efficiency above 100 watts.



(a)



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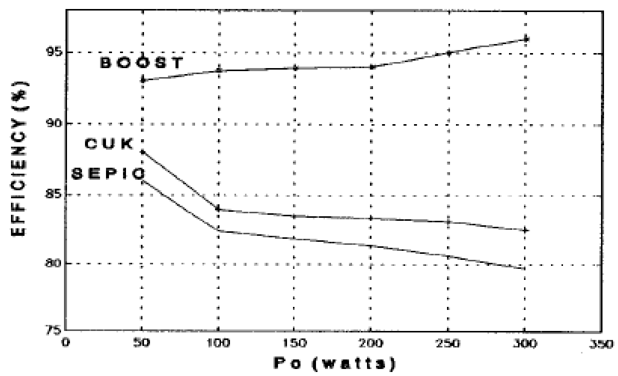


(c)

Fig. 8 (a) PF, (b) THD, (c) Efficiency vs output power for the Boost CCM, Cuk and Sepic DCM converters

Other interesting aspect of comparison is the relative volume evaluation of the topologies analyzed. In this case, the volume is represented by all the energy transfer and storage elements. Fig. **9** shows results normalized with respect to the Boost converter volume, where we can conclude that, unless the value of the inductor in the DCM Sepic and Cuk converters is smaller than the CCM Boost converter, the total volume is higher due to the additional reactive elements present in the Cuk and Sepic topologies.

In all cases, the PF and THD present a good results (PF > 90 % and THD < 10%). However, the Sepic and Cuk converters have a decrease in efficiency. Therefore, the PF, THD vs efficiency evolution in Cuk and Sepic converters are an important aspect to be considered. These parameters are shown in fig. 10 and **11** for Cuk and Sepic respectively. Based on these figures we select the power range of operation for PF, THD and efficiency requirements.

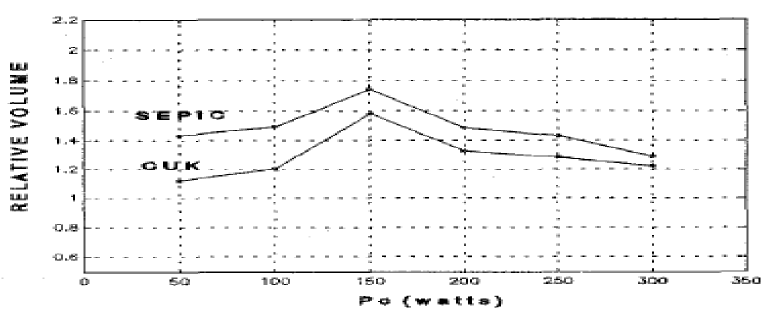


Fig. 9 Sepic and Cuk relative volume (normalized with respect to the Boost topology volume) vs output power.

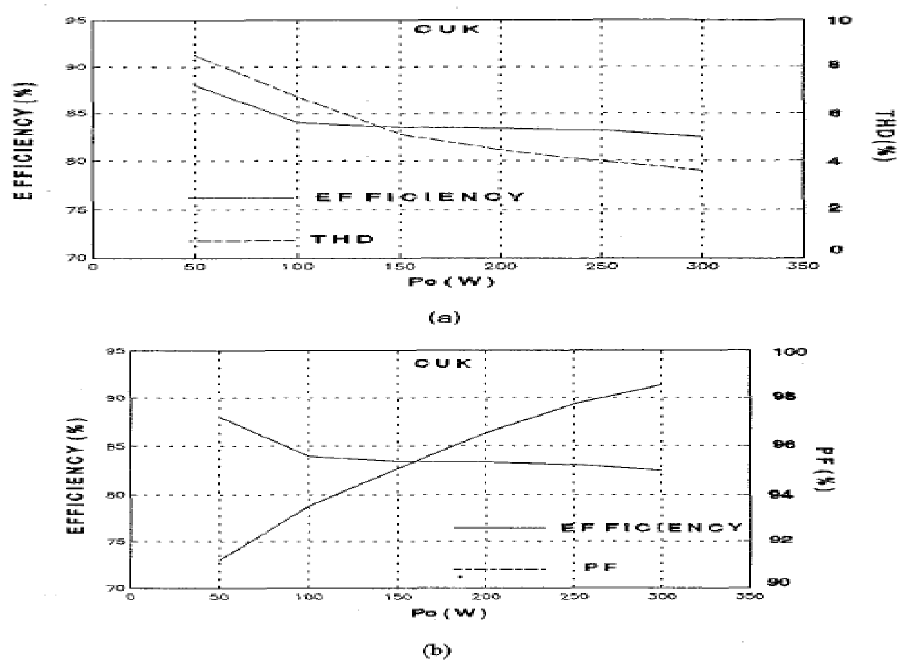
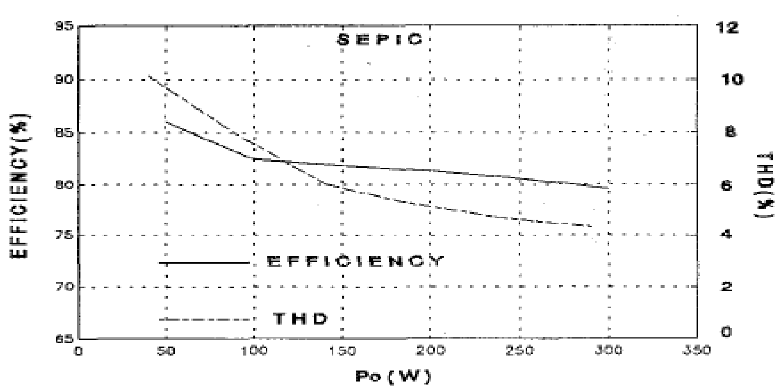


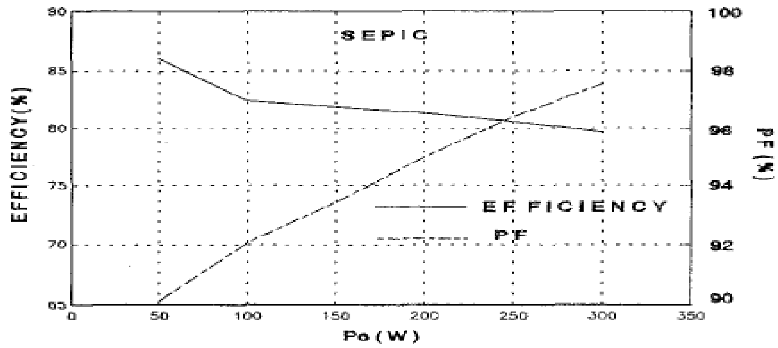
Fig. 10 (a) Efficiency and THD, (b) Efficiency and PP, **vs** output power for the Cuk topology

V. CONCLUSIONS

Nowadays, to include power factor correction in electronic equipment is very important. The Boost converter operating in CCM offers excellent results in low and medium power applications. On the other hand, in recent years, some Buck-
Boost derived topologies working in DCM have been proposed as PFC, offering several advantages over the Boost approach, concerning the control loop simplicity (in the Buck-Boost derived topologies in DCM, it is not necessary the current loop).



(a)



(b)

Fig. 11 (a) Efficiency and THD, (b) Efficiency and PP**,** vs. output power for the Sepic topology.

In this paper a comparative analysis between the PWM Boost CCM, Sepic and Cuk DCM topologies has been presented for a PFC up to **300** watts, evaluating their PF, THD, Efficiency characteristics, as well as their volume. The results of this study confirm that beyond 300 watts limit, *Cuk* and Sepic solutions are not attractive, unless other strategies such as Frequency Modulation, inductors coupling or ZCS-QRC's solution are used. It is important to remark that the Boost, Sepic and *Cuk* converters meet the IEC-555 requirements. Finally, we can conclude that depending on the application requirements (PF, THD, power density and cost) the results obtained **in** this work could help us to decide the best solution.

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