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A new, simple and economic AC-AC converter with improved performance

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ABSTRACT: This work proposes a new model, simple and economic single-phase AC-AC converter regarding control strategy and power assembly. The aim is to reduce costs while ensuring high efficiency and low harmonics. Pulses Width Modulation, with variable duty cycle, control strategy is applied to two power assemblies. The first uses four transistors and four diodes, while the second, the new one, uses two transistors and eight diodes. Simulation on Matlab Simulink shows that the new strategy, simple and economical, works on both assemblies in terms of power variation with good power factor, low Total Harmonic Distortion rate of its output voltage and current, and input current. The new power assembly is economical and efficient with minimum source perturbation. The dimmer can be used for power variation in industrial applications such as heating resistance, Asynchronous Motor Speed drive, light variation…

KEYWORDS: AC-AC power conversion, assembly system, control, costs, harmonic distortion, industrial power system economics, power quality

I. INTRODUCTION

This work consists of applying a new, simple, and economical, PWM control strategy for AC-AC converters[1]. They are intended for variable-power supply of RL-type loads[2]. The aim is to reduce costs while ensuring high efficiency and low harmonics[3]–[5]. The control strategy, PWM with variable duty cycle, is used on two power assemblies whose difference lies in the bi-directional switch model implemented. The first uses two transistors and two diodes, while the second uses one transistor and four diodes. The methodology adopted is the simulation on Matlab Simulink, which will enable us (a) to highlight the performance of the control strategy (b) to compare the two power circuits' efficiencies.

II. THE PROPOSED SYSTEM

a. Power assembly and control strategy

Two bidirectional switches are used, K in series with the load to supply it with power, K' in parallel to freewheel the discharge currents in the inductor[6], [7].

These two switches are therefore complementary. The pulse-width modulation control strategy, with fixed period T and variable duty cycle Alpha, is adopted to supply the load only at portions of the period. A low PWM control [8] frequency is adopted to ensure robustness and long component life [9].

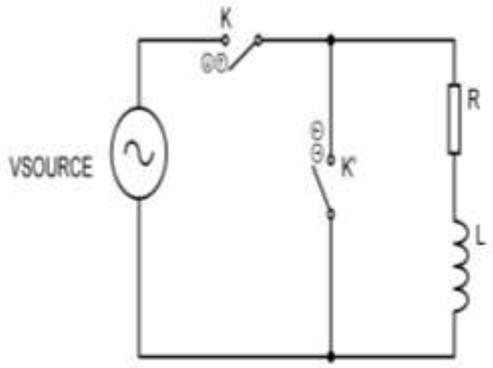

Fig. 1. Dimmer power assembly

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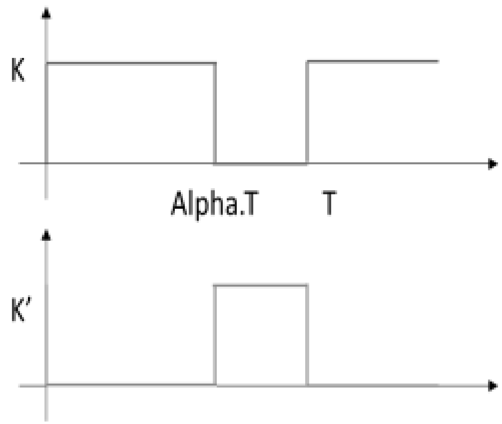


Fig. 2. PWM with variable duty cycle, Alpha, control strategy

b. PWM dimmer operation

K bidirectional switch is closed for load supply from the source, K' is closed to let the freewheel current from the load flow.

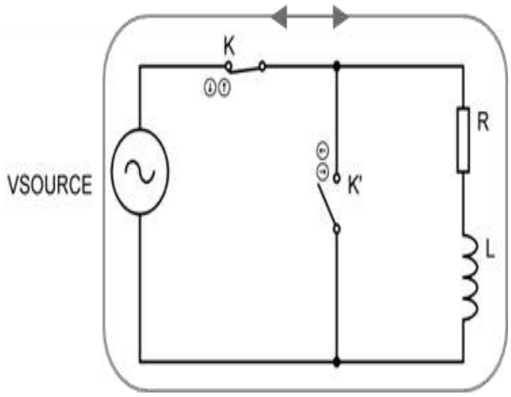


Fig. 3. Load supply from source

The current flows in both directions through the source, the switch K, and the Load.

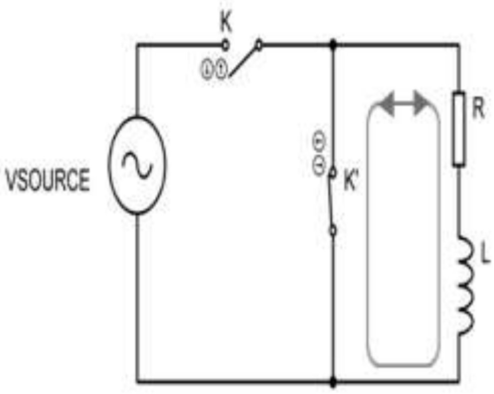


Fig. 4. Freewheel (current discharge of the inductor)

The current flows in freewheel through the load and the switch K'.

c. Bidirectional switches used [6]

i. Bidirectional switch with two transistors and two diodes

An arrangement of two transistors and two diodes, mounted head-to-tail, is used as a bidirectional switch (Fig. 5). Current flows in either direction through a transistor and a diode. The power circuit is shown in Fig. 6. The new strategy consists in controlling the two transistors of a switch with the same signal, as their emitter pins are connected, thus reducing the number of components and simplifying its generation [10]–[13].

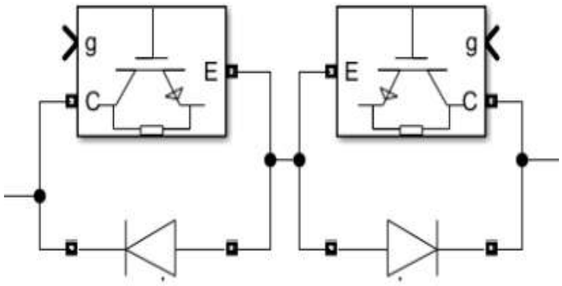


Fig. 5. Bidirectional switch with two transistors and two diodes

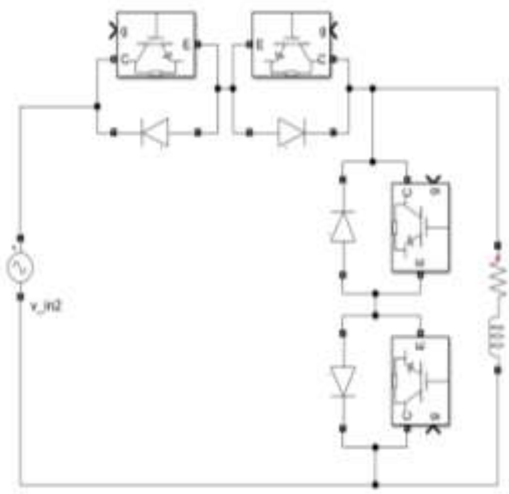


Fig. 6. PWM dimmer with 4 transistors and 4 diodes

ii. Bidirectional switch with one Transistor and four Diodes

A circuit consisting of a transistor and four diodes is used as a bidirectional switch (fig. 7). The advantage of this arrangement is that there is only one controlled component for each switch, which reduces the cost of switching assistance circuits [12]. However, the current must pass through a transistor and two diodes to flow in either direction. The new power assembly uses this bidirectional switch and is shown in fig. 8.

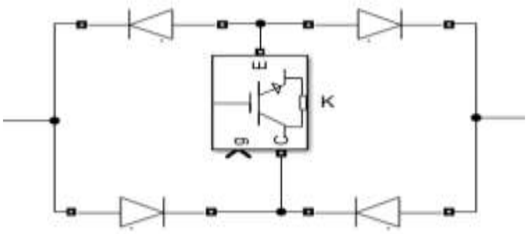


Fig. 7. Bidirectional switch with 1 transistor and 4 diodes

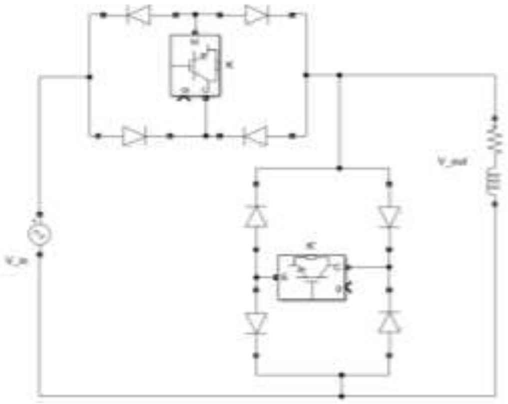


Fig. 8. PWM dimmer with 2 transistors and 8 diodes

III. SIMULATION IN MATLAB SIMULINK

The two PWM dimmers will be simulated in Matlab Simulink, powered by a sinusoidal voltage generator V_in = 220V RMS, 50Hz, and supplying an RL-type load (power factor cosfi = 0.8 at 50Hz).

Load: RL series

R=17.6Ω L= 42.017mH

IGBTs will be used as transistors:

- Internal resistance of 0.001 Ω
- Voltage drop during conduction of 0.6V

For diodes

- Internal resistance of 0.0001 Ω
- Voltage drop during conduction of 0.6V

Voltage, current and power measurements will be made to analyze the input and output behavior of each circuit. These measurements will be carried out for RMS values of the fundamental output voltage VH1 equal to :

0.25xV_in RMS = 55V

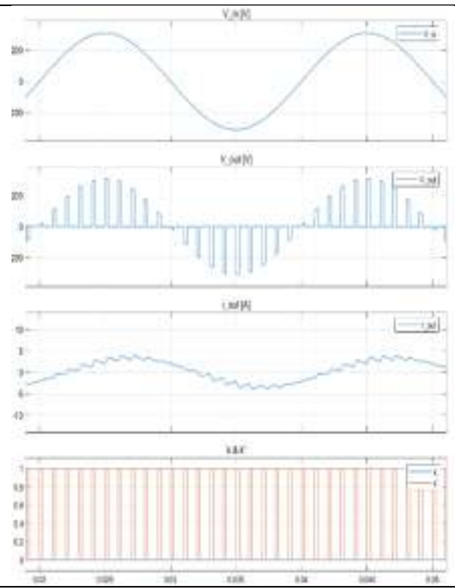
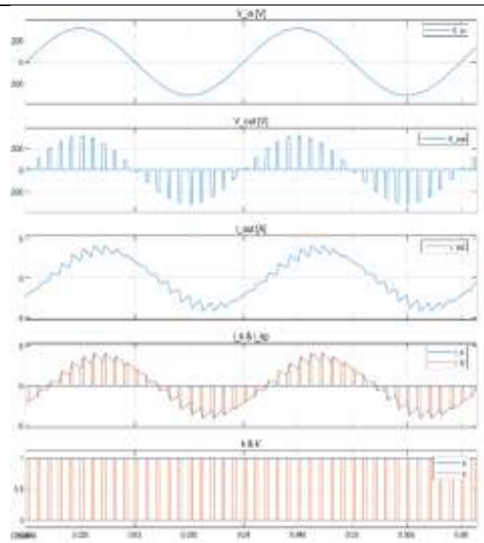
0.5xV_in RMS = 110V

0.75xV_in RMS = 165V

IV. SIMULATION RESULTS

a. Output voltages and currents

The input and output signals curves for the various setups are shown in fig. 9

V_out RMS	4-transistors PWM dimmer	2-transistors PWM dimmer
55V		

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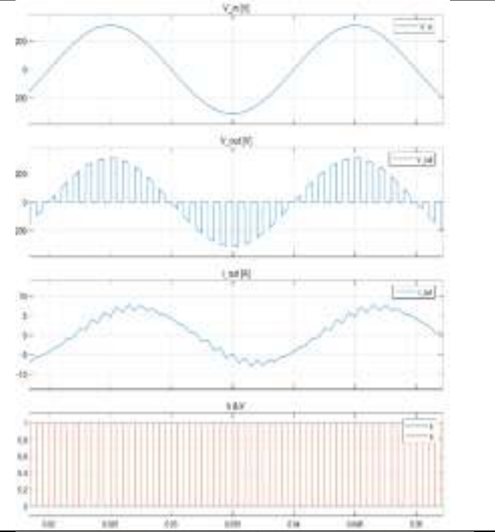
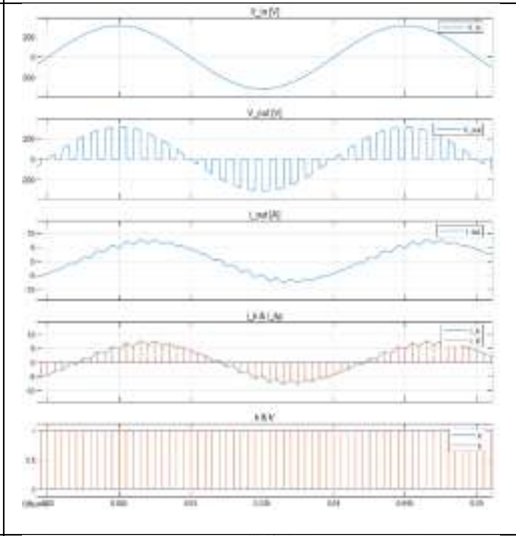
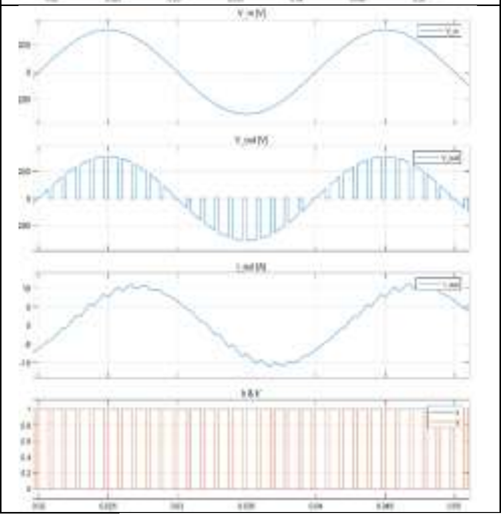
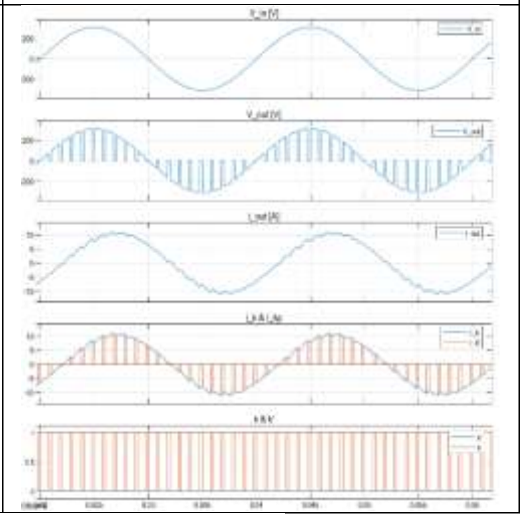
V_out RMS	4-transistors PWM dimmer	2-transistors PWM dimmer
110V		
165V		

Fig. 9. Input and output signals curve in Matlab Simulink

PWM voltage chopping and quasi-sinusoidal output currents, I_OUT, are well achieved.

b. Output voltage RMS value variation

The fundamental output voltage value, at 50Hz, is variated, from zero to the input voltage RMS value, by the mean of the duty cycle, Alpha. For the two power circuits, the curves that show this correlation are displayed in fig. 10.

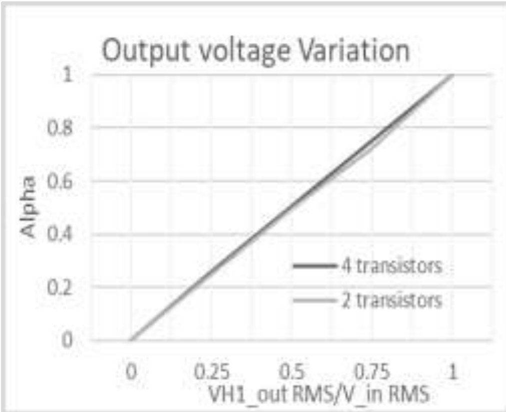


Fig. 101. Fundamental output voltage variation

The variation between the fundamental output voltage and Alpha is quasi-linear for the two power circuits.

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c. Output voltage and current THD

The values of the Total Harmonic Distortion rates of the output voltage V_OUT, and current I_OUT, for different values of the fundamental output voltage, are shown in fig. 11 :

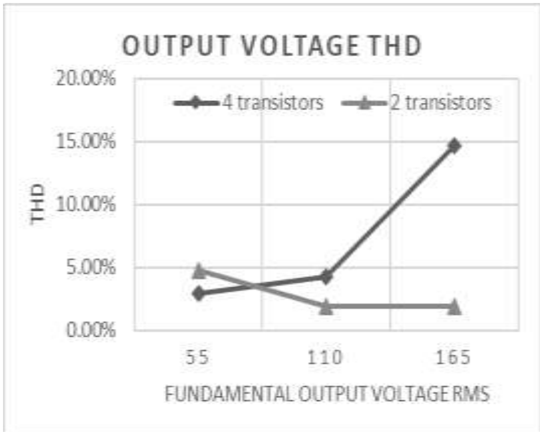

Fig. 112. Output voltage THD in Matlab Simulink

The output voltage THD increases up to 14.71% for the 4-transistors dimmer and decreases down to 1.92% for the 2-transistors one as the output voltage RMS value increases.

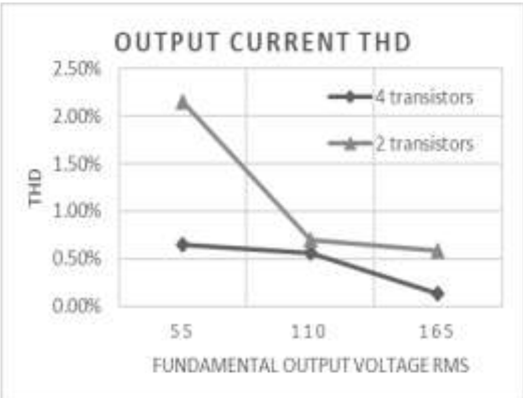

Fig. 123. Output current THD in Matlab Simulink

The THD value decreases from 2.16% for the 4-transistors dimmer and from 0.65% for the 2-transistors one, as the output voltage rises.

d. Input current THD

The values of the THD rate of the input current for different values of the fundamental output voltage are shown in fig. 13**Fig. 134** :

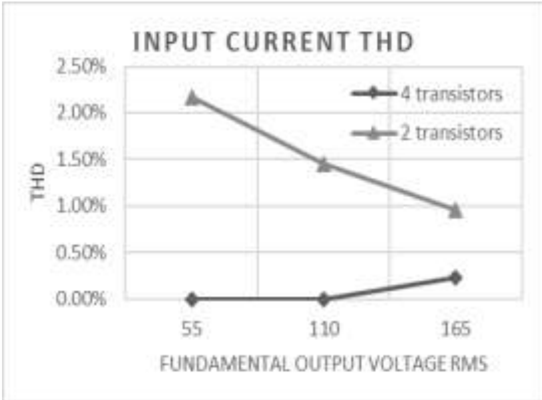

Fig. 134. Input current THD in Matlab Simulink

The input current THD rate keeps below 2.17% for the 2-transistors dimmer and below 0.23% for the 4-transistors one.

e. Active electric power efficiency P_out/P_in

The values of the active electrical power efficiency P_out/P_in, for different values of the fundamental output voltage, are shown in fig. 14.

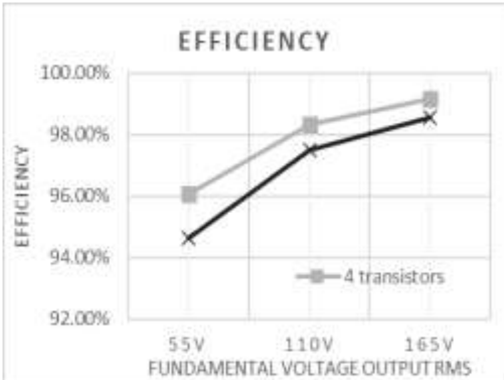

Fig. 145. Active electric power efficiency P_out/P_in in Matlab Simulink

Efficiency ranges from 94.63% to 98.56% for the two-transistor dimmer, and from 96.04% to 99.15% for the 4-transistor PWM circuit.

f. Input and output fundamental power factor

The values of fundamental input and output power factors, cosfi_in and cosfi_out, for the three values of the output fundamental voltage, are shown in Fig. 15 and Fig. 16.

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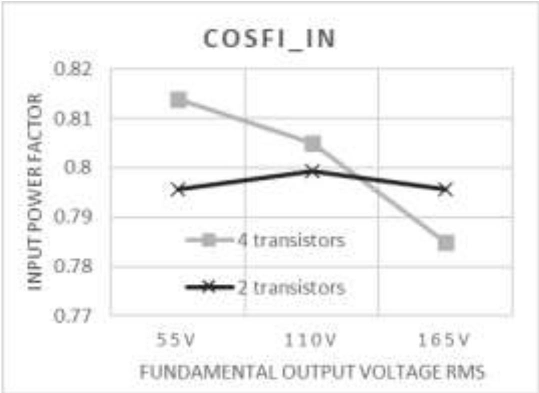

Fig. 156. Input power factor in Matlab Simulink

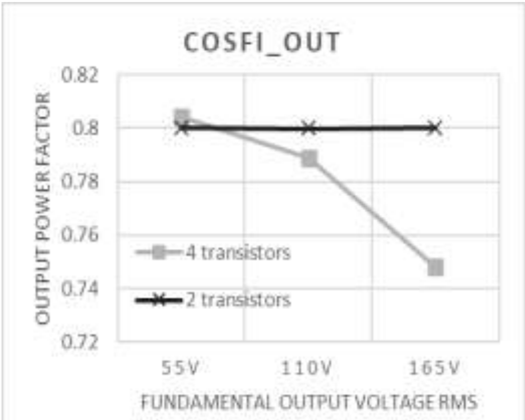

Fig. 16. Output power factor in Matlab Simulink

The load power factor value for a pure-sine supply is 0.8.

The 2-transistors circuit has a cosfi_in of 0.7956 to 0.7991 and a cosfi_out of 0.8.

The cosfi_in and cosfi_out of the 4-transistors PWM circuit has decreasing values as the fundamental output voltage increases (between 0.0.8139 and 0.7848 for cosfi_in and between 0.8041 and 0.7481 for cosfi_out).

V. DISCUSSIONS

Complementary control of the two switches K and K' ensures that the supply and freewheeling currents flow in both directions.

In the case of a bidirectional switch with 2-transistors and two diodes mounted head-to-tail, simultaneous control of both transistors enables current to flow in both directions. A single control signal drives both transistors.

The new control strategy does not require knowledge of the phase of the supply voltage. Signals can be generated, for example :

- by mounting an astable multivibrator with NE555 and a Logic NOT gate;

- by a microcontroller with two output ports.

The quasi-linear relation between Alpha and the fundamental output voltage simplifies the command for regulation purposes for example.

Power assemblies do not require filtering devices, which considerably reduces costs and increases robustness.

Considering the output voltage and current THD, the values are very low, ensuring good energy efficiency and low-temperature rise for RL-type loads. These voltage harmonicas values are better for the two-transistor circuit.

Input current THD has very low values, so the network current is only slightly polluted.

From an efficiency point of view, the four-transistor dimmer has better values. The difference is due to the number of conducting diodes: two for the 1-transistor switch and one for the 2-transistors switch. The additional diode results in a voltage drop and therefore a loss of power.

The active electric power efficiency does not consider the command power consumption; however, the design’s simplicity and the reduced number of commanded components will minimalize it in practice.

From a power factor point of view, the 2-transistor dimmer has better values, between 0.79 and 0.8, than the 4-transistors dimmer.

For implementation, we need to take into account the transistors' closing and opening times. In this case, overlap times must be respected between the switching of switches K and K'.

VI. CONCLUSION

The proposed control strategy is efficient in terms of dimmer output voltage and power variation. Requiring only two complementary PWM signals, two switching aid circuits, and no power supply phase detector for either the 2-transistors or 4-transistors converter, this control strategy is economical. No filtering devices are required for power assemblies. Harmonics rates are close to those of a pure sine wave power supply for both setups, with a slight advantage for the 1-transistor switch, thus, the dimmers ensure high efficiency without polluting the mains current. Electrical efficiency P_out/P_in is high for both circuits. Input and output power factor values are close to those of the pure sine supply, with a slight advantage for the 1-transistor switch.

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