

## Design of a multifunction low power converter with reduced freedom degrees for photovoltaic and mobile applications

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### ABSTRACT

This paper is an approach to design a new full bridge single-phase multifunction converter. Reduction of freedom degrees is the principal mean to build the converter dedicated mainly to mobile applications fed by photovoltaic cells. The rules of reducing controllable semiconductors are analyzed and simulation and experimental results prove the feasibility of the approach.

**Index Terms**— Multifunction, converter, full bridge, mobile applications, photovoltaic

### I. INTRODUCTION

Full bridge power converter is used in several fields of power electronics. They are mainly used in drives and more and more in mobile applications such as photovoltaic converter, electric vehicles, etc.

The start point is to design a static converter adaptable to different electrical sources and loads with the minimum number of components. Expected advantages from such structures are: minimum control variables, less switches with less snubbers, variety of power forms at output: AC & DC, possibility to switch between different operating modes by simple control tuning, possibility of reversibility during recovery mode. However, naturally, some limitations in voltage, frequency and power range will be met during the design procedure.

To validate this first approach an example of five switches single-phase full bridge converter is studied, simulated and experimentally tested.

### II. TOPOLOGY DESIGN PROCEDURE

Single-phase full bridge power electronics converter is a static structure composed of two parallel arms with usually two semiconductor switches in each one. Aim of this topology is to allow switching of load voltage and current in two directions. Also, this structure is widely used in AC-DC variable uninterruptible power supply, DC-DC four quadrant speed drive, single-phase DC-AC inverter, etc.

The main goal of this study is to design a static converter that could operate in different modes namely a *several-in-one converter*.

The switching from one mode to another (AC-DC to DC-AC for example), only requires a proper selection of the different control states.

In full bridge topology, bidirectional switches in each half arm become a design principle in our new structure.

Initially, choice of two directions in half arm can be obtained by acting on control states of bidirectional controllable semiconductor.

The latter is chosen as two opposite series transistors with antiparallel diodes (Fig.1).

It results in eight transistors-diodes with eight control ports.

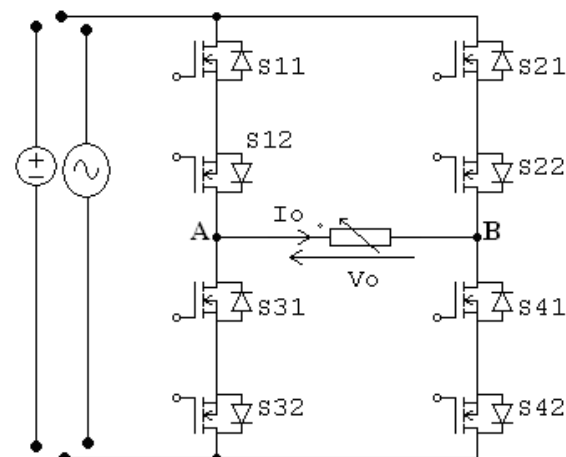


Fig. 1. Initial topology

Following some operating rules will help reducing this large number of controllable switches. Essential reasons for this option are the reduction of control algorithm complexity, implementation cost and the size and weight.

Our initial specifications for this converter are to realize the following operations: inverter, rectifier and reversible chopper. The selection of the operating mode is made by the user.

For each switch, « 1 » and « 0 » positions are attributed to indicate conduction and blocking states respectively.

For inverter or rectifier mode, they are two half waves: positive and negative. But, in chopper mode (direct or reverse), active and passive operation phase are found: feeding and freewheel.

The first step of our analysis of each operation mode starts by forcing conduction and blocking states on some switches. This requirement is either to choose a desired operation mode or to avoid abnormality like short-circuit for example.

The remaining states are optional.

Table.1 shows switching states for each operation sequence associated to each mode.

Logical values with grey background are mandatory states. Logical values with white background are optional states.

		S11	S12	S21	S22	S31	S32	S41	S42
Inverter	Halfwave +	1	0	0	1	0	1	1	0
	Halfwave -	0	0	1	1	1	1	0	1
Rectifier	Halfwave +	1	0	0	1	0	1	1	0
	Halfwave -	1	0	0	1	0	1	1	0
Chopper1	Active	1	0	0	1	0	1	1	0
	Passive	0	0	0	1	1	1	1	1
Chopper2	Active	0	0	1	1	1	1	0	1
	Passive	0	0	0	1	1	1	1	1

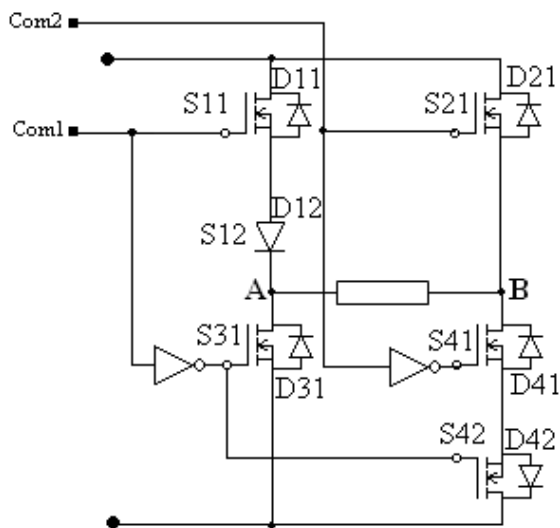
**Table.1.**Switches logical states versus operation modes

Optional states are chosen so as to unify some columns in order to eliminate some switches or to short-circuit them. Thus, the number of controllable switches and therefore control variables can be reduced.

As an example, for switch S12, a logical value « 0 » in all cases means that it can be eliminated. Only the antiparallel diode is maintained.

For S22, the logical value is always « 1 », this transistor and its antiparallel diode can be eliminated and replaced simply by a wire (short-circuited).

After this analysis of Table 1, the resulting structure is displayed Fig.2.



**Fig.2.** Resulting structure

This topology takes into account operation sequences of each mode. All that is necessary is to provide two control signals Com1 and Com2 in

order to obtain the switching between modes in accordance with the source type (AC or DC).

### III. ANALYSIS OF THE DESIGNED STRUCTURE IN DIFFERENT MODES

Sequential analysis is a practical tool to study this new converter. For reasons of referencing, point « A » represent terminal « Plus + » for DC load and terminal « Phase P » for AC load. In the next, three operation modes are studied for different sequences.

#### A. Single-phase inverter mode

The goal is to generate an output alternative voltage  $V_{alt}$  (which frequency  $f$  and amplitude are controllable) from a DC voltage  $V_{in}$ .

Considering an inductive load, the control delay angle is called  $\beta$ . The resulting operation mode is composed of six sequences: 2 feeding sequences, 2 freewheel sequences and two recovery sequences.

The RMS value of the output voltage is given by:

$$V_{alt,rms} = V_{in} \sqrt{1 - \frac{\beta}{\pi}} \quad (1)$$

#### B. Single phase rectifier mode

Single-phase rectifier operation mode produces a variable DC voltage  $V_{DC}$  from a sinusoidal source denoted  $V_{ph}$ .

With an inductive load and considering a discontinuous conduction mode with an extinction angle  $\alpha$ , the operating mode results in three sequences: negative feeding sequence, extinction sequence and positive feeding sequence.

The average output voltage is given by:

$$V_{DC,AV} = \frac{V_{ph}}{2\pi} (3 + \cos \alpha) \quad (2)$$

#### C. Four-quadrant chopper

Four-quadrant chopper produces a variable DC voltage  $V_{ch}$  from a voltage DC source  $V_{in}$  that is continuous at source.

With an inductive load and considering continuous conduction mode with a duty cycle  $d$ , the operating mode results in two sequences for each direction (+ or -): feeding sequence and freewheel sequence.

The average of the output voltage is given by:

$$V_{ch,AV} = d \cdot V_{in}$$

This is the same conversion rate as a buck converter type in two directions positive and negative.

Switching between different directions is made through the control values.

#### IV. SIMULATION OF DESIGNED STRUCTURE IN DIFFERENT MODES

The first step of validation of the multifunction converter is performed through numerical simulation using graphical software PSIM<sup>®</sup> version 6. The results are compared to those obtained with the classical structures for each operating mode (inverter, rectifier and chopper).

For the simulation, the following parameters are used:

- DC and AC Supply voltage:  $V_{in}=20V$ ,
- Load resistance:  $R_o=100\Omega$ ,
- Load inductance:  $L_o=5mH$ .
- Input or output frequency:  $f_o=50Hz$ ,
- Extinction and delay angle in rectifier and inverter mode respectively:  $\alpha = \beta = 30^\circ$ ,
- Switching frequency in chopper mode :  $f_s=20kHz$ ,
- Duty cycle:  $d=0,8$ .

On the following curves, voltages and currents are drawn.

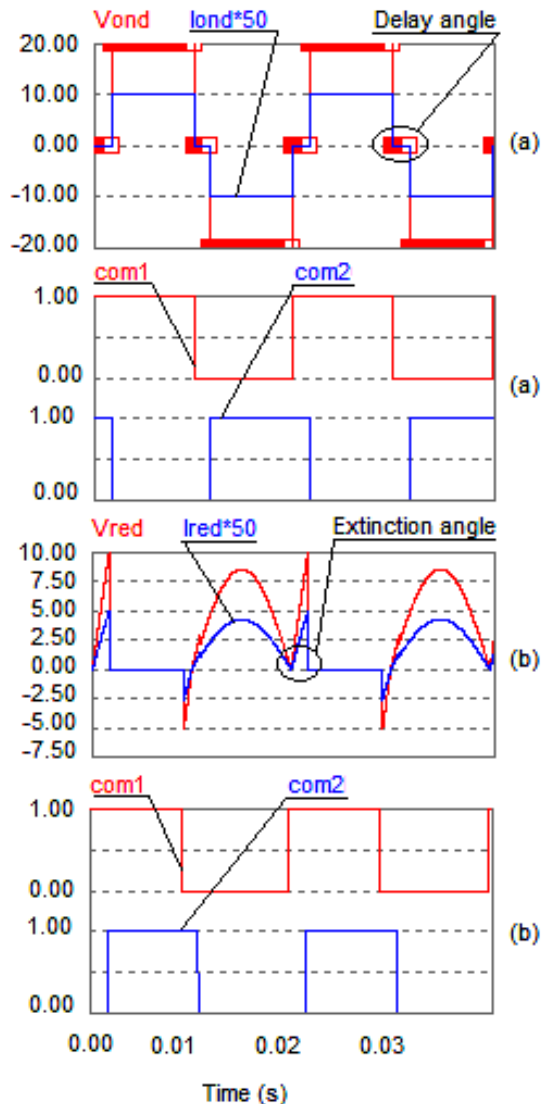


Fig.3. Output voltages & currents in inverter (a) and rectifier (b) modes for pure resistive load

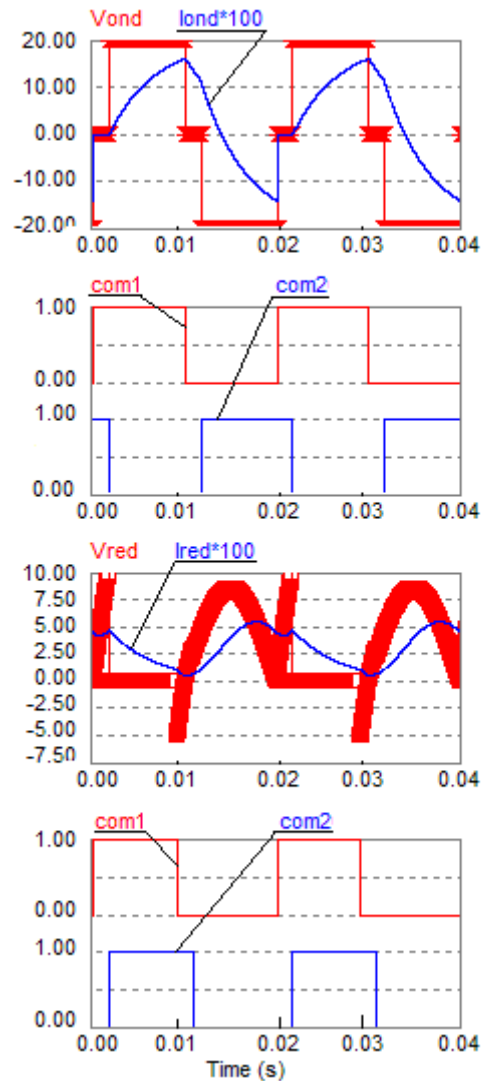


Fig.4. Output voltages & currents in inverter (a) and rectifier (b) modes for inductive load

##### A. Single-phase inverter and rectifier modes

Concerning the single-phase inverter analysis, for a delay angle of  $30^\circ$ , two classical control pulses Com1 & Com2 are applied to switches with time rate of 50% each.

For pure resistive load, output voltage and current are perfectly alternating with amplitudes of 20V and 0.2A respectively.

For inductive load, output voltage and current has curves nearly as classical ones except during recovery sequence. The latter present zero voltage and current during delay angle. For delay angle of  $30^\circ$ , RMS values of output voltage and current are 18.23V and 0.10A respectively.

Concerning the single-phase rectifier analysis, for an extinction angle of  $30^\circ$ , control pulses Com1 & Com2 are injected for a period of 0.02s with a duty cycle of 50%. A delay of  $30^\circ$  is applied between these two pulses.

With a pure resistive load, output voltage and current has curves nearly as classical one except in the region of extinction angle. In this region,

negative halfwave is absent except a small part during extinction angle. Mean values of voltage and current for this type of load are 3V and 30mA respectively.

For an inductive load, the output current is smoothed with an average value of 8mA.

### B. Four-quadrant chopper

For a duty cycle of 80%, complementary control pulses Com1 & Com2 are injected with a period of 50  $\mu$ s.

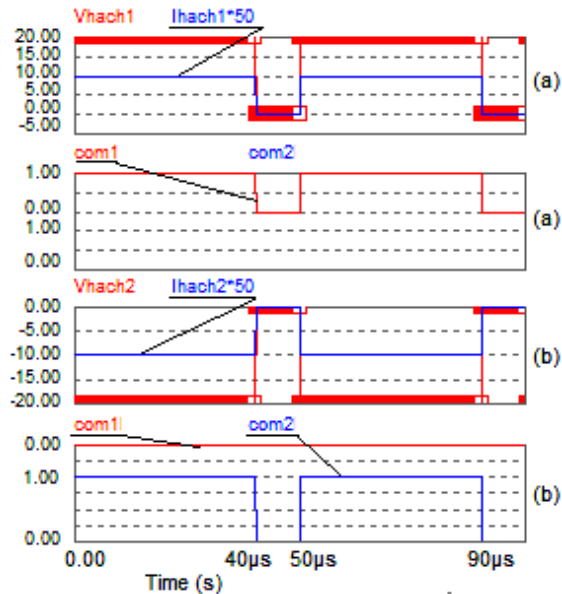


Fig.5. Output voltages & currents in chopper + (a) and chopper - (b) direction modes for pure resistive load

In pure resistive load, for both directions, output voltage and current has curves perfectly similar to the classical converter. Mean values of voltage and current for this type of load are 16V and 160mA respectively.

## V. EXPERIMENTAL IMPLEMENTATION

Theoretical analysis and promising simulation results encourage implementing an experimental test bench.

The power converter (Fig.6) is constructed with the following semiconductors:

5 MOSFET transistors characterised by:

- Reverse repetitive maximal voltage: 50V
- Direct maximal current: 4A
- Maximal frequency: 100kHz

6 diodes characterised by:

- Reverse repetitive maximal voltage: 50V
- Direct maximal current: 4A

Maximal resistive load: 40W

Power supply voltage: 12V to 25V (RMS or average)

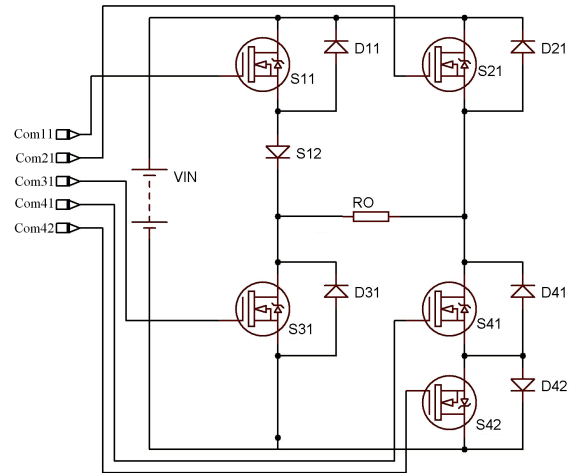


Fig.6. Implemented multifunction topology

For interfacing control and power system, 3 logical NOT gates and 5 bipolar transistor drivers are used to transmit two control pulses Com1 & Com2 to the five MOSFET (Fig.7). A 12V DC voltage feeds the interface system.

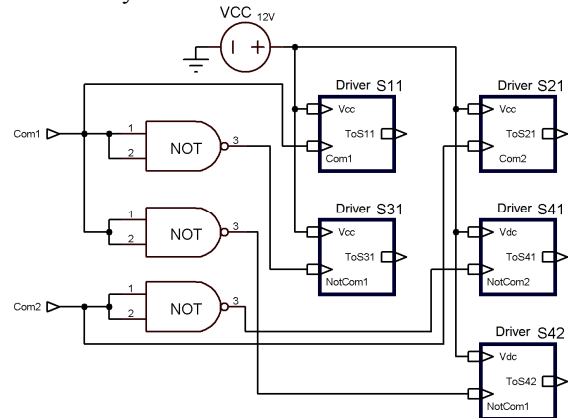


Fig.7. Driving system from 2 to 5 control pulses

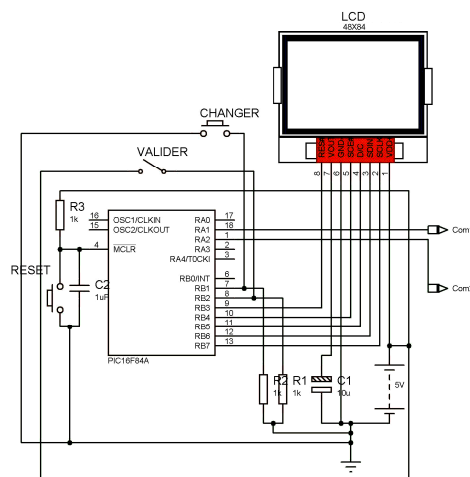


Fig.8. Control and display systems

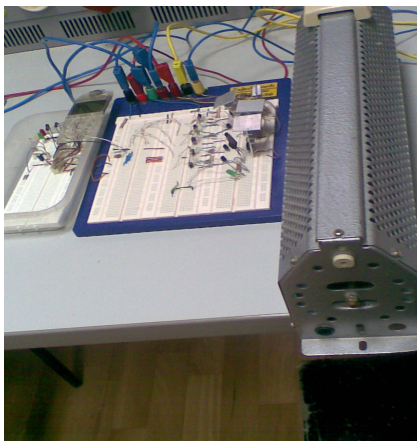
The digital controller is embedded in a Microchip® PIC16F84A microcontroller. The programming language is assembler. It generates suitable TTL pulses corresponding to the selected

mode. Switching between modes and their validation are performed using “*changer* and *valider*” pushbuttons respectively. A reset pushbutton is included to restart the program in case of wrong operation.

To view current executed mode or prompt user to select a mode, an LCD screen is used as display tool (Fig.8).

## VI. EXPERIMENTAL RESULTS AND DISCUSSIONS

Circuits of whole system are implemented in laboratory on test platform (Fig.9). A variable resistance of  $100\Omega$  is used as resistive load. Power supplies used in test are 20V DC and 20V AC. Acquisition and display of the results are performed with Unitrain<sup>®</sup> unit of Lucas-Nülle.



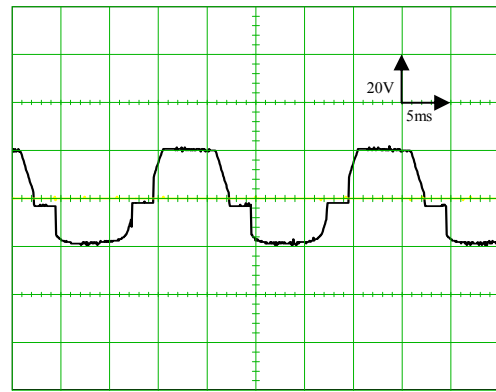
(a)



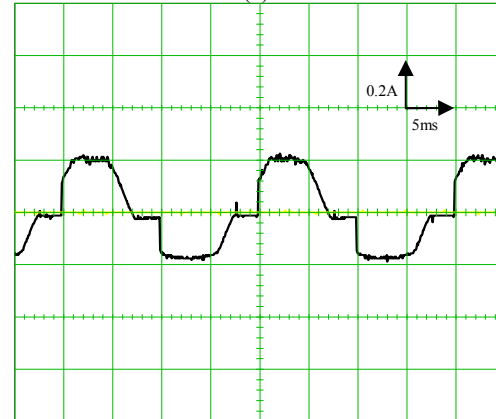
(b)

**Fig.9.** A picture of the test bench under operation (a) and the LCD showing the selected mode (*Hach* stands for chopper) (b)

To validate multifunction full bridge operations, voltages and currents curves are acquired for each selected mode and compared with simulation results.



(a)

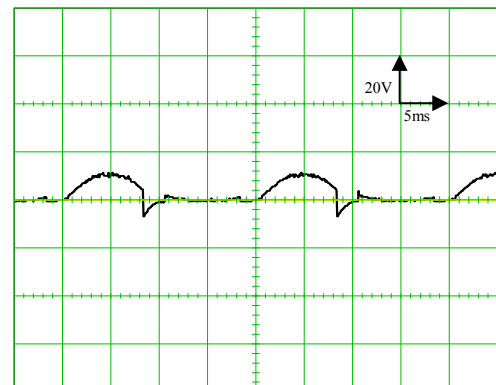


(b)

**Fig.10.** Output voltage (a) and current (b) for single-phase inverter mode.

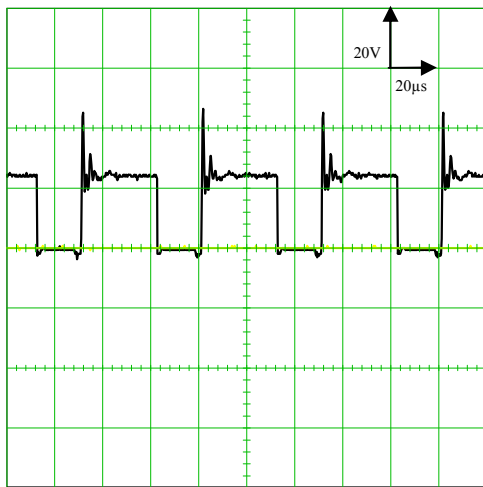
In inverter mode (Fig. 10) the output voltage is alternative as predicted and is nearly rectangular. There is a delay of 2.4ms between positive and negative halfwave. Amplitude is 20V with a frequency of 50Hz (20ms). As for a resistive load, the current has the same shape as the voltage with amplitude of 0.2A.

In rectifier mode (Fig. 11), the output voltage is nearly rectified single halfwave sinusoid with amplitude of 12V and frequency of 50Hz (20ms). In this mode, with our structure only simple rectifying can be obtained. Also, absence of extinction angle region ( $30^\circ$ ) is due to acquisition sampling time of Unitrain<sup>®</sup> unit that is close to extinction angle time ( $30^\circ \equiv 0.00167$  s).



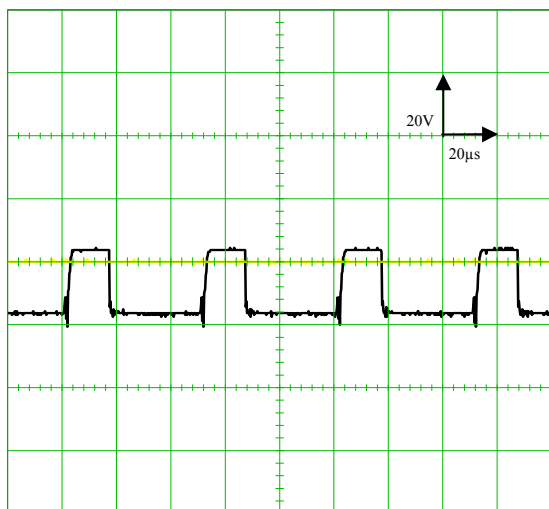
**Fig.11.** Output voltage curve in rectifier mode.

In the chopper mode (Fig. 12), the output voltage of amplitude 22V is « chopped » with a duty cycle of 0.6 at frequency of 20kHz (50µs).



**Fig.12.** Output voltage curves for four-quadrant chopper positive direction

The same results are obtained in the negative direction (Fig. 13).



**Fig.13.** Output voltage curves for four-quadrant chopper negative direction

## VII. CONCLUSION

Starting from the idea of multifunction converter for portable power supplies, a new structure of conversion (AC-DC, DC-AC and DC-DC) has been designed. Advantages of single-phase full bridge converter urge us to suppose a new topology which can work as inverter, rectifier and chopper in its two directions. The initial converter was composed of eight power switches with antiparallel diodes. Using logical table of possible sequences in each operation mode, a new structure with reduced number of switches and therefore control buses has been derived.

Simulation results of the three operation modes are promising despite some drawbacks. Experimental

tests have been conducted with a DC or AC power supply voltage of 20V and a resistive load of 100Ω. In rectifier mode, the results need to be improved but for inverter and chopper mode the results are satisfactory. Different kind of loads should be tested even if most of the classical loads can be considered as mainly resistive.

Moreover, the multifunction converter should be evaluated in terms of efficiency and reliability. Experimental validation should also be done with a PV panel as DC source to prove the converter suitability for solar home systems.

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