Asymmetrical Half-Bridge Flyback for the Design of Auxiliary Power Supplies in Hybrid Inverters

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***Abstract*—Hybrid inverters are gaining importance because they combine the benefits of regular solar inverters with the flexibility of battery inverters. For increasing their deployment, the aim is to make them efficient and economically viable. This requires techniques that raise the output voltage of the photovoltaic strings. Hence, the auxiliary power supply, which is the focus of research in the last few years, must be capable of efficiently providing a high gain conversion ratio over a wide input voltage range. It must keep the sensing systems, gate drivers and control system in permanent operation. Solutions based on the flyback topology are available in the state of the art. However, they have some limitations: the operating range of the input voltage is wide and the voltage stress that semiconductor devices must withstand is high. In this paper, the Asymmetrical Half-Bridge (AHB) flyback preceded by a boost with PFC capability is proposed for the design of the auxiliary power supply. With this topology, the maximum voltage stress to be withstood by the devices is limited to the input voltage. In addition, it has a good performance over a wide input voltage range, and thanks to its hybrid nature between flyback and forward topologies, it allows reducing the size of the transformer, thus increasing its power density. A converter design that can operate under the challenging specifications of this architecture with an input voltage between 100 V and 1100 V, and providing an output of 24 V and 75 W, is proposed to validate its operation.**

***Index Terms*—Asymmetrical Half-Bridge flyback, Hybrid inverter, Auxiliary Power Supply, Solar energy**

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I. Introduction

Solar power generation is growing thanks to its benefits of being a clean and inexhaustible source of energy [1]. The focus of current research is on improving efficiency and financial viability [2], [3]. Decentralized systems, such as microinverters or low power inverters in solar applications, are expensive products, but thanks to advances in the technology employed, they are becoming increasingly affordable.

The energy conversion of photovoltaic (PV) systems must be highly efficient. To achieve this, distribution losses and energy conversion losses must be minimized. One alternative is to increase the voltage at the output of the photovoltaic string to reduce the current. In this way, the distribution losses, calculated as I^2R, are reduced. This is achieved by connecting several solar panels in series, so that the output voltage can be up to 1100 V, or even 1500 V [4]. However, this makes the design of the auxiliary power supplies of the decentralized power converters, which are intended to power the gate drivers, the control system and the sensing system, typically powered at 24 V, more challenging [5], [6]. They must operate with high conversion rates and high efficiency, while being cost effective.

Fig. 1 shows the functional structure of a hybrid inverter in solar applications. The power conversion stage, the control stage and the communication interface can be identified. It features a DC/DC power conversion between the photovoltaic string and the battery, a DC/AC power conversion between the photovoltaic string and the grid, and a DC/AC power conver-

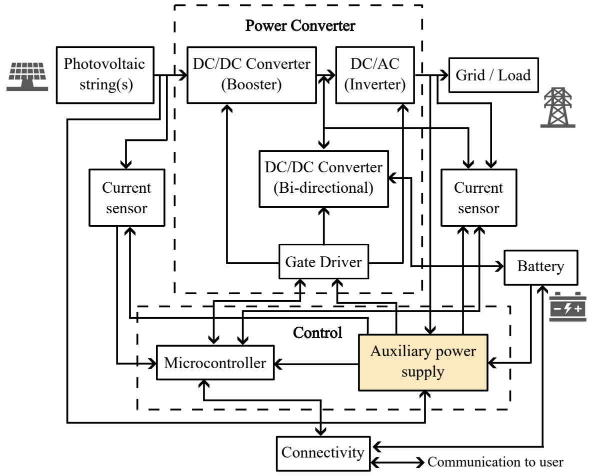

Fig. 1. Functional structure of a hybrid inverter.

sion stage between the battery and the grid [7]. The auxiliary power supply can be powered either by the photovoltaic string, the battery or the grid, and it feeds the current sensors, the gate driver and the microcontroller [8].

Considering the grid as an AC input of AC220V or AC380V, the battery as a DC input of between DC100V and DC600V, and the PV strings as a DC input of DC150V to DC1100V, and knowing that the systems powered by the auxiliary power supply operate at DC24V, a high efficiency DC/DC converter capable of supporting a wide input range from 100 V to 1100 V, with an output of 24 V [8], and operating at a power of up to 75 W is required. In addition, since it handles high voltages at the input, the output must be galvanically isolated from the input. The design of the auxiliary power supply must comply with the standard "IEC 62109: Safety of Power Converters for use in Photovoltaic Power Systems", both "Part 1: General requirements" [9] and "Part 2: Particular requirements for inverters" [10].

In the state-of-the-art there are different isolated topologies, such as flyback and forward, that are used for the design of the auxiliary power supply. However, they have problems to operate with such a wide and high input voltage range [11]. In the case of flyback, the voltage and current stress on the switching devices within the converter can be extremely high when varying the duty cycle to regulate the output voltage V_{out} [12] and more complex topologies are needed to limit the peak stress [13].

The focus of this paper is the optimization of the auxiliary power supplies in hybrid inverters. For that, it presents the limitations that arise when using a conventional flyback for the design of the auxiliary power supply. As an advantageous solution, Asymmetrical Half-Bridge flyback topology is proposed for the design of this power supply. Unlike the forward converter [11], it can operate efficiently over a wide input voltage range. Compared to a flyback [12], it has the disadvantage of having more components and being more complex, but it has the benefit of limiting the voltage stress of the devices to the input voltage, regardless of the duty cycle. Moreover, while being complex, its design is simpler than that of an LLC and derivatives, whose bill-of-material is larger [14]. Furthermore, this paper shows the benefits of merging this topology with a previous boost stage with PFC capability in case input power is over 75 W. Finally, the conclusions of the study are presented.

II. Design of the auxiliary power supply

A. Flyback design challenges

One advantage of using the flyback topology, that it shares with other topologies, for the design of the auxiliary power supply is that it can provide multiple outputs very easily [15], as shown in Fig. 2. Thus, the inverter gate drivers can be powered in isolation from each other.

The ratio between input voltage V_{in} and output voltage V_{out} for the flyback with a single output is calculated as in (1), where N is the turns ratio of the transformer ($N = Np : Ns$), D_1 is the duty cycle of the switch in the primary side, and is equal to the magnetization period, and D_2 is the demagnetization period, equal to $(1 - D_1)$ when the converter operates in continuous conduction mode CCM.

$$V_{out} = \frac{1}{N} \cdot \frac{D_1}{D_2} \cdot V_{in} \tag{1}$$

Voltage modulation is achieved by varying the conduction pulse width as shown in Fig. 3. The relationship between the length of the magnetization period and the demagnetization period depends on the transformer turns ratio. It should vary in a range of a factor of 10 to achieve the desired gain. For the extreme case where N is equal to the maximum input voltage divided by the output, the length of the magnetization period is always going to be larger than the length of the demagnetization period. For the opposite extreme case, where N is equal to $V_{in_{min}}$ divided by V_{out}, the ratio D_1/D_2 is always going to be lower than one.

Therefore, N must be set to know the pulse width modulation range. Its value affects the maximum voltage to be handled by the semiconductors devices, as shown in (2). Fig. 4 illustrates this dependence. The transformer design can lead to voltage stress higher than 1.7 kV. It also shows the graph for the maximum voltage to be handled by the switches within the AHB flyback topology, that is going to be explained below, only for comparison.

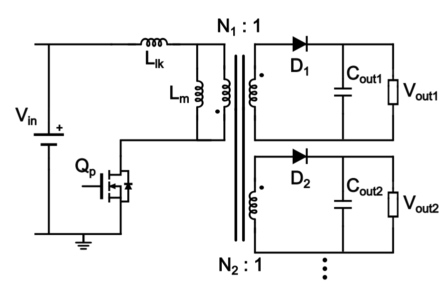

Fig. 2. Circuit schematic of a multiple output flyback.

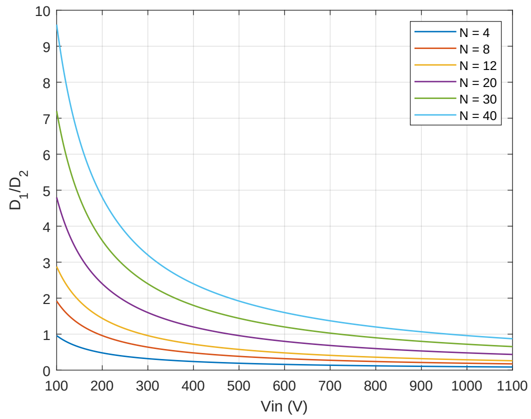

Fig. 3. Duty cycle factor in a flyback converter with $V_{out} = 24\ V$.

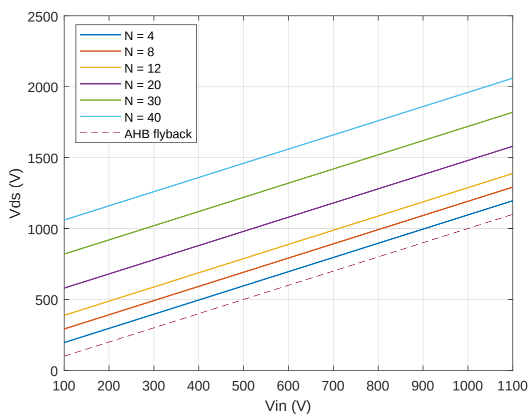

Fig. 4. Voltage stress across the semiconductor devices in the primary side.

$$V_{ds_{max}} = V_{in_{max}} + N \cdot V_{out} \tag{2}$$

Without power derating, it would not be convenient to have a D_1/D_2 ratio greater than approximately 2.33 corresponding at low V_{in} range to a magnetization interval of 70% of a period and a demagnetization interval of 30%, that results in selecting a small value of N. The problem comes from the fact that with a high V_{in}, the magnetization period is reduced, and the control of the converter becomes difficult. On the other hand, the problem in selecting a high turns ratio is that it could lead to a design where the commercial devices operate close to their maximum blocking voltage limits with the risk of leading to early failures, i.e. due to voltage surges. Some alternatives are proposed in [11], [16]. They study a series-connected flyback converter and an input-series-output-parallel flyback.

B. New AHB flyback design

This paper proposes the Asymmetrical Half-Bridge (AHB) flyback topology [17]–[19] preceded by a boost converter with PFC capability [20] to improve the performance, or in case input power is above 75 W. Thus, the converter supports both DC and AC voltage signals at the input. Its circuit diagram is shown in Fig. 5. The advantage of this topology is its hybrid

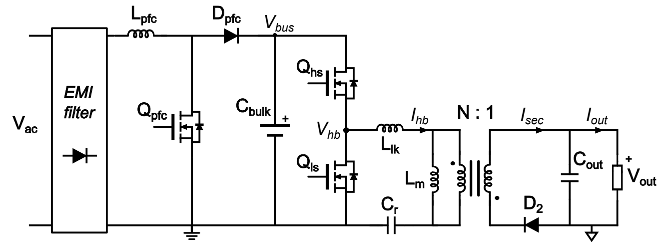

Fig. 5. Diagram of the AHB flyback preceded by a PFC boost converter.

nature between forward and flyback topologies thanks to its resonant behavior between L_{lk} and C_r.

As in the flyback, the turns ratio N is decisive in the selection of the rest of the components. Considering an ideal transformer, the ratio between V_{in} and V_{out} is set by (3) in the AHB flyback, where D is the duty cycle, defined as the time in which the high-side switch is turned on in a period.

$$V_{out} = \frac{1}{N} \cdot D \cdot V_{in} \tag{3}$$

If only the DC/DC stage of the converter is considered, the duty cycle must be confined to a large amplitude range. The advantage of placing the upstream PFC boost is that the range of the AHB flyback input voltage can be reduced in the dimensioning. The DC bus can be set to a minimum value of 400 V. For input voltages below 400 V, the boost raises the voltage to this value. For higher input voltages, this first stage does not work, and only the isolated DC/DC converter is considered. Thus, the AHB flyback would have to be designed to be able to operate in an input voltage range between 400 V ($V_{in_{min}}$) and 1100 V ($V_{in_{max}}$), as in Table I.

The design of the auxiliary power supply with an AHB flyback also has the advantage of reducing voltage stress on the semiconductor devices. The maximum voltage to be withstood by the semiconductor switches is limited to the input voltage, compared to the flyback in Fig. 4. It will never be higher than $V_{in_{max}}$, equal to 1100 V, that allows the use of smaller and more efficient semiconductors. On the other hand, the voltage stress of the secondary devices is determined by (4). Now, the blocking voltage of commercial semiconductor devices is a more relaxed constraint for the design of the converter.

$$V_{dsSR_{max}} = \frac{V_{in_{max}}}{N} \tag{4}$$

TABLE I
AHB FLYBACK DIMENSIONING.

Parameter	Value
V_{in}	400 V to 1100 V
V_{out}	24 V
I_{out}	3.125 A
L_p	560 μH
N	11
D	66.0% to 24.0%
F_{sw}	105 kHz to 238 kHz

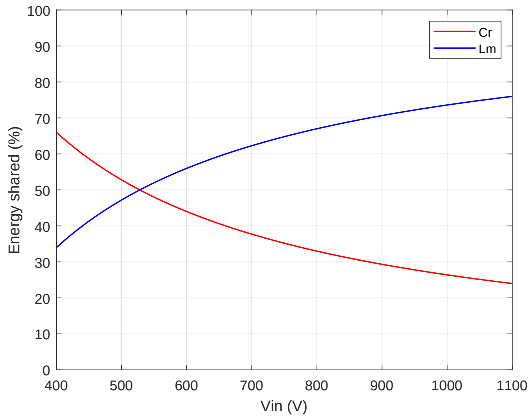

Fig. 6. Energy shared between L_m and C_r in the AHB flyback topology.

C. Comparison between Flyback and AHB flyback

The study of the AHB flyback in other applications has shown that it is usually more efficient than conventional flyback topologies due to its nature of forward energy transfer [19]. AHB flyback operates under ZVS and ZCS condition. It offers high efficiency and a very high power density. In [21], it is demonstrated that planar transformers can be used to increase power density also improving the efficiency obtained by using wire-wound transformers in a 100 W prototype.

The AHB flyback can operate well over a very wide input voltage range [20]. It does not have the flyback limitation of the blocking voltage in semiconductor devices. In a flyback, the primary current is discontinuous, and the transformer inductance generates excessive voltage stress on the devices. In the proposed topology, the voltage stress is limited to V_{in}.

In terms of cost and complexity, the flyback design has fewer devices since only one transistor is needed in its design. The proposed design of the AHB flyback would require two switches, or three if the PFC is needed. However, these devices will be cheaper since they will have to withstand less voltage.

The main difference is the hybrid nature forward-flyback of the AHB flyback, what increases its power density. The factor of the energy F_{Ecr} obtained with (5) is the percentage of the total energy that is transferred in forward mode. This energy is stored in the capacitor, not in the transformer. Hence, the magnetic energy storage is lower than in a flyback, where 100% of the energy is stored in the transformer, what reduces the transformer size. Fig. 6 illustrates this energy balance between the transformer and the resonant capacitor and its dependence on the input voltage.

$$F_{Ecr} = N \cdot \frac{V_{out}}{V_{in}} \tag{5}$$

III. Results

To validate the performance of the proposed converter, a design with the dimensioning of Table I is examined. It can be built with the components in Table II. Half-bridge transistors must be able to withstand a voltage above 1100 V, which is $V_{in_{max}}$. Table III shows the details of the transformer design. Due to the hybrid forward-flyback nature of this topology, the transformer design can be realized with a ferrite core of 96.6 mm^2 effective area A_e [21].

TABLE II
Components for the converter prototype.

Parameter	Value	Part number
HS SiC	350 mΩ / 1200 V	IMBG120R350M1H
LS SiC	350 mΩ / 1200 V	IMBG120R350M1H
SR MOSFET	130 mΩ / 300 V	BSC13DN30NSFD
Input capacitor	66 μF / 1.3 kV	B32320I1666K000
Output capacitor	3x330 μF / 50 V	A750MW337M1HAAE020
Controller	AHB controller	XDPS2221

TABLE III
Transformer properties.

Parameter	Value
Core type	RM10
Core material	3C95
L_p	560 μH
N_p	44 turns
N_s	4 turns
A_e	96.6 mm^2
I_{pp}	1.487 A
B_{max}	135.41 mT

The main waveforms of the converter operating at 400 V input voltage and 24 V and 75 W output, are shown in Fig. 7, where ZVS and ZCS can be observed.

Fig. 8 also shows the operating of the converter at 75 W, but now running at 1100 V input voltage. The converter gain has been modulated by reducing the duty cycle and increasing the switching frequency in an inversely proportional relationship between both parameters.

IV. Conclusions

The need to increase the energy conversion efficiency in hybrid inverters requires a high-efficiency auxiliary power

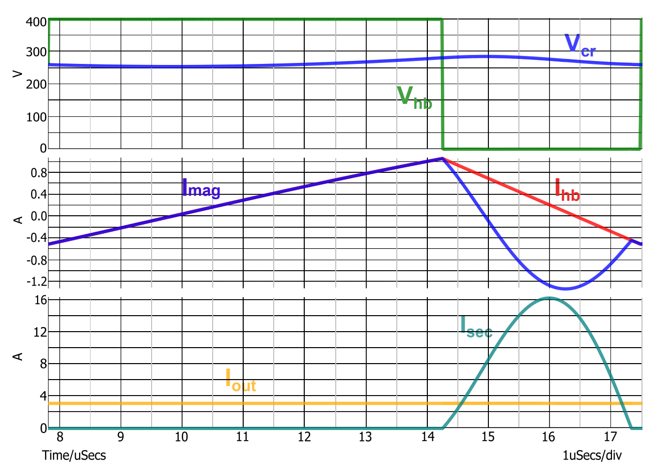

Fig. 7. Simulation waveforms of the AHB flyback at 400 V input operation.

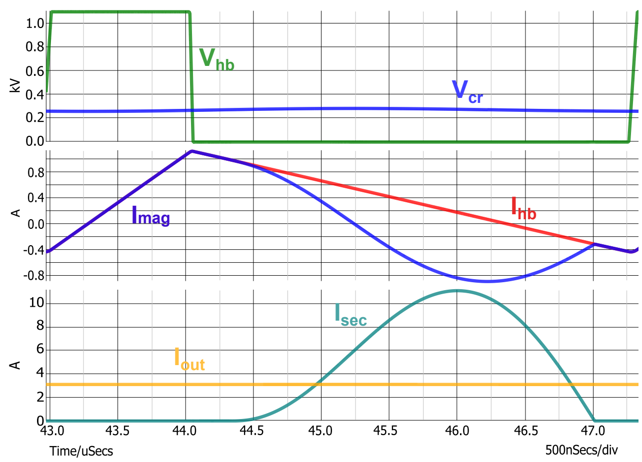

Fig. 8. Simulation waveforms of the AHB flyback at 1100 V input operation

source with a high conversion ratio due to the triple input architecture: distribution grid, batteries and PV panels. For this reason, this paper presents the option of having an AHB flyback preceded by a boost converter for that purpose. This architecture can operate over a wide input voltage range and it reduces the voltage stress on the semiconductors devices at the value of the input voltage, which allows it to be designed with commercial devices. Additionally, it is shown its advantage due to its hybrid nature between flyback and forward. Thanks to it, part of the energy is stored in the resonant capacitor and part of the energy is stored in the magnetizing inductance of the transformer. This allows to reduce the size of the magnetic component, and increases the power density and efficiency of the auxiliary power source.

To validate its operation over the entire operating range of the input voltage, a prototype design is proposed and validated by simulation. A correct operation achieving soft switching is observed, thanks to the modulation in the duty cycle and frequency of the converter.

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