$$T(s) = \frac{V_0(s)}{V_1(s)} = \frac{(\frac{W_0}{Q})s}{s^2 + (\frac{W_0}{Q})s + W_0^2} \quad (7)$$

where $W_0 = 2\pi f_0 = 1/\sqrt{[LC]}$, f_0 is the central frequency, and $Q = R\sqrt{[C/L]}$. An RC biquad is derived by substituting the inductor L by the structure of Fig. 1, with $Z_2 = (1/sC)$, $Z_1 = Z_3 = R$. The corresponding circuit was breadboarded using dual opamps, MOS transistor arrays, $R = 1\text{k}\Omega$ and $C = 1\mu\text{F}$. Fig. 2*b* shows the obtained gain transfer functions of the filter in accordance with the design specifications (f_0 = 1, 2, 3, 4 and 5kHz). The filter parameters were tuned by varying the control voltage ΔV_C of the LVCI.

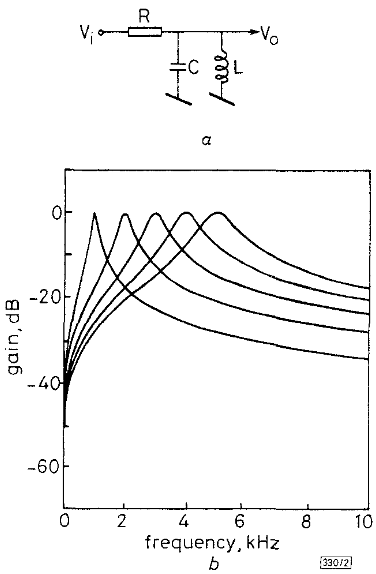

Fig. 2 *Second-order passive LC filter and amplitude responses of band-pass active filter derived from the passive LC filter*

a Second order filter
b Amplitude response

Conclusions: A new active circuit has been proposed that provides wide range LVCI. This structure has the advantage of facilitating the realisation of positive as well as negative impedances from the same topology. It also can be used for the linear tuning of different types of analogue circuits.

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T. Ndjountche (*BP 4543 Yaounde, Cameroon*)

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Optimising single-phase PFC pre-staged AC/DC/AC topology via common-neutral connection

Wen-Jung Ho, Mu-Shen Lin and Wu-Shiung Feng

Indexing terms: Power converters, Power electronics

A new topology for the single-phase PFC-pre-staged AC/DC/AC converter is presented. The introduction of a common-neutral connection simplifies the conventional connection of an AC/DC/AC structure, and gives a new topology that still has good performance, conforms with output safety regulations and has other advantages such as requiring fewer power devices and having lower conduction losses.

Introduction: Since utility systems can be easily contaminated, the demand for an AC/DC/AC converter with input power factor correction (PFC) is growing rapidly because it could serve as the main power stage of an uninterruptible power supply (UPS), AC cycloconverter, AC line conditioner, etc. [1 – 5]. An AC/DC/AC converter usually consists of a PFC and a PWM inverter. Both attracted interest for many years, however very little has been discussed about their connection topologies. Hence, by changing the conventional connection type into a common-neutral one, this Letter gives a new economical topology for the AC/DC/AC converter.

AC/DC/AC with common-neutral connection: Besides basic electrical functions, a practical power stage should satisfy the following:
(i) Cost reduction: mainly determined by the numbers of power semiconductor devices and bulk transformers, which are usually more expensive than other power components
(ii) Compliance with safety regulations: it must comply with electric safety regulations otherwise the power stage could not be used in power supply equipment [1, 2].

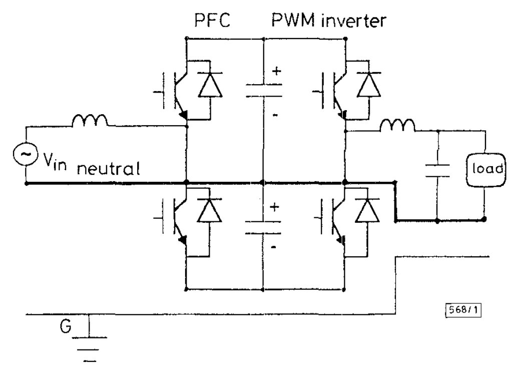

Fig. 1 *Economic AC/DC/AC topology with common-neutral connection*

By connecting a voltage-doubler PFC and a half-bridge inverter via a common-neutral (bold line), an efficient and compact structure can be obtained, as shown in Fig. 1. This AC/DC/AC structure can satisfy the above demands. Nevertheless, its performance is not good enough because it has to use a non-optimal bipolar PWM switching scheme for the PFC and inverter. This results in imperfect input current shaping and serious conduction/radiation electric magnetic interference (EMI) [4]. Furthermore, a half-bridge inverter has an inherent limitation with regard to reactive loads, and cannot therefore be effectively used in an AC power supply.

Proposed topology: Fig. 2 shows the conventional connection of an AC/DC/AC structure which consists of a two-switch H-bridge PFC, full-bridge inverter and isolation transformer, including all dashed-line components (pseudo-switch open). This structure is performance-oriented because the PFC uses a unipolar-voltage switching scheme which yields lower input current distortion and less EMI, and the full-bridge inverter is more capable of handling reactive and heavy loads [5]. However, this configuration has two more power transistors and diodes than that in Fig. 1, and

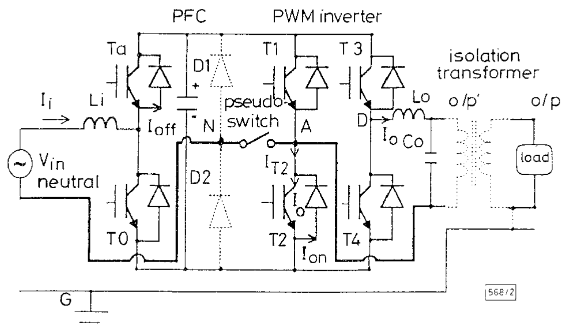

Fig. 2 *Performance-oriented AC/DC/AC topology*

(1) Pseudo-switch open: conventional connection, including dashed line devices
(2) Pseudo-switch closed: proposed common-neutral structure, excluding dashed line devices (D_1, D_2, and *o/p* transformer), the load connected to *o/p′*

requires a bulk isolation transformer at the output. This is because the neutral-ground voltage V_{AG} is related to the PWM waveforms of the inverter switches (T_1–T_4), and if a transformer is not used, the new output terminal, denoted by *o/p′*, cannot be connected to ground *G* to comply with safety regulations [2]. Fig. 3 shows the simulated voltage waveforms of interest. We find that V_{AG} is a quasi-sinusoidal waveform carrying a saw-toothed PWM waveform, and its amplitude is around half the inverter output V_{AD}. Hence, the bulk transformer is used to separate V_{AG} and connect the second side of it to ground.

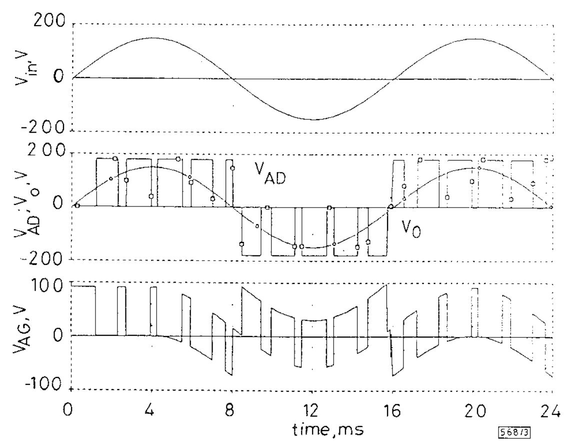

Fig. 3 *Simulated waveforms of Fig. 2, including V_{in}, V_{AD}, V_o and V_{AG}*

The simulated waveforms are for the converter shown in Fig. 2 with the pseudo-switch open and/or closed

The proposed topology is an improvement of the structures in Figs. 1 and 2, and it satisfies both the demands for high performance and economy. In Fig. 2 if we connect node *A* with node *N* (pseudo-switch closed), the common-neutral connection, then we can remove all the components enclosed by dashed lines, consisting of output transformers D_1 and D_2. In this way $V_{AG} = V_{NG}$, and the new output *o/p′* can keep the same neutral-ground connection as for the input network, just as in Fig. 1. Usually the utility neutral-ground V_{NG} is less than a few volts, neutral earthing through the input network, for safety reasons [1, 2]. Moreover, D_1 shunts using T_1's built-in diode and D_2 shunts using T_2's built-in diode. Thus both D_1 and D_2 can be omitted for redundant situations.

Because all the active components T_a–T_b and T_1–T_4 are unchanged, the proposed structure can employ the same driving and control circuits as the original conventionally connected structure. Hence, switches T_a and T_b are controlled to shape the input current to be sinusoidal for the PFC function; switches T_1–T_4 are operated in a PWM fashion to generate an output voltage for the inverter function. When the input voltage is positive, switch T_b turns on, I_i flows via T_2's built-in diode (instead of D_2) to energise L_i, then off-boosts the input to charge the DC link capacitor, shaping the input current to be sinusoidal and in phase with input voltage. In the negative cycle, switch T_a with its corresponding components will also perform in the same way [4, 5].

Now that the proposed circuit has no D_1 and D_2 in the PFC to carry the switching current and transfer it to T_1's and T_2's built-in diodes, an interesting question arises: will switches T_1 and T_2 experience an increase in current? The answer is 'no'. In the positive cycle, I_{on} carries I_i while T_b is closed, and I_{off} carries I_i while T_b is open. Meanwhile, if the inverter switches T_1–T_4 work with the synchronous PWM waveform as usual, I_o will flow through T_3 and T_2, thus the current through switch T_2 will be $I_{T2} = I_o - I_{on}$ when T_b is closed ($I_{T2} = I_o$ when T_b open) as indicated in Fig. 2. Comparably, in the conventionally connected topology, $I_{T2} = I_o$ whenever T_b is closed or open. We know that the conduction losses of T_2 depend on the product of transistor voltage and current ($P_{cond.\ loss} = V_{T2} \cdot I_{T2}$). Therefore the proposed topology has lower conduction losses because of the smaller average transistor current I_{T2} when compared with the conventional connection. In the negative cycle, T_1 will have equivalent results.

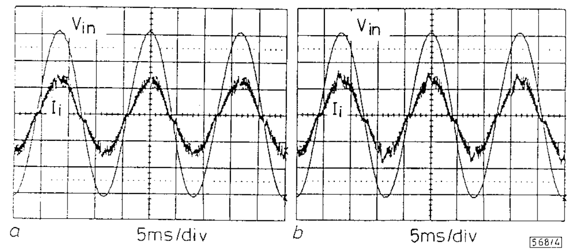

Fig. 4 *Input waveforms*

a Input waveforms of conventional connection structure
b Input waveforms of proposed structure; V_{in} (50V/div) and I_i (5A/div)

Test results: To verify the feasibility of the proposed AC/DC/AC converter, a 1 kW prototype with two-switch H-bridge PFC and full-bridge inverter was implemented, and was then converted to the proposed configuration. The PFC operated around 20 kHz, and the inverter operated around 10 kHz with L_i = 2.2mH, L_o = 2.2mH, and C_o = 10μF. Fig. 4*a* and *b* shows the test results of similar input waveforms for the conventional and proposed connection, respectively. I_{T2} = 4.0A RMS (I_{T2} = 5.2A RMS for the conventional connection), i.e. the new topology shows lower conduction losses.

Conclusions: A new PFC-pre-staged AC/DC/AC topology with common-neutral connection has been proposed. This topology provides good performance, complies with safety regulations, has few power devices, and low conduction losses.

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Wen-Jung Ho, Mu-Shen Lin and Wu-Shiung Feng (*Department of Electrical Engineering, National Taiwan University, Taipei 10617, Taiwan, Republic of China*)

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