Common-Neutral-Type AC/DC/AC Topologies with PFC Pre-regulator

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

Department of Electrical Engineering
National Taiwan University
Taipei 10617 , Taiwan

Abstract

In this paper new topologies of single-phase PFC-pre-staged AC/DC/AC converter are presented. By introducing the common-neutral connection to simplify a conventional connection of AC/DC/AC structure, they derive new topologies but keep good performance, output safety-code conformed and provide extra advantages -- fewer power devices and lower conduction losses.

I. Introduction

With the utility systems being fluctuated and contaminated easily, the demand for AC/DC/AC converter with input power factor correction (PFC) is growing rapidly because it can serve as the main power stage of uninterruptible power supply (UPS), AC cycloconverter, and AC line conditioner etc. [1~4].

A PFC-pre-staged AC/DC/AC converter with common-neutral connection consists of a pre-staged PFC and a post-staged PWM inverter. For example, connecting a two-switch voltage-doubler PFC and half-bridge inverter via common-neutral connection (bold-line) can built a frugal structure as shown in Fig. 1 [1]. This AC/DC/AC structure can satisfy the demands of cost reduction and compliance of safety-code. Although its performance is not good enough because it has to use non-optimal bipolar PWM switching scheme for PFC and inverter.

PFC and inverter have been the source of interest in the literature for many years, yet very little is discussed about the relationships of connection. Hence, this paper explores new topologies of AC/DC/AC converter with common-neutral connection and their superior performance.

II.The Proposed AC/DC/AC Topologies

A. An Economical AC/DC/AC Topologies with Common-Neutral Connection

Connecting a single-switch voltage-doubler PFC and half-bridge inverter via common-neutral connection of bold-line can built an improvement structure as shown in Fig. 2. Although it has half-bridge inverter

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with non-optimal bipolar PWM switching scheme, the PFC employs unipolar-voltage switching scheme which yields lower input current distortion and less EMI [2].

Switches T_a are controlled to shape the input current to be sinusoidal for PFC function; switches T_1~T_2 are operated in a PWM fashion to generate output voltage for inverter function. When input voltage is positive, switch T_a turns on, I_i goes forward to energize L_i, then off boosts input via D_1 to charge upper DC capacitor, shaping the input current to be sinusoidal in phase with input voltage simultaneously. In the negative cycle, also do the same job but charge the other DC capacitor.

B. H-bridge AC/DC/AC Topologies with Common-Neutral Connection

Fig. 3 shows a conventional connection of AC/DC/AC structure which consists of a 2-switch H-bridge PFC, full-bridge inverter and isolation transformer, including all dash-line components (pseudo-switch open). It is of a performance-oriented structure because the PFC employs unipolar-voltage switching scheme which yields lower input current distortion and less EMI, and the full-bridge inverter is more capable of undertaking reactive and heavy load [3]. However, this configuration has more power transistors and diodes than Fig. 1 and Fig. 2, and especially it has to add a bulk isolation transformer to the output. Because the neutral-ground voltage V_{AG} is of PWM-related waveforms during inverter transistors T_1~T_4 switching. If without the transformer, the new output terminal, denoted by *o/p*', cannot connect with the ground G to comply with safety code [4]. Fig. 4 shows the simulated voltage waveforms we interest. We can find that V_{AG} is a quasi-sinusoidal waveform carrying with saw-toothed PWM, and its amplitude is around half the inverter output V_{AD}. and dangerous to be touched. Hence, the bulk transformer is an inevitable device to separate V_{AG} and connect the second side of it to the ground.

The proposed topology is also an improvement of structure, and it satisfies both sides -- the demands of performance and economy. In Fig. 3 if we connect the node A with node N (pseudo-switch closed) -- common-neutral connection -- we can save all the dash-line components consisting of output transformer, D_1 and D_2. Because in this way $V_{AG} = V_{NG}$, the new output *o/p'* can keep the same neutral-ground relationship as the input network just like Fig. 1 and Fig. 2. Usually the utility neutral-ground V_{NG} is under few volts -- neutral earthing through the input network -- for safely touching it [4]. Moreover, D_1 shunts with T_1's built-in diode and D_2 shunts with T_2's built-in diode. Thus both D_1 and D_2 can be omitted for redundant situation.

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 conventional connection one. Hence, switches T_a and T_b are controlled to shape the input current to be sinusoidal for PFC function; switches T_1~T_4 are operated in a PWM fashion to generate output voltage for inverter function. When input voltage is positive, switch T_b turns on, I_i goes via T_2's built-in diode (instead of D_2) to energize L_i, then off boosts input to charge DC link capacitor, shaping the input current to be sinusoidal in phase with input voltage simultaneously. In the negative cycle, switch T_a with the counterpart components will also do the same job [2,3]. Fig. 5(a) and 5(b) show the test results of similar input waveforms of the conventional and proposed connection respectively.

In the positive cycle, I_{on} carries I_i while T_b closed, and I_{off} carries I_i while T_b open. Meanwhile, if the inverter switches T_1~T_4 work on synchronous PWM action as usual, I_o will go through T_3 and T_2, thus the switch T_2's current $I_{T2} = I_o - I_{on}$ when T_b closed ($I_{T2} = I_o$ when T_b open) as indicated in Fig. 3. Comparably, in the topology of conventional connection, $I_{T2} = I_o$ whenever T_b is closed or open. We know the conduction losses of T_2 depend on the product of transistor voltage and current ($P_{cond.\ loss} = V_{T2} \bullet I_{T2}$). Therefore the proposed topology has less conduction losses because of smaller average transistor current I_{T2} when compared with the conventional connection. In the negative cycle, T_1 will have the analogous results.

C. 3ϕ input / 1ϕ output AC/DC/AC Topologies with Common-Neutral Connection

Fig. 6 ~ Fig. 8 shows the topologies of 3 phase input / single-phase output, which can reduce the value of input current and the DC-bus capacitor, and many other beneficial points as well. Fig. 6 employs two-switch voltage-doubler PFC as the input and half-bridge inverter as the output via common-neutral connection (bold-line) can built a frugal structure. Fig. 7 employs single-switch voltage-doubler PFC as input and half-bridge inverter as the output via common-neutral connection of bold-line can built an improvement structure. Fig. 8 employs the proposed topology of single-phase common-neutral-type AC/DC/AC as the input (pseudo-switch closed) that is also an improvement of structure, and it satisfies both sides -- the demands of performance and economy.

III. Test Results

To verify the feasibility of the proposed AC/DC/AC converter, a 1KW prototype with 2-switch H-bridge PFC and full-bridge inverter was implemented, and then converted it to the proposed configuration and still worked well. The PFC operated around 20kHz, and inverter operated around 10kHz with Li=2.2mH, Lo=2.2mH, and Co=10uF. Fig. 5(a) and 5(b) show the test results of similar input waveforms of the conventional and proposed connection respectively. And, I_{T2}=4.0A rms (I_{T2}=5.2A rms for conventional connection), i.e. the new topology shows lower conduction losses.

IV. Conclusions

The new PFC-pre-staged AC/DC/AC topologies with common-neutral connection has been presented. They provides good performance, safety-code conformed, few power devices, and low conduction losses as well.

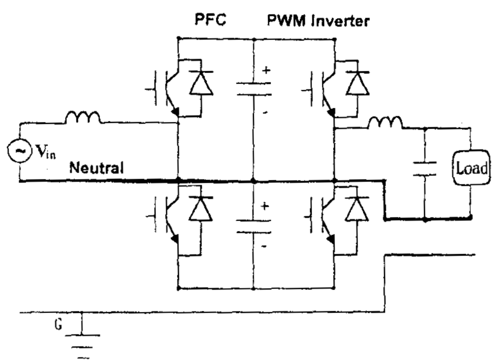


Fig. 1: An AC/DC/AC topology with common-neutral connection.

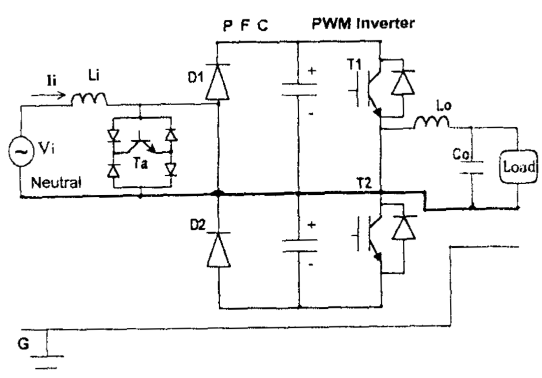


Fig. 2: The proposed AC/DC/AC topology with common-neutral connection.

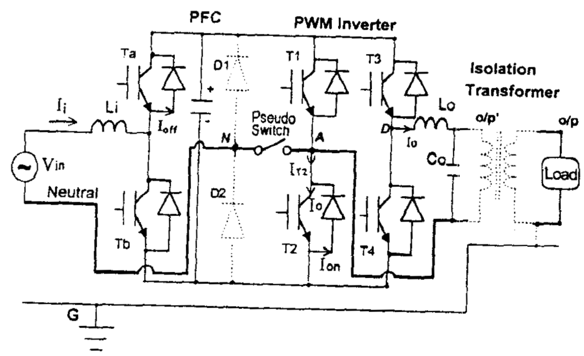


Fig. 3: A performance-oriented AC/DC/AC topology
1) pseudo-switch open -- conventional connection, including dash-line devices.
2) pseudo-switch closed -- the proposed common-neutral structure, excluding dash-line devices (D_1, D_2, & o/p transformer), the load conneted to o/p'.

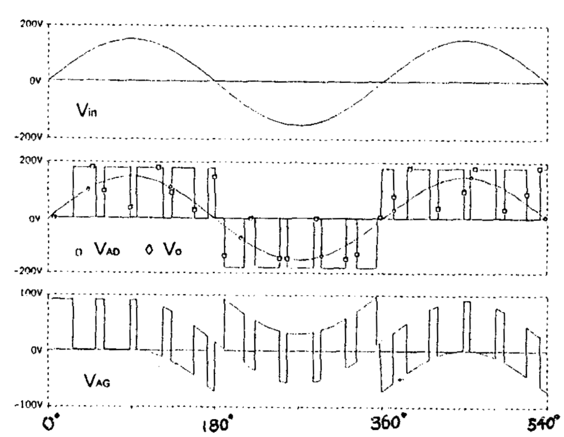
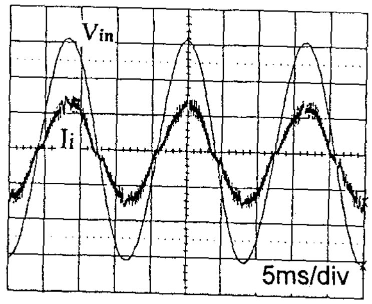
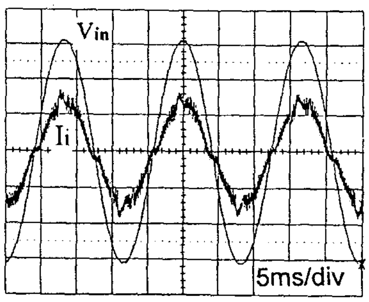


Fig. 4: Simulated waveforms of Fig. 3, including V_{in}, V_{AD}, V_o and V_{AG}.



(a)



(b)

Fig. 5: (a) Input waveforms of conventional connection structure, and 5(b) Input waveforms of the proposed structure, V_{in} (50V/div) and I_i (5A/div).

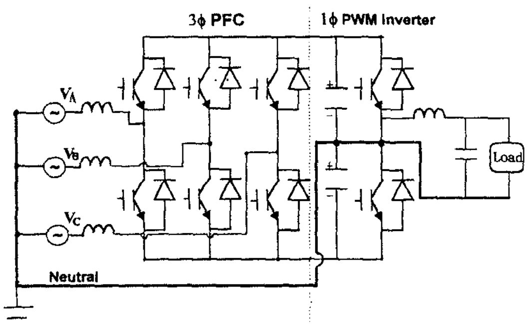


Fig. 6: 3ϕ input / 1ϕ output AC/DC/AC topologies with common-neutral connection using two-switch voltage-doubler PFC and half-bridge inverter

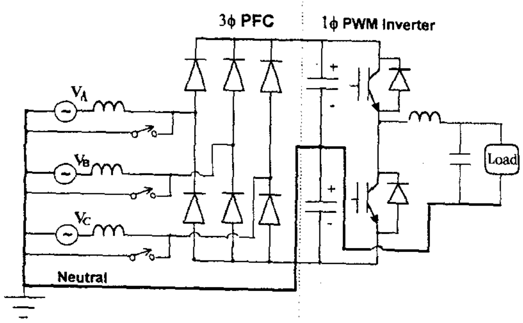


Fig. 7: 3ϕ input / 1ϕ output AC/DC/AC topology with common-neutral connection using single-switch voltage-doubler PFC and half-bridge inverter

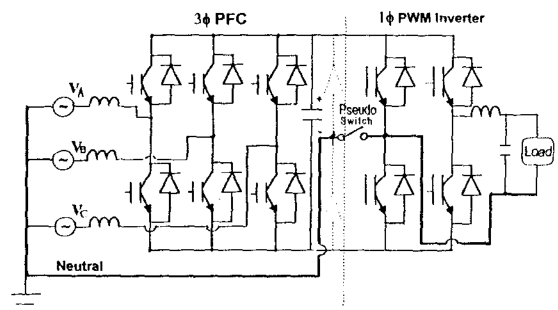


Fig. 8: 3ϕ input / 1ϕ output AC/DC/AC topology with common-neutral connection using H-bridge AC/DC/AC topology

References:

[1] Yuasa Corporation, Osaka, Japan, " Development of UPS using new type of circuits," IEEE INTELEC'94, Conf. Proceedings, pp. 635-642.

[2] John C. Salmon, "Circuit topologies for single-phase voltage-doubler boost rectifiers, " IEEE Trans. Power Electronics, Vol. 8, No. 4, pp. 521-529, Oct. 1993.

[3] I. Kubo, Y. Ozawa, R. Nakatsuka, A. Shimizu, "A fully digital controlled UPS using IGBT's," IEEE IAS'91, Conf. Proceedings, pp 1042-1046.

[4] Kimmo Dahl, IVO Engineering, "Different Methods of UPS Neutral and Protective Earthing and Their Impact on Human Safety and System Disturbances," IEEE INTELEC'91, Conf. Proceedings, pp. 443-448.