



US011451139B2

(12) **United States Patent**
Forouzesh et al.

(10) **Patent No.:** US 11,451,139 B2

(45) **Date of Patent:** Sep. 20, 2022

(54) **THREE-PHASE SINGLE-STAGE**

(56)

References Cited

REFERENCES

WITH POWER FACTOR CORRECTION

U.S. PATENT DOCUMENTS

(71) Applicants: **Queen's University at Kingston,**
Kingston (CA); **Ganpower**
International Inc., Vancouver (CA)

10,686,385 B2 6/2020 Brown et al.
2003/0151935 A1* 8/2003 Lubomirsky H02M 7/10
363/125

(Continued)

(72) Inventors: **Meitaba Forouzesh,** Kingston (CA);

- (51) **Int. Cl.** 2021/0399624 A1* 12/2021 Brown H02J 7/02
H02M 1/08 (2006.01)
H02J 7/02 (2016.01)
H02M 3/00 (2006.01)
H02M 3/335 (2006.01)
B60L 53/00 (2019.01)
H02M 1/00 (2006.01)
- (52) **U.S. Cl.**
 CPC *H02M 3/33573* (2021.05); *B60L 53/00*
 (2019.02); *B60L 2210/30* (2013.01); *H02J*
2207/20 (2020.01); *H02M 1/0009* (2021.05);
H02M 1/0058 (2021.05)

FOREIGN PATENT DOCUMENTS

CN 102201750 B * 10/2014
 CN 105305842 A * 2/2016
 WO WO-2018109103 A1 * 6/2018 B60L 53/20
 WO WO-2020089739 A1 * 2/2020

OTHER PUBLICATIONS

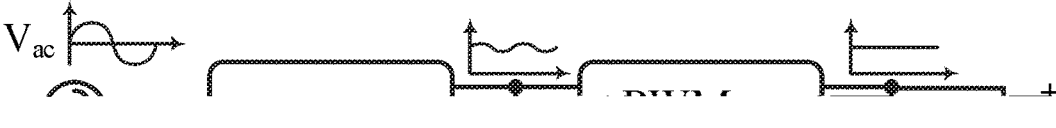
Kamnarn, U., et al., "Analysis and Design of a Modular Three-Phase AC-to-DC Converter Using CUK Rectifier Module With Nearly Unity Power Factor and Fast Dynamic Response". IEEE Transactions on Power Electronics, vol. 24, No. 8, pp. 2000-2012, (2009).
 Zhang, J., et al., "A Dual Active Bridge DC-DC-Based Single Stage AC-DC Converter With Seamless Mode Transition and High Power Factor", IEEE Transactions on Industrial Electronics, vol. 69, No. 2, pp. 1411-1421, (2022).

(56) **References Cited**

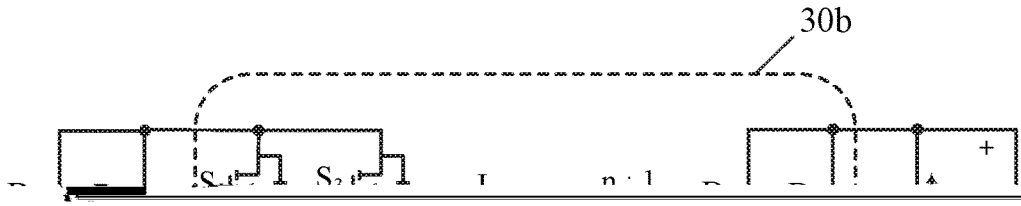
U.S. PATENT DOCUMENTS

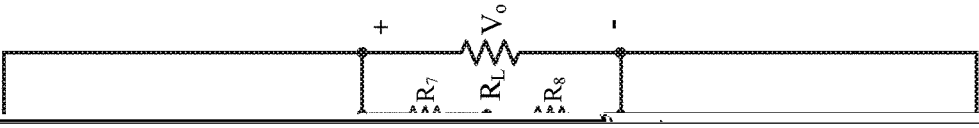
2007/0051712 A1* 3/2007 Kooken B23K 9/1043
 219/130.1
 2012/0120697 A1* 5/2012 Cuk H02M 1/4258
 363/126
 2015/0014290 A1* 1/2015 Kooken B23K 9/173
 219/130.1

* cited by examiner



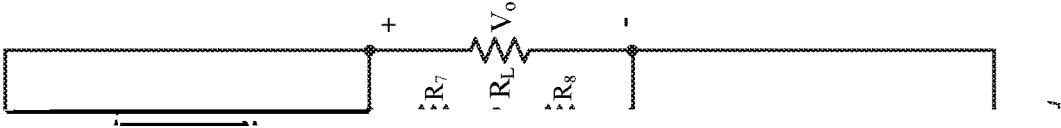


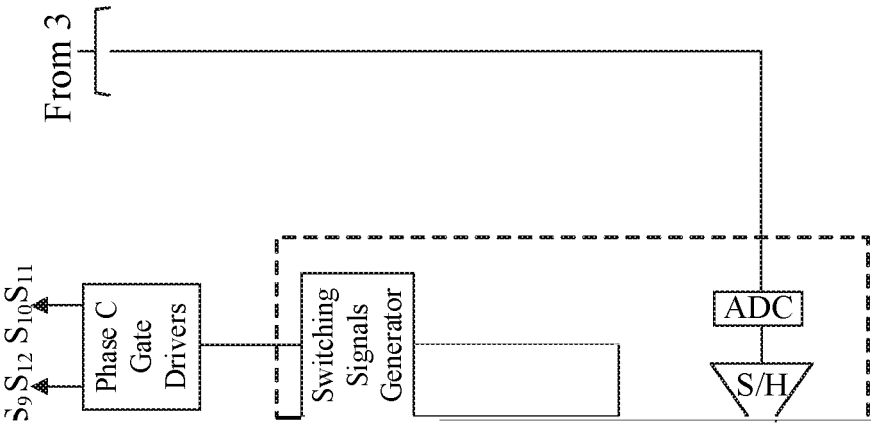


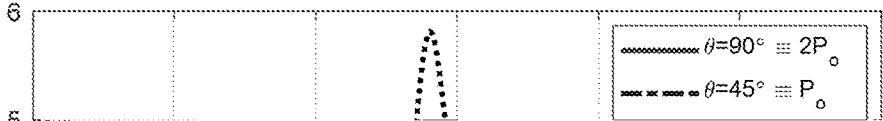


From c









ILr1



THREE PHASE SINGLE STAGE

suitable for high power applications, and four-wire three

**SOFT-SWITCHING AC-DC CONVERTER
WITH POWER FACTOR CORRECTION**

RELATED APPLICATION

This application claims the benefit of U.S. provisional application 62/795,375 filed on Jan. 22, 2019, the contents of which are incorporated herein by reference in their entirety.

phase systems are not desirable because of the higher cost of implementation.

SUMMARY

5

10

According to one aspect of the invention there is provided a three-phase AC-DC converter, comprising: first, second, and third input terminals that respectively receive first, second, and third AC voltage phases of a three-wire three-phase AC input voltage; first, second, and third rectifier circuits that respectively rectify the first, second, and third

3

circuits to respectively rectify first, second, and third AC voltage phases of a three-wire three-phase AC input voltage

4

FIGS. 5A-5B are schematic diagrams of a three-phase single-stage PFC isolated PWM boost converter with a

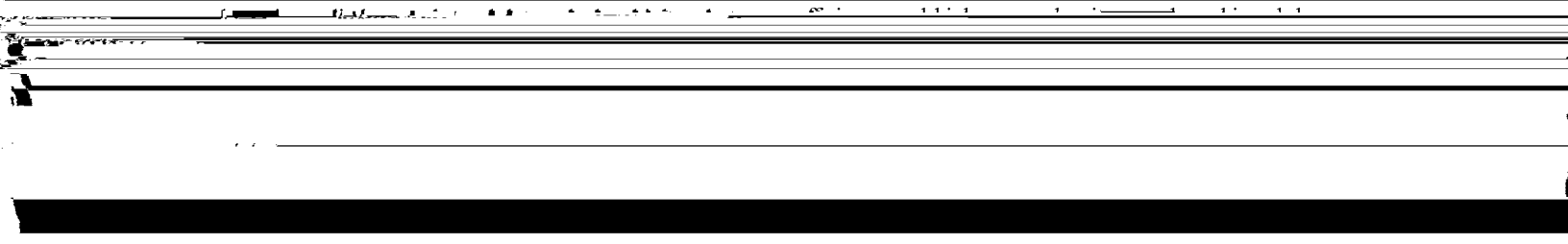
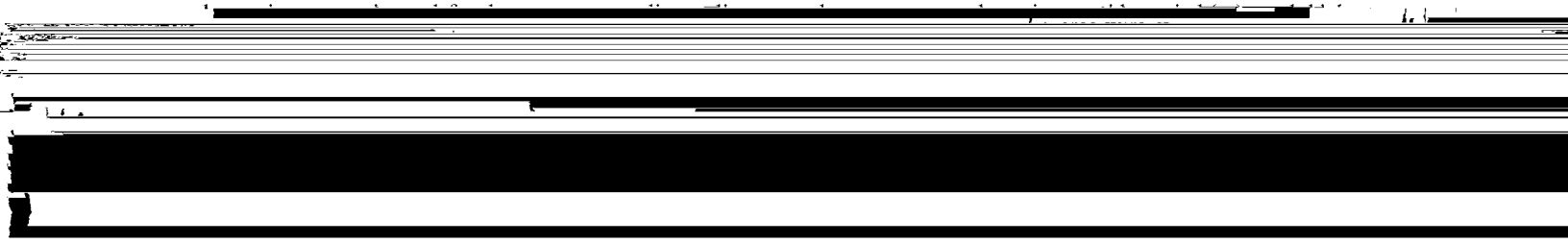
and respectively produce first, second, and third input DC voltages; using first, second, and third single-stage power factor correction (PFC) modules that respectively receive the first, second, and third input DC voltages and respectively produce first, second, and third output DC voltages; and connecting the first, second, and third output DC voltages together in parallel to produce a final output voltage; wherein the first, second, and third single-stage PFC mod-

digital control implementation, according to one embodiment.

5 FIG. 6 is a plot showing voltage gain of an LLC tank circuit at different phase angles.

FIG. 7 is a plot showing simulation results of a three-phase single-stage resonant PFC LLC converter according to the embodiment of FIGS. 4A-4B, with 380 VAC RMS three-phase input voltage (upper panel), three-phase input current (middle panel) and 400 VDC output voltage (lower

10



(3) n is the turns ratio of the transformer and is defined (2) as $f = 139.6$ kHz. For PFC operation, the minimum

as $n = N_p/N_s$. In (4) K is the inductance ratio and is defined as $K = L_p/L_s$ and f_n is the frequency ratio and is defined as

switching frequency is set to about f_p to ensure operation in the inductive mode and the minimum inductance L_p .

$f_n = f_s/f_p$. In PFC operation the instantaneous output power of (1) is set slightly high than f_p to ensure output voltage regulation

ively considering 380×1.7 V RMS three-phase voltage. It [12] Y. Iano et al. A new two-switch isolated three-phase

resonant frequency, confirming that ZCS is achieved for the output diodes (D_1 - D_{12}).

EQUIVALENTS

- Conference and Exposition (APEC), San Antonio, Tex., 2018, pp. 60-67.
- 5 [13] Y. K. E. Ho, S. Y. R. Hui and Yim-Shu Lee, Characterization of single-stage three-phase power-factor-correction circuit using modular single-phase PWM-DC to

11

3. The three-phase AC-DC converter of claim 1, further comprising first, second, and third input filters connected between the first, second, and third input terminals and the first, second, and third rectifier circuits.

12

first, second, and third input DC voltages and respectively produce first, second, and third output DC voltages;
connecting the first, second, and third output DC voltages together in parallel to produce a final output voltage;