A Single-Phase Converter for Using Circuit Breaker Testing Application

P.RAMESH CHANDRA HOD, ASSOCIATE PROFESSOR,DEPT.OF EEE, GDMM COLLEGE OF ENGINEERING AND TECHNOLOGY A.P, INDIA

N.NAGA DIVYA ASSISTANT PROFESSOR, DEPT.OF EEE, GDMM COLLEGE OF ENGINEERING AND TECHNOLOGY A.P, INDIA

Abstract—This paper presents a novel single-phase ac-ac converter with power factor correction and output current control for circuit-breaker testing according to the IEC 60898 standard. The important advantages of the proposed circuit are low component count and fast responses for the standard requirement, especially a current step at the beginning of the test. The proposed single-phase ac-ac converter can operate in either buck or boost mode to accommodate the need for a wide range of output current while satisfying the ramping and step current requirements in the standard. The control circuits consist of two parts, dc voltage control of dc-link capacitors and ac output current controls operating simultaneously. The proposed circuit is verified through both computer simulation and hardware experiment. An example of a 50A circuit breaker testing according to the IEC 60898 is demonstrated in the paper.

I. INTRODUCTION

CIRCUIT-BREAKER (CB) is indispensable equipment in residential, commercial and industrial systems. It is designed to protect an electrical circuit from damage caused by overload or short circuit. The capability of interrupting the flow of the current to protect devices enables its utilization in virtually every applications. The time tripping characteristics of the CB and the test procedures detailed in IEC 60898 [1] are necessary in the process of quality control. Commercially available current sources for CB testing are designed using a motor-driven tap-changing auto-transformer for ac output current regulation. Recently, several ac-ac converters have been developed and improved in terms of higher current rating capability and higher efficiency. Also, they have included the power factor correction (PFC) to regulate the input current to be sinusoidal wave shaping with nearly unity power factor. In practice, the ac-ac converters are widely applied to various industrial applications such as UPS, voltage stabilizer, electric Several topologies of single-phase ac-ac converter had been reported. The single-phase ac-ac two-leg, three-leg and four-leg (two full-bridges) converters have been presents [4]-[7]. They are widely adopted choices of converters in UPS, motor drive or grid-connected applications [4]-[5]. These topologies consist mainly of two stages; a controlled rectifier (e.g., boost PFC topology) and a single-phase inverter. They can be operated in either buck or boost mode for the desired level of ac output voltage. The output frequency is controllable and can be set to the values different from the input frequency. The three-leg and two-leg single-phase ac-ac converters are operated in hard switching scheme, producing the switching loss and electromagnetic interferences [5], [6]. In addition, the two-leg single-phase converter has high ripple voltage at the dc-link capacitors.

In a buck-type ac-ac converter reported in [8], the ac output voltage is controlled using the modified sinusoidal pulsed-width modulation (SPWM). This topology introduces a distortion on the ac output voltage at the zero-crossings. Also, the output voltage is limited to the values less than the input voltage due to its buck-type topology.

Resonant converter topologies have also been used in the ac-ac conversion applications [9], [10]. The resonant converter is suitable for applications with a fixed frequency where the output frequency cannot be significantly differed from this frequency. For instance, the 60 Hz signal is not achievable with the 50 Hz input signal.

In ac-ac z-source converters, the z-source network is primarily used to store energy and the output voltage is load dependent [10]-[11]. The output voltage is varied through the duty ratio created from a PWM signal.

The key requirements of ac-ac converter for circuit-breaker testing are a wide range of output voltage with low harmonic distortion and high input power factor. Therefore, it must be capable of operating in buck and boost modes with the required dynamics of step current and ramp rate specified in [1].

The single-phase ac-ac converter has been presented in the system application for CB testing [2] according to the CB testing standard (IEC 60898) in Table I. It used four switches to control input current and output current with the same ground. The first part integrates rectifier and boost converter to regulate the dc-link voltages and control the ac input current with sinusoidal waveform in phase with the ac input voltage. The output current control is based on half-bridge topology to drive the positive and negative pulses by means of *SPWM* technique to the output.

Recently, a novel single phase ac-ac converter has been presented [3] and it is also suitable for CB testing application because it supports all key requirements of CB testing standard. This converter operates similarly with converter in [2], but its difference is about the converter output separated ground instead of shared ground. The ac-ac converter application for CB testing does not require the ac current output sharing the same ground with ac input voltage. As a result, the novel ac-ac converter has been selected to implement the proposed system for CB testing application. In addition, the proposed system is realized by the digital implementation according to the CB testing standard

The novel ac-ac converter topology can be compared with the four-leg converters (two full-bridges) [7]. They are the same operation both input current control and output voltage control with separated ground between input and output sides. A number of components is counted and compared between novel converter and four-leg converter as shown in Table II.

The novel topology has the reduced number of switches from eight to only four switches. Although the number of diodes is increased but the cost of switches is much more expensive than one of diodes.

The CB testing under the over current test condition consists of five tests, a, b, c, d, and e where the test currents vary from 1.13 to 20 times of the nominal rated current of CB (I_n) as shown in Table I [1]. The first three tests (a, b, and c) require that the peak of the test current is gradually varied whereas a step change is required in the other tests. The time current characteristics for over current CB test provided in Table I are the requirements for various CB types (B, C and D). Note that the current characteristics of each test are determined by the initial condition specified in the standard. For instance, the initial condition for tests a, c, d, or e is cold, meaning that there is no previous loading of CB before testing. However, the initial condition of the test b is performed immediately after the end of test a.
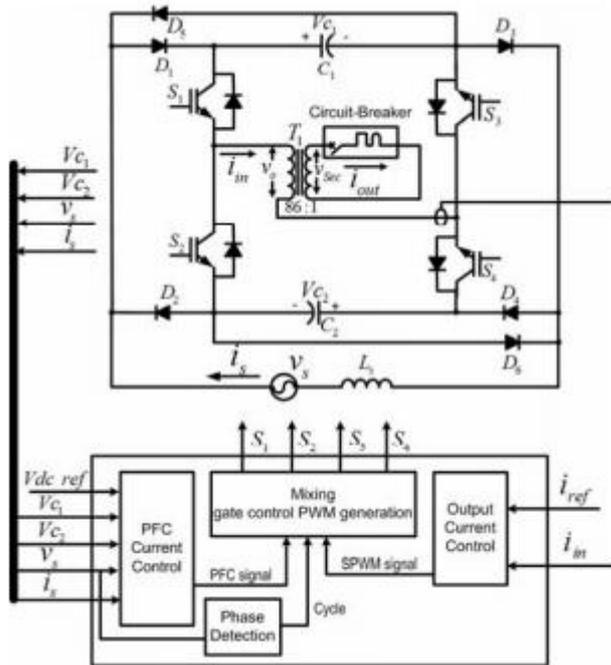
Fig. 1. Proposed ac-ac converter with dc-link voltage and ac output current controllers.

II. PROPOSED SYSTEM

The proposed system is shown in Fig.1. The ac-ac converter topology consists of four main switches (S_1 - S_4), two dc-link capacitors (C_1 and C_2), an inductor (L_s), diodes (D_1 - D_6), and a power transformer (T_1). In the system, the V_{C1} , V_{C2} , i_s and v_s are measured and fed back to the digital controller. The dc-link capacitor (C_1) is charged and V_{C1} is maintained constant during the positive cycle of v_s while the capacitor voltage V_{C2} is charged and maintained constant during the negative cycle. The input voltage is used as the reference signal for controlling the input current, i_s . The output current is regulated by the switches S_1 and S_3 during the positive pulse while the switches S_2 and S_4 operate during the negative pulse, using the sinusoidal PWM ($SPWM$) technique. The primary winding of the power transformer T_1 , with a turn ratio

of 86.3, is connected to the output of the dc-ac converter.

TABLE I
TIME-CURRENT OPERATING CHARACTERISTICS

Test	Type	Test current	Limits of tripping or non tripping time	Results to be obtained
a	B, C, D	$1.13I_n$	$t \geq 1h\ (I_n \leq 63\ A)$ $t \geq 2h\ (I_n > 63\ A)$	No Tripping
b	B, C, D	$1.45I_n$	$t < 1h\ (I_n \leq 63\ A)$ $t < 2h\ (I_n > 63\ A)$	Tripping
c	B, C, D	$2.55I_n$	$1s<t<60s(I_n \leq 32A)$ $1s<t<120s(I_n >32A)$	Tripping
d	B	$3I_n$	$t \geq 0.1\ s$	No Tripping
	C	$5I_n$		
	D	$10I_n$		
e	B	$5I_n$	$t < 0.1\ s$	Tripping
	C	$10I_n$		
	D	$20I_n$		

The transformer's secondary winding is short-circuited through the CB during testing. The output current is amplified by an order of the T_1 's turn ratio. The proposed topology yields power factor in the range of (0.97-0.99) under various output frequencies.

A.Integrated Rectifier/Boost Converter

The integrated rectifier and boost converter in the proposed system include three functions as follows.

       a) Rectifying the input voltage into a dc voltage signal;

       b) Boosting the dc voltage;

       c) Shaping the ac input current to be sinusoidal waveform.

The switches S_1 and S_2 are operated during the positive half cycle of the input voltage v_s to boost the voltage of the dc-link capacitor C_1 . The waveform of the input voltage v_s is used as a reference for shaping the inductor current (i_s). The aim is to force the input current i_s to be in phase with the input voltage for unity power factor. Meanwhile, the capacitor voltage, V_{C1} , is maintained to a constant value. Figs. 2 and 3

show the circuit configurations during the charging and discharging cycles of the inductor current i_s . During the positive cycle of the input voltage, the switches S_1 and S_2 are turned on and the inductor current i_s increases as shown in Fig. 2(a). To complete the boost cycle, the switch S_1 or S_2 is turned off, depending on the output pulses, and the inductor current i_s is decreased,

B. DC-AC converter

The proposed dc-ac converter is described in this section. The switches S_1 and S_3 are turned on to drive positive pulses to shown in Fig. 4(a). Similarly, during the negative output pulse, the dc-link voltage V_{C2} is connected to the converter output by turning on the switches S_2 and S_4 , as shown in Fig. 4(b). The output of the dc-ac converter is directly connected to the primary winding of the transformer T_1 .

C. Power Transformer

      Since the current required for the CB testing is in the range of hundreds of amperes, a transformer is included in the proposed system. The addition of the transformer serves two purposes, a low-pass filter

circuitry and a current amplification for the desired output current.Taking the transformer's impedance into consideration, the cutoff frequency (f_c) of the low-pass filter

The proposed system has been designed the turn ratio of 86 for power transformer, using as the current gain amplifier. The output current is controlled by feeding primary side current back into controller for current regulation.

D. Controller

The controls of the proposed system are divided into two parts. The first part is the ac input current control for PFC and the dc-link capacitor voltage control. The block diagram of the first part is shown in Fig.5. The reference signal is obtained from the input voltage for shaping the input current. Each dc-link capacitor voltage is measured and fed through a PI controller. The outputs of two PI controllers are toggling alternately with the cycle of input voltage. The absolute ac input voltage is multiplied by the output of multiplex block to generate a reference signal for the input current. Next, the error of the input current is sent to a PID controller. The output of the PID controller is then modulated with a triangular signal to generate a PWM signal for the PFC part.
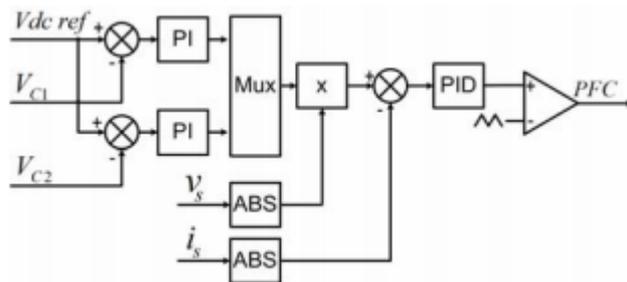

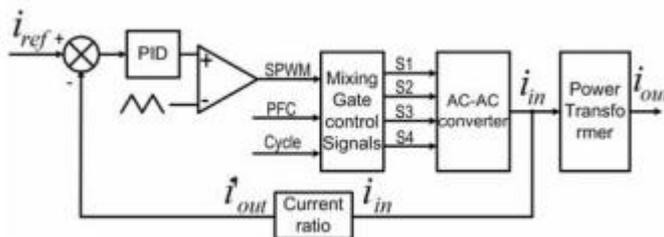fig. Block diagram for PFC current control.

Fig.. Block diagram for output current control.

The second part is the output current control illustrated in Fig.6. The PID controller is used as a control signal to create PWM signals for the switches S_1 , S_2 , S_3 and S_4 , in Fig. 1 The output of dc-ac converter is connected to the primary winding of the transformer T_1 . Note that the current control is through the transformer's primary current. This means that the current transformation ratio must be known a priori to properly compensate for the secondary current control. In the mixing gate control signals block, there are two mixing controls, SPWM signals and PFC signal for ac input current control. The mixing of gate control signals can be logically expressed as follows,

$$S_1 = SPWM \, OR \, (PFC \, AND \, Cycle) \qquad (3)$$
$$S_2 = \overline{SPWM} \, OR \, (PFC \, AND \, Cycle) \qquad (4)$$
$$S_3 = SPWM \, OR \, (PFC \, AND \, \overline{Cycle}) \qquad (5)$$

where *SPWM* is a digital logic signal created by the SPWM switching scheme, *PFC* is a digital logic signal of the input current control and *Cycle* is a digital logic signal representing the positive cycle of the input voltage. The switches S_1 and S_3 deliver the positive pulse to the output when the *SPWM* logic status is high. On the other hand, the *SPWM* is active low to drive the switches S_2 and S_4 for negative pulse.

. CONCLUSIONS

In this paper, the novel single-phase ac-ac converter with ac output current controls is proposed and digitally implemented according to the circuit-breaker (CB) testing standard (IEC 60898). Both simulation and experimental results show the improved transient step current control performance over the traditional ac current source based on the motor driven tap changing of auto-transformer. The proposed system is simple and low cost with minimum number of switches employed. The boost PFC topology with dual dc-link voltage controls is also incorporated in the proposed system. A laboratory prototype rated 600A(rms) output was constructed to verify the proposed system. According to results, the proposed topology accomplishes the sinusoidal input line current with unity power factor and low THD¡ of output current. The satisfactory transient step responses of output current are obtained.

REFERENCES

1.*Circuit-breaker for over current protection for household and similar installations*, IEC 60898-1, 2003-2007.
2.S. Kitcharoenwat, , M. Konghirun, A. Sangswang, "A Controlled Current AC-AC Converter for Circuit Breaker Testing," in *Proc. Electrical Machines and Systems Conf. (ICEMS)*, 2012, pp. 1-6

3.S. Kitcharoenwat, , M. Konghirun, A. Sangswang, "A Digital Implementation of Novel Single Phase AC-AC Converter with Power Factor Control," in *Proc. Electrical Machines and Systems Conf. (ICEMS)*, 2012, pp. 1-6
4.S. B. Bekiarov and A. Emadi, "A New On-Line Single-Phase to Three-Phase UPS Topology with Reduced Number of Switches," in *Proc*, *IEEE PESC*, 2003, pp.451-456.
5.J.-H. Choi, J.-M. B. kwon, j.-H. jung, and B.-H. Kwon, "High-Performance Online UPS Using Three-Leg-Type Converter," *IEEE Trans. Ind. Electron.*, vol. 52, no.3, pp. 889-897, Jun. 2005.

6.C. B. Jacobina, T. M. Oliveira and E. R. C. da Silva, "Control of the Single-Phase Three-Leg AC/AC Converter," *IEEE Trans. Ind. Electron*., vol.53, no. 2, pp.467-476, Apr 2006.
7.I. S. de Freitas, C. B. Jacobina, E. C. dos Santos, "Single-Phase to Single-Phase Full-Bridge Converter Operating With Reduced AC Power in the DC-Link Capacitor," *IEEE Trans. Power Electron.*, vol.25, no.2, pp. 272-279. Feb.2010.
8.K. Georgakas and A. Safacas, "Modified sinusoidal pulse-width modulation operation technique of an AC-AC single-phase converter to optimise the power factor," *IET Power Electronics*, vol.3, lss.3, pp. 454-464.

9.L. Garcia de Vicuña, M. Castilla, J. Miret, J. Matas and J. M. Guerrero, "Sliding-Mode Control for a Single-Phase AC/AC Quantum Resonant Converter," *IEEE Trans. Ind. Electron.*, vol. 56, no. 9, pp. 3496-3504, Sep. 2009.