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# A NOVEL THREE TO SINGLE PHASE MATRIX CONVERTER AC-AC CONVERTER FOR CIRCUIT BREAKER TESTING APPLICATION

**SHALIYA.S[1], SHAIK NEELOFER[2]**
[1]PG SCHOLAR.DEPT OF EEE, ESWAR COLLEGE OF ENGINEERING-NARASARAOPET, AP, INDIA
[2]ASSISTANT PROFESSOR, DEPT OF EEE, ESWAR COLLEGE OF ENGINEERING-NARASARAOPET, AP, INDIA
shalumahi1728@gmail.com,neelofar2345@gmail.com

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

A 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 welding, and etc [4]-[5].

Several topologies of single-phase ac-ac converter had been reported. The single-phase ac-ac two-leg, three-leg and fourleg (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

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the CB testing standard (IEC 60898). 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 (In) 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.

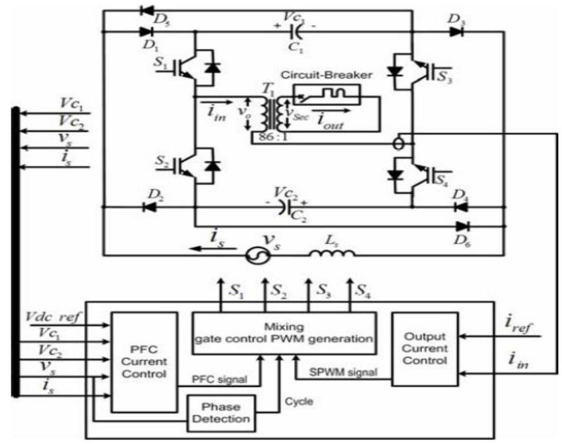


Fig.1. Proposed ac-ac converter with dc-link voltage and ac output current controllers.

## 2.HVDC transmission, power conditioning:

A **high-voltage, direct current** (**HVDC**) electric power transmission system uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current (AC) systems.[1]For long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. For underwater power cables, HVDC avoids the heavy currents required to charge and discharge the cable capacitance each cycle. For shorter distances, the higher cost of DC conversion equipment compared to an AC system may still be warranted, due to other benefits of direct current links.

HVDC allows power transmission between unsynchronized AC transmission systems. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz. This improves the stability and economy of each grid, by allowing exchange of power between incompatible networks.

The modern form of HVDC transmission uses technology developed extensively in the 1930s in Sweden (ASEA) and inGermany. Early commercial installations included one in the Soviet Union in 1951 between Moscow and Kashira, and a 100 kV, 20 MW system between Gotland and mainland Sweden in 1954.[2] The longest HVDC link in the world is currently the Xiangjiaba–Shanghai 2,071 km (1,287 mi), ±800 kV, 6400 MW link connecting the Xiangjiaba Dam to Shanghai, in thePeople's Republic of China.[3] Early in 2013, the longest HVDC link will be the Rio Madeira link in Brazil, which consists of two bipoles of ±600 kV, 3150 MW each, connecting Porto Velho in the state of Rondônia to the São Paulo area, where the length of the DC line is 2,375 km

### 3.High voltage transmission

High voltage is used for electric power transmission to reduce the energy lost in the resistance of the wires. For a given quantity of power transmitted, doubling the voltage will deliver the same power at only half the current. Since the power lost as heat in the wires is proportional to the square of the current for a given conductor size, but does not depend on the voltage, doubling the voltage reduces the line losses per unit of electrical power delivered by a factor of 4. While power lost in transmission can also be reduced by increasing the conductor size, larger conductors are heavier and more expensive.

High voltage cannot readily be used for lighting or motors, so transmission-level voltages must be reduced for end-use equipment. Transformers are used to change the voltage levels in alternating current (AC) transmission circuits. Because transformers made voltage changes practical, and AC generators were more efficient than those using DC, AC became dominant after the introduction of practical systems of distribution in Europe in 1891[5] and the conclusion of the War of Currents competition at the same time in the US between the direct current (DC) system of Thomas Edison and the AC system of George Westinghouse.

Practical conversion of power between AC and DC became possible with the development of power electronics devices such as mercury-arc valves and, starting in the 1970s, semiconductor devices as thyristors, integrated gate-commutated thyristors (IGCTs), MOS-controlled thyristors (MCTs) and insulated-gate bipolar transistors (IGBT).

### 4.SIMULATION SETUP

Simulink/SimPowerSystems was used to simulate two cases. Case I demonstrates

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reactive power control with a changing active power reference and case II shows the capability of SPVC to follow a changing reactive power reference with fixed . In addition to the control loop in Fig. 4, two more control loops have been added. The first (depicted in Fig. 5) is for active power control which comparesthe reference dc-link current on the HVDC line with to generate the required firing delay angle. The second loop (shown in Fig. 6) is for keeping at a fixed value around 15 , a compromise between minimum reactive power consumption and fast power control above rated power for limited duration. is kept constant through the use of relatively slow onload tap changers (OLTCs) on the converter transformers, which change the voltage magnitude upon sensing the change in to bring it back to the reference value. SimPowerSystems does not contain OLTC transformer blocks for time-domain simulations. We have, therefore, created an alternative solution by creating the grid voltages behind its impedance using controlled-voltage source blocks. The loop in Fig. 6 controls these voltages based on the comparison of The simulations start with the SPVC bypassed in both cases. The SPVC is connected at 3 s and demonstrates its capability of following . At 6 s, the reference ( or ) is changed,and the performance of the SPVC is demonstrated for the next 3s. The base values are 1000 MVA, 500 kV, and 2 kA for plotting

**Case1:**

The active and reactive powers are plotted in Fig. 7. As the SPVC is connected, drops from a value of 0.55 to 0 p.u., as

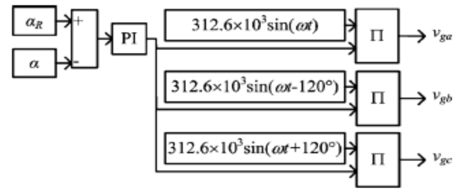


Fig. 6. Constant-$\alpha$ control loop. The initial amplitude of $v_{gk}$ is $312.6\times10^3$ V.

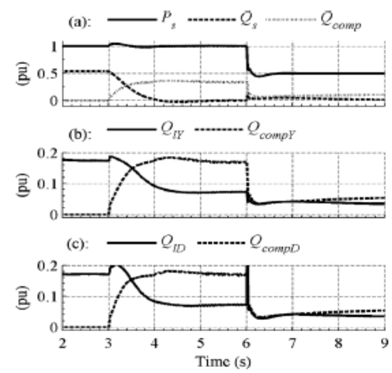


Fig. 7. Active and reactive powers (a) into the two converter transformers, (b) in the $Y$ branch, and (c) in the $D$ branch.

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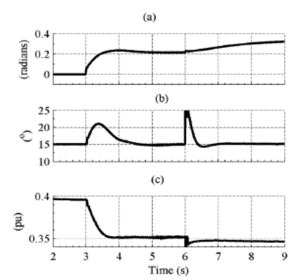


ig. 8. Operation of the control loops in case I. (a) $Y_{charge}$, (b) $\alpha$, and (c) $V_{sa}$.

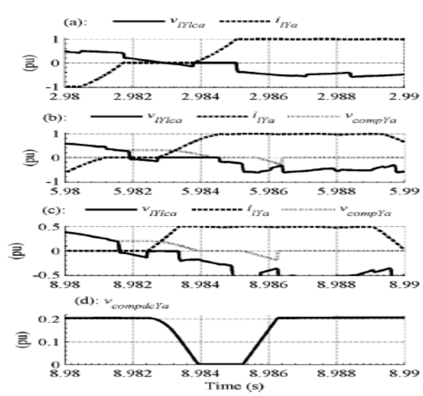


Fig. 9. Half-cycle plots in the $Y$ branch: (a) without SPVC, (b) with SPVC and $P_s$ = 1 p.u., (c) with SPVC, and $P_s$ = 0.5 p.u., and (d) the SPVC dc-link voltage with the SPVC and $P_s$ = 0.5 p.u.

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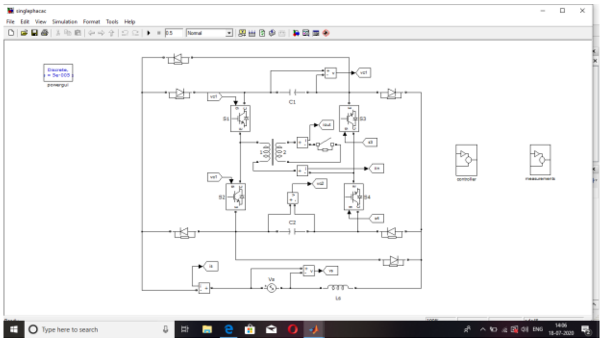
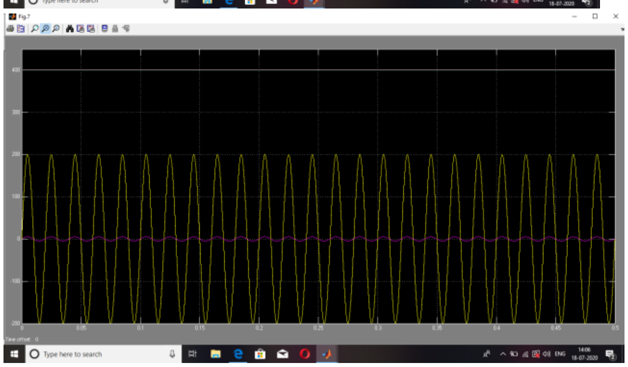
## 5. RESULTS





**Nodal voltage vs Time**

## 5.CONCLUSION

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 THDi of output current. The satisfactory transient step responses of output current are obtained.

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