Design and Analysis of AC/AC Buck-Boost Converter based on Power Electronic Transformer for Power Quality Improvement

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ABSTRACT:

In this paper, a new Y-source and matrix converter combination that can be used as an AC/AC buck-boost for intelligent transformer application is proposed. This mixture can be used to solve the sag and swell issues of output voltage in various electrical power systems and to reduce the size and weight of the traditional power transforms by using power electronic devices. Relative to the input voltage, the suggested AC-AC matrix configuration can enhance the output voltage in both out-of-phase and in-phase. The output voltage can also be compared to the input voltage in an out-of-phase or in-phase method. The proposed AC/AC single-phase Y-source matrix converter's complete analysis and working principles have been presented. Also, using the Mathematica version 11.2 software, a comprehensive mathematical model of the converter has been developed and validated. A co-simulation using OrCAD/PSpice and Matlab/Simulink has been constructed for both the ZS-MC and the suggested YS-MC in order to evaluate the performance of the converter. Where the thorough simulation analysis indicates that in terms of gain, input current, input power factor, and unifying the ground, the proposed YS-MC performs better than the ZS-MC. The results further prove that by adjusting the duty cycle, the output voltage can be either boosted or bucked and by modifying the PWM technique, the output voltage may be either out-of-phase or in-phase with the input voltage.

الخلاصة:

في هذا البحث ، تم اقتراح جديد من مصدر Y ومحول مصفوفة يمكن استخدامها كتعزيز باك للتيار المتردد / التيار المتردد لتطبيق المحولات الذكية. يمكن استخدام هذا الخليط لحل مشاكل الترهل والانتفاخ لجهد الخرج في أنظمة الطاقة الكهربائية المختلفة ولتقليل حجم ووزن محولات الطاقة التقليدية باستخدام أجهزة إلكترونيات القدرة. بالنسبة لجهد الإدخال ، يمكن أن يعزز تكوين مصفوفة AC-AC المقترح جهد الخرج في كل من خارج الطور وفي الطور. يمكن أيضًا

مقارنة جهد الخرج بجهد الدخل في طريقة خارج الطور أو في الطور. تم تقديم التحليل الكامل لمحول مصفوفة المصدر Y / AC / AC أحادي الطور ومبادئ العمل. أيضًا ، باستخدام برنامج Mathematica الإصدار ١١,٢ ، تم تطوير نموذج رياضي شامل للمحول والتحقق من صحته. تم إنشاء محاكاة مشتركة باستخدام OrCAD / PSpice و Matlab / Simulink لكل من ZS-MC و YS-MC المقترحة من أجل تقييم أداء المحول. حيث يشير تحليل المحاكاة الشامل إلى أنه من حيث الكسب, ومدخلات التيار , وعامل قدرة الإدخال , وتوحيد الأرضي ، فإن YS-MC المقترح يعمل بشكل أفضل من ZS-MC. تثبت النتائج أيضًا أنه من خلال ضبط دورة التشغيل ، يمكن تعزيز جهد الخرج أو عكسه ومن خلال تعديل تقنية PWM ، قد يكون جهد الخرج إما خارج الطور أو متزامنًا مع جهد الدخل.

KEYWORDS: Buck-Boost Converter, HVDC, SST Solid State Transformer, LVAC, FACTS, ST Smart Transformer.

1. Introduction

The solid-state transformer (SST), also called the intelligent universal transformer or power electronic transformer has received a lot of interest in recent years and has been thoroughly studied for distribution systems [1-3].

The electronic transformer was the first kind of SST to be proposed. In the years that followed, numerous efforts were made in order to create a low-power and voltage SST prototype [3–7]. SSTs haven’t yet entered distribution networks since they are currently constrained by the power and voltage ratings of the devices and the availability of circuit topologies. The fundamental idea behind the SST is voltage change from low- to high-frequency, which will result in a reduction in the weight and volume of the transformer in comparison to the conventional transformer [1].

The design of the SST is shown in Fig.1. When a high-frequency transformer is used to step up or step down an AC voltage with a high frequency, which reduces volume and weight, the actual 50/60 Hz AC voltage is converted to an AC voltage with a high frequency (often from several to tens of kilohertz). This reduction is due primarily to how the transformer operates, which includes storing energy in the magnetic field of the core before rereleasing it at a different current/voltage. The core’s flux capacity and the frequency at which it is switched determine how much energy can be transformed [4], [8] and [9]. The magnetic core must therefore have a large capacity at a low frequency (50/60 HZ) in order to transform a considerable amount of electricity. According to the transformer's E.M.F. equation, the quantity of flux required to store energy decreases as frequency increases, and these two factors are inversely connected E=4.44.f. N. A. B. [4]. Where f=frequency, N= no. of turns, A=area, B=flux density. The original 50/60-Hz AC voltage, which will feed straight to the load, is reconfigured from the high-frequency AC voltage at the end [8-10].

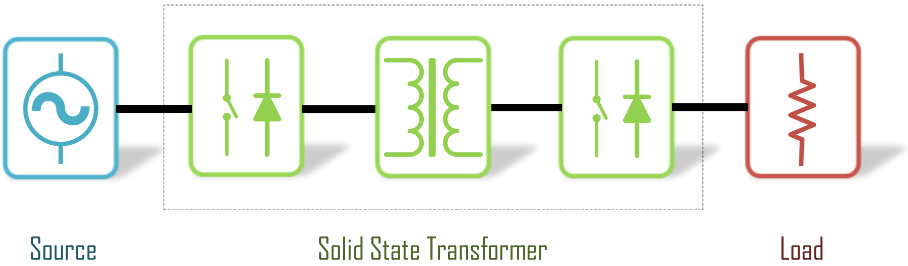


Fig.1. Architecture SST.

The SST can be referred to as a Smart Transformer in the distribution grid if it plays a management role and enhances the performance of the transmission and distribution grids by offering ancillary services. The Smart Transformer's purpose is to continuously control the voltage while connecting to the smart grid to enable remote administration, receive feedback, and offer details about the transformer and power source [7]. Also, during power fluctuations, this transformer acts as a protection mechanism for electrical equipment. There are several crucial attributes of SST, and these attributes include:

1. SST's provide the precise amount of power required and react quickly to grid variations.
2. SST serves as a voltage regulator and guarantees that the optimal voltage hasn't been tampered with.
3. By supplying an ideal, reliable power source that delivers the electrical equipment's normal voltage. SST's immediately cut down on energy utilization and greenhouse gas emissions.

By giving the necessary power to the electrical equipment, they also serve as protection devices.

2. Design of the Proposed Converter

Fig.2 depicts the suggested single-phase Y-source AC/AC buck-boost matrix converter. It uses an input inductor Lin, a bi-directional switch, a Y-network, a matrix converter, an LC output filter, and an R load. The Y-Source network consists of a single magnetic core, two capacitors, and three connected inductors. The demand for the capacitor and inductor must be low due to the high switching frequency utilized in the converter to trigger the switches, which is more than the line frequency.

This work proposes the Y-Source matrix converter configuration, and Fig.2 depicts the circuit schematic for such a setup. The configuration will be considered this paper’s primary converter. Despite this, the setups have been thoroughly modelled and simulated mathematically to analyse them.

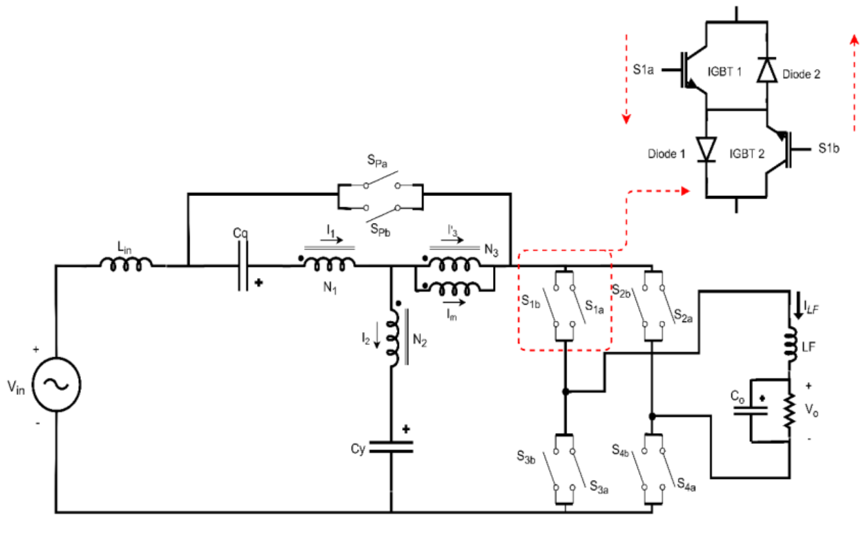


Fig.2. The Proposed YSMC Circuit.

According to Fig.2, the Y-source matrix converter requires five bi-directional switches. Four of these switches, S1i, S2i, S3i, and S4i I = a, b), are used to create the single-phase matrix converter. The fifth bi-directional switch, Spi I = a, b), is connected in parallel with the Y-source network. The a/b symbols denote switches 1 and 2. The bi-directional switches are arranged back-to-back. In order to make it simple to make the voltage at the output out-of-phase or in-phase with the input voltage, the proposed converter has been integrated with a devised PWM method. Due to the presence of a Y-source in this converter, the gain may also be altered, allowing for switch duty cycle changes as well as step-down-step-up output voltage.

The switching method employed in this converter is depicted in Fig.3, where T (time) stands for the overall switching duration and for the equivalent duty-ratio. It's important to note that the suggested converter has two primary operating modes:

- Boost mode.
- Buck mode.

There are two states for every mode: in-phase and out-of-phase modes.

The following processes have been taken into consideration in order to determine the voltage gain of the converter and the variables that affect it:

$$V_o = \frac{(-1+\delta)(N_2 - N_3)V_{\text{in}}}{\delta N_1 + (-1+\delta)N_2 + N_3} \quad (1)$$

where the definition of the winding turns ratio is

$$K_{\text{YM}} = \frac{N_2 + N_1}{N_2 - N_3} \quad (2)$$

From (1) equ. and (2) equ., the voltage gain can be expressed as:

$$G_{YM} = \frac{V_o}{V_{\text{in}}} = \frac{(1-\delta)}{(1-\delta\, K_{\text{YM}})} \quad (3)$$

It may be seen from above that δ and K_Y or K_{YM} indicate the main influences on voltage gain.

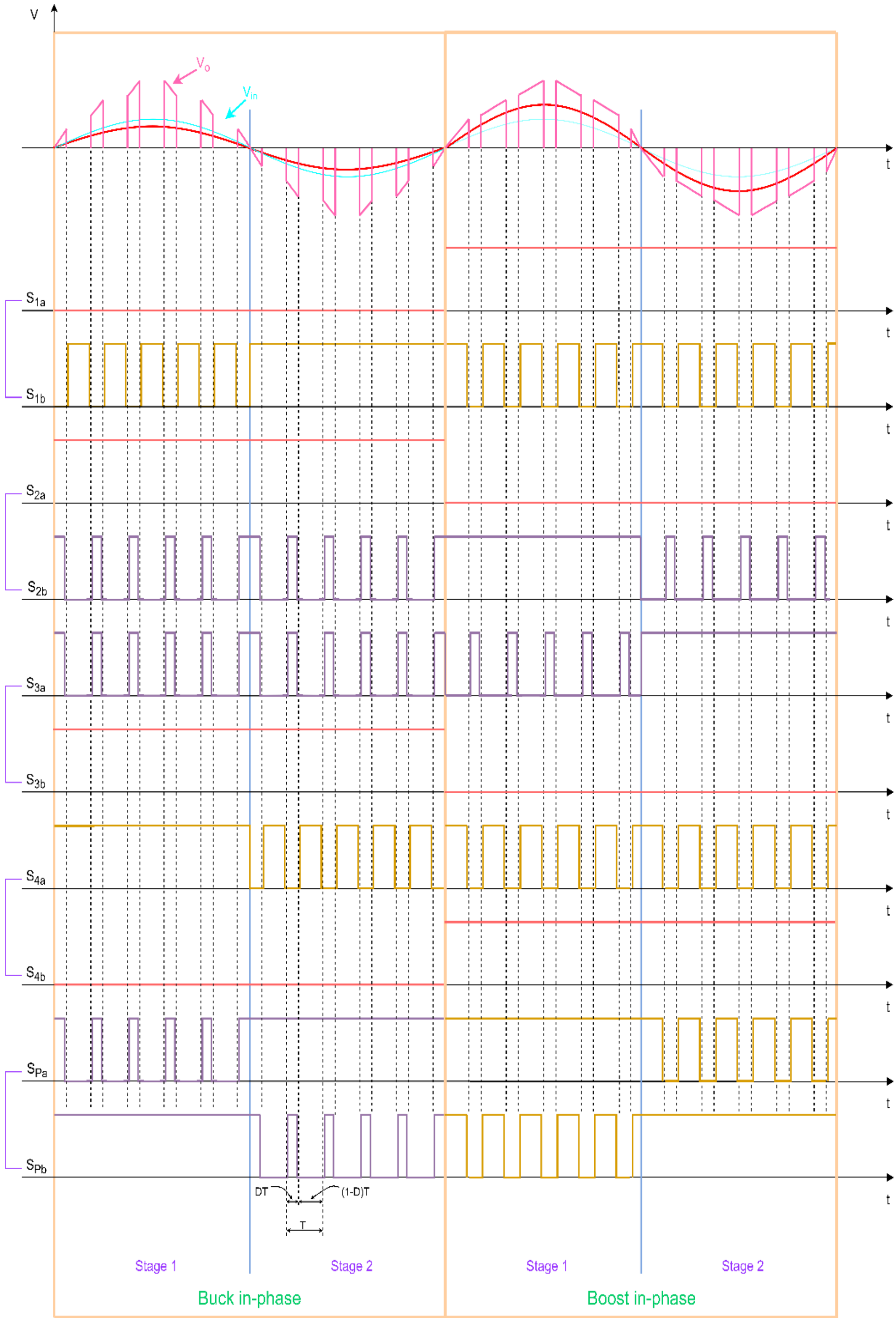


Fig.3 PWM waveform with smart-commutation technique for the proposed converter's in-phase boost/buck modes.

3. Simulation and Experimental Results

This section's main purpose is to assess how well the proposed single-phase Y-source AC-AC matrix converter will perform. Different simulation results based on a 200W load were generated in order to assess the performance of the proposed Matrix Converter (MC). The total system performance has been analyzed and evaluated utilizing a co-simulation between OrCAD/PSpice 17.2 software and the MATLAB/Simulink 2018b (64bit) environment that was integrated using SLPS software, ensuring that the results are usable in the real world.

Fig.4 shows the proposed YS-MC circuit, The PWM generated for S1 and S2 based on the needed modes is shown in Fig.5.

Table 1 Y-MC parameters that are used to verify simulation results

Parameter		Value
Capacitors	C_y C_q	65 µF 60 µF
Inductors	L_{in} L_{lof} L_m	1 mH 260 µH 50 µH

Table 2 Y-MC parameters that required to verify simulation results

Parameter		Value
Source voltage (V)		110 V r.m.s
Inductors	L_{in} L_{lof} L_m N_1 N_2 N_3	1.5 mH 320 µH 100 µH 15,30 45,60 15,30
Capacitors	$C_y = C_q$ C_o	75 µF 10 µF
Dead time		0.25 µs
Operation frequency *Switching frequency*		50 Hz 20 kHz
K_{YM}		2: 15:45:15 3: 30:60:30
Internal resistance R_1 R_2 R_3		100 mΩ 10 mΩ 1 mΩ
Load resistance R_L		55 Ω
Output Power		200 W

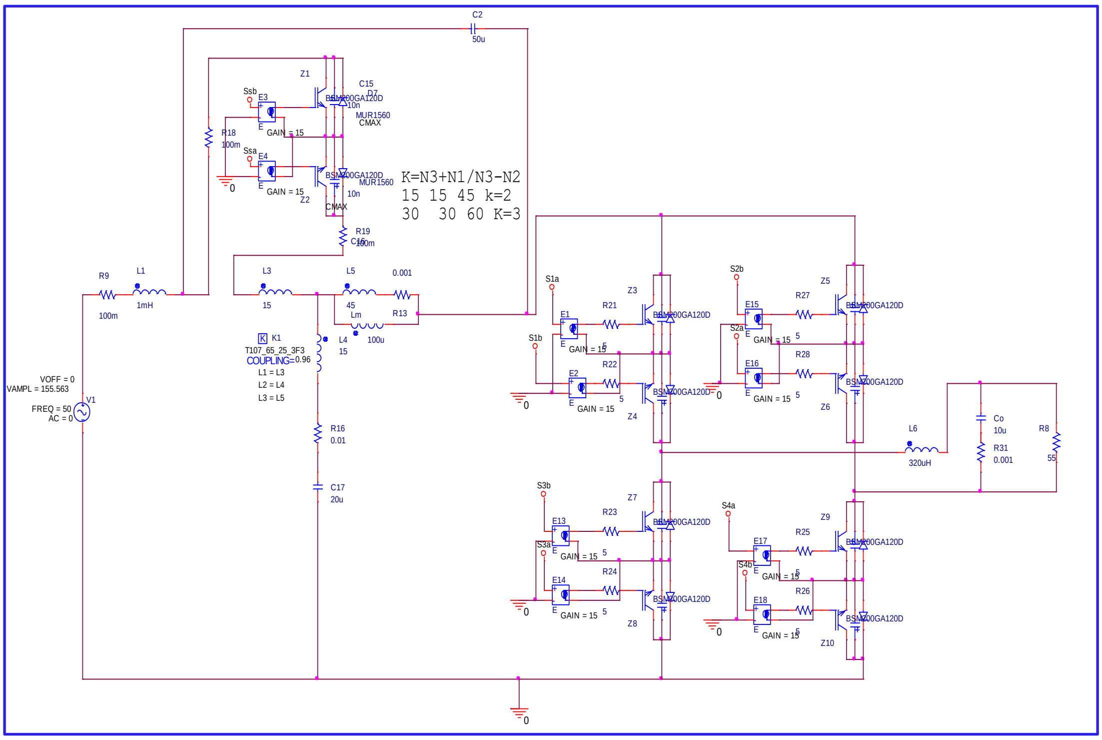


Fig.4 Proposed YS-MC.

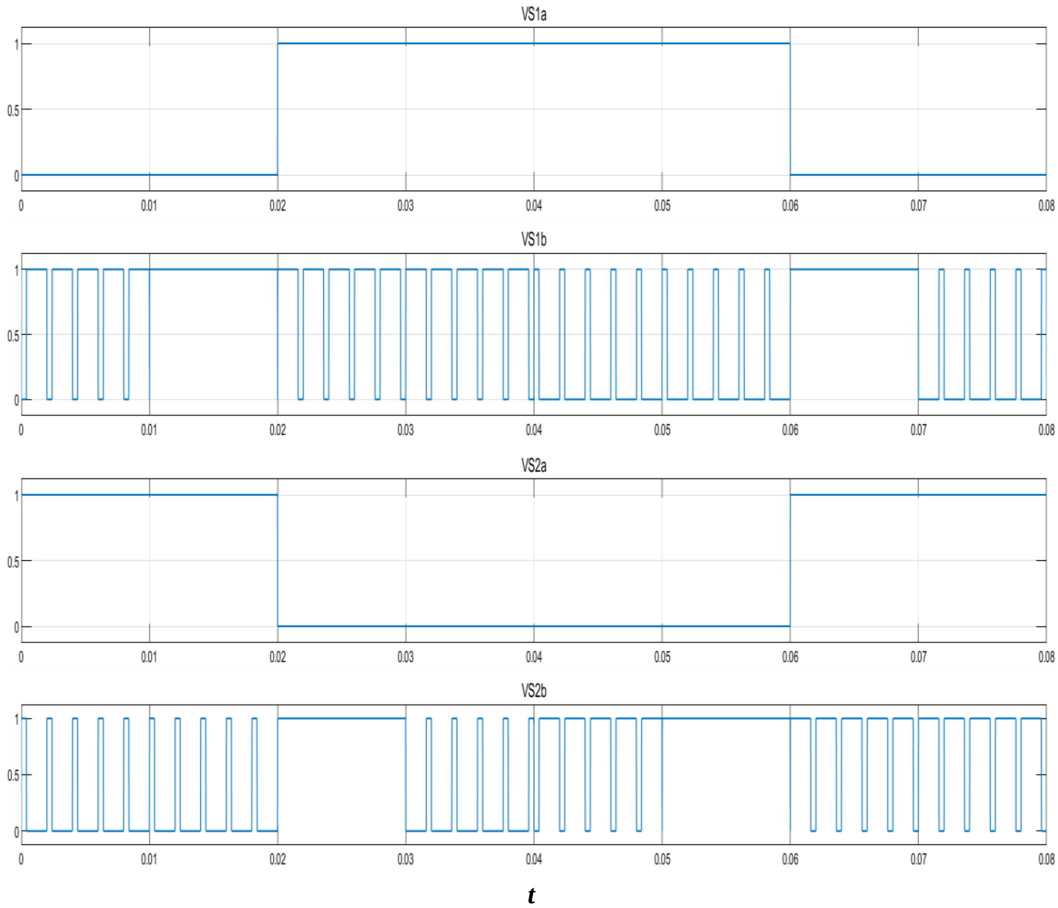


Fig.5 The PWM signals for S1a, S1b, S2a, and S2b were generated for the operation modes of buck/boost, and in/out phase.

Fig.6 displays the output voltage in relation to the input voltage for the YS-1 MC setups. This Fig. also displays the voltage stress across the input bidirectional switch.

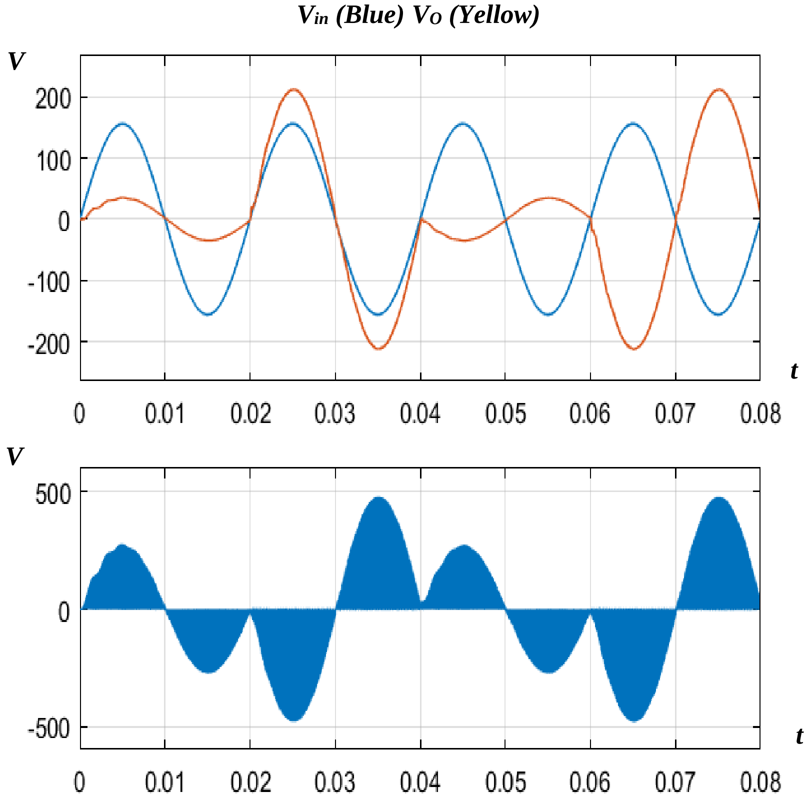
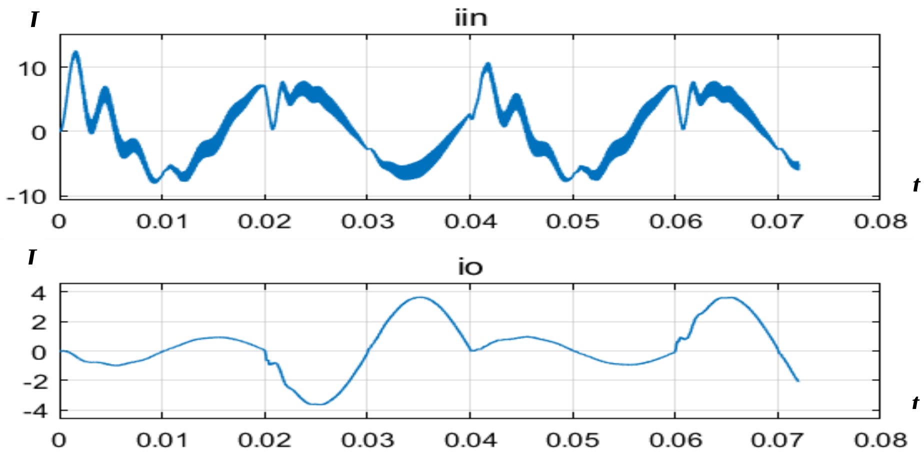


Fig.6 Results of the converter for the YS-1 running in all modes during simulation. Voltage stress across the input switch is depicted at the bottom of the diagram, with input and output voltages represented in the TOP figure.

Figure 7 shows the current via input and output of the converter as simulated results.



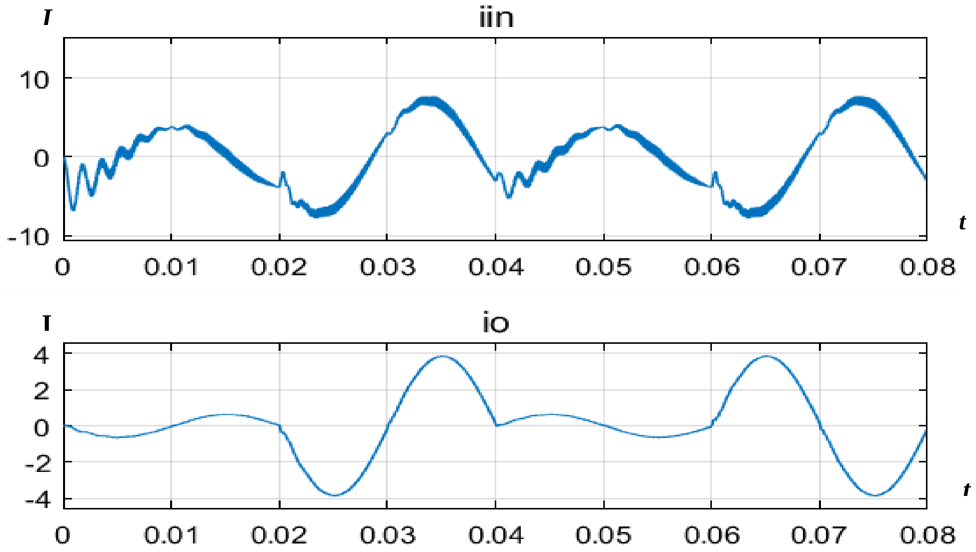


Fig.7 Results of the converter's input and output current simulation YS-1 is in constant operations in all modes.

4. CONCLUSION

The work presented in this paper mainly concentrated on the ST concept and the design of an AC-AC converter that could satisfy ST requirements for resolving sag and swell issues in the output voltage of the AC power system in addition to the power factor problem. Additionally, using the Mathematica version 11.2 software, a comprehensive mathematical model of the converter was created and validated. For the proposed YS-MC, a co-simulation utilizing OrCAD/PSpice and Matlab/Simulink has been built to assess the converter’s performance. The design suggested has many advantages over previous AC-AC converters, allowing for smooth output voltage changes across a large range. Additionally, because the proposed converter uses a complex PWM with a safe commutation strategy rather than a sunbber circuit, which creates a path for the current to be always continuous, the stresses on the switches are reduced and there is no high spark on the switches when commutating from one state to another.

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