Design of Indirect AC-AC Converter Based on Linear Controller for Power Systems

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***Abstract*— This paper proposes an indirect AC-AC converter based on linear controller and analyzing the variations in input supply and load demands. The proposed converter has controlled by a three-phase switch to achieve the optimal AC frequency. The proposed converter has dramatically reduced the output voltage ripples and sustains the voltage stability when connected with different loads. As a result, the proposed converter provides high output stability.**

Keywords—AC-AC converter; linear controller; Power systems

I. Introduction

Power converters are electronic circuits which perform electric power conversion, control, and conditioning [1]. Due to the high demand on power converters, more reliable power converters become a hot research area for industry. Hence, additional improvement throughout converter strength productivity can be translated to increase productivity of power systems.

The most prevalent technology among electric converters is usually switched-mode electrical power converters. This type of converters changes the input voltage to a new voltage waveform which temporarily storing the feedback energy after releasing the energy towards the output for different voltages [2]. The merit of switched-mode converters is the ability to switch at high frequency in an efficient means. Power is commonly controlled and modified by controlling the [ON & OFF] switch timing of the electronic switch and converters are utilized as a way to change the particular supply voltage according to some performance specifications, for electrical power efficiency [3].

The current applications of power electronic systems consist on particular degradation of one portion that may perhaps influence particular operations and as a result influence system stability [4]. One example is linked to reduce the size of capacitance which boosts the associated voltage ripples and help to sustain the voltage stability when connected with transitioning products despite the fact that the particular capacitor themselves could nevertheless work underneath an average manner [5].

In addition, the changes in input and output performance of different power electronic converters could result in a sudden failure of other subsystems. For that reason, it is more difficult to look for the inability standards of a portion or even method within power systems as compared to other domains. The particular inability standards intended for electrolytic capacitors could reach 100% to enhance with the equivalent-series-resistance or even 20% lessening with the capacitance. Diverse results could possibly be generated intended for different choices with the inability indicator [6]. Chopping circuit typically includes a high frequency switching element like a Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) [7], a Bipolar Junction Transistor (BJT) or Insulated Gate Bipolar Transistor (IGBT). In order to obtain a high current voltage stabilizer, the switching resistance has to be very low [8]. However, the efficiency problem could arise where the chopper circuit decreases the input voltage by changing the switching resistance as a part of dynamic voltage divider circuit, which means that any voltage skipped at the input will be dissipated in the form of heat at the fixed resistance of this dynamic voltage divider.

This paper proposed an indirect AC-AC converter which has been controlled by a three-phase switch to achieve the optimal AC frequency.

The remainder of this paper is organized as follows. Section II presents the background. Section III introduces the proposed converter. Section IV presents the results and discussion. Section V concludes the paper.

II. Background

In [9], it has shown that in the event of high efficiency power converter design, the controller cannot consume much power, hence, optocouplers can be used instead of the solenoid optocouplers, and a low power digital controller can also be used instead of an analog control system. As such, providing efficient linear controller design for power electronic converter can comprise a multi tap transformer with a group of normally open opto-isolator (optocouplers) connected between the taps and an initial output line. In addition, the linear controller design relied on a low-frequency transformer, which, in turn, converts AC mains to a desired voltage, and rectifies and filters the voltage to a DC level [10]. Furthermore, linear controller regulate the power clamps excessive voltage at the predetermined level and dissipates unwanted voltage in the form of heat in which linear power supplies is commonly reserve a limit to the variable range of the AC input voltage [11].

Resonant converters have got the benefits of soft-switching characteristics, thus, they are chosen to function the dc/dc conversion process at large changing consistency and to meet the routine specifications based on the small dimension and vitality proficiency [12]. With most of these single-stage approaches, a boost or a buck–boost converter is usually functioned as a power factor correction, and also a full- or

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half-bridge resonant routine which acquired mainly for the dc/dc converter. Therefore, it can be summated that the full-bridge variety works for high-power systems, whereas, the half-bridge variety possesses the benefits of easy topology, large proficiency, and cost effective [13].

III. PROPOSED DESIGN

AC to AC converters are utilized rectifiers to transform the AC input to a DC signal. The DC signal is transformed back to AC signal using bridges and pulse width modulators (PWM). The benefit of such an approach is that the frequency of the output waveform can be modified based on the desired specifications. A controller acts in the DC to AC transformation part of the system measures the output voltage or output current and provides control signal to the PWM converter/bridges. Figure 1 shows the block diagram of an indirect AC to AC converter. The AC source is encoded in the initial phase by converting the received signal into DC converter for further decoding. After that, the DC signal is decoded into AC signal with harmonics that have sufficient signal strength to fall within the processed signal. The controller is used to give a reference waveform for the processed signal. This reference waveform is then passed into inductive filter. After all, the processed signal will be processed from the output AC.

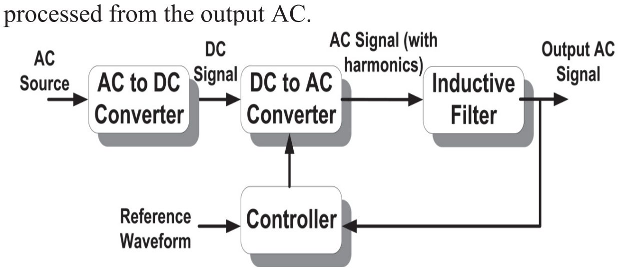

Fig. 1 Indirect AC - AC converter

Figure 2 shows the structure of the proposed control loop. The loop consists of *r* which is the main driver of the converter's position. However, the output *y* refers to the output value that compresses on the position of the angle. In this research, the researcher designed the controller in order to provide a step reference to the system for regulating its state when it is becoming zero.

In addition a local inner loop with proportional gain (K_p) is utilized which used to get the desired performance from a "P only" controller. To estimate the ratio of output response to the error signal, the proportional gain (K_c) has been used.

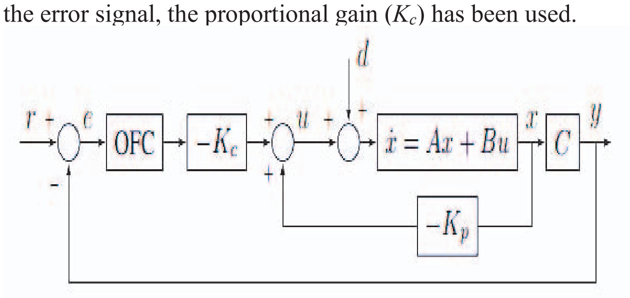

Fig. 2 Structure of the proposed control loop

Implementation of such scheme of the AC to AC converter requires further considerations. In this study, The Analog to Digital (AC and DC) converters are utilized to transform discretized measured values (such as error and prior processed values) to the micro-controllers. The processing of the error is taken place using digital processing units within the micro-controllers and the generated control signal is transformed back to analog form using Digital to Analog (DC/AC) converters as shown in Fig. 3.

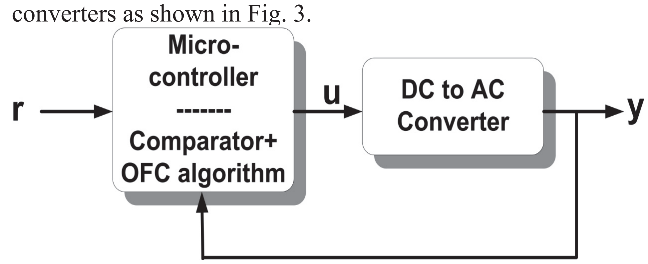

Fig. 3 DC/AC converter with a feedback

In the proposed control scheme, the output value is scaled down by the gain factor. The output signal can either be compared with the input or reference signals array already-stored in the memory of the micro-controller to speed-up the processing. To reduce an unwanted harmonics (is obtained via the substitution of the nonlinear equations with a set of systems of linear equations) and the total harmonic distortion (THD), a filter is used at the output of the system.

The micro-controller implements the output feedback control algorithm. The micro-controller takes the input signals as the two of its input pins. On one of the pins, the signal is passed through a capacitor to produce DC version of the input signal. When an input signal is provided to the micro-controller as the feedback signal, the micro-controller compares this signal with the reference signal already-stored in it the memory. The reference signal generated by the microcontroller is fed to comparator as shown in Fig. 3 in order to compare it with the actual DC-AC signal obtained from output of the converter. On the other hand, the resulted error signal by comparator is also utilized to activate the converter such that the power on the output of the converter is inline with the profile of the original reference signal. Then the control signal is produced based on the designed linear control strategy. At the steady state situation the tracking error will approach zero and the corresponding control signal will also approach to a steady state value.

The indirect AC to AC converter consists of two main blocks which are AC to DC converter and DC to AC converter. The input signal is first converted to a DC signal and then the output waveform with desired frequency is constructed using DC to AC converter. The block diagram of the indirect AC to AC converter is depicted in Fig 4. Design summary of illustrated block as follows:

1. Input signal is received from a three-phase AC source.
2. AC to DC Converter is utilized as a rectified AC signal to produce a DC signal by using full-bridge-rectifier.

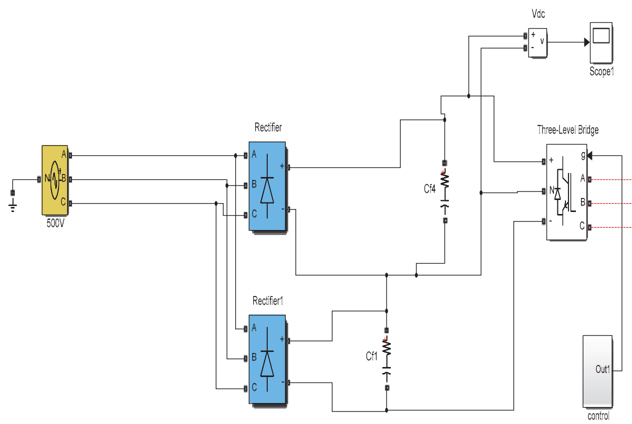

Fig. 4 Indirect AC to AC converter

The DC Signal from the rectifiers goes into a switch bridge which is controlled by a feedback control loops. DC to AC Converter process the rectified signal which later switched at the desired frequency to produce the desired output waveform. In order to improve system performance, the output signal is compared with the reference array signal. This produces the error or attenuating signal. The attenuating signal is adjusted through feedback configuration as shown in Fig 5.

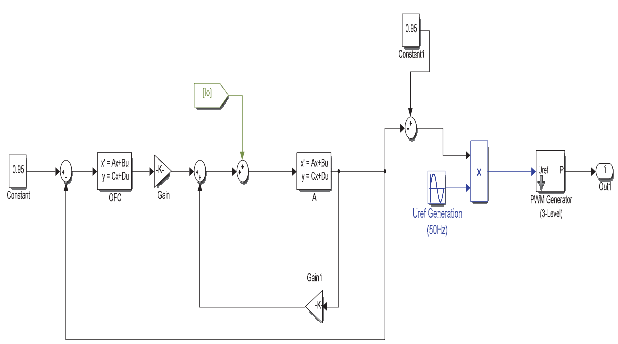

Fig. 5 Feedback configuration and adjusting of attenuated signal

3. As shown in Fig. 6, the generated AC signal contains unwanted harmonics and cannot be directly applied to the load, so an inductive filter is used which reduces the harmonic content and improves the overall THD of the system

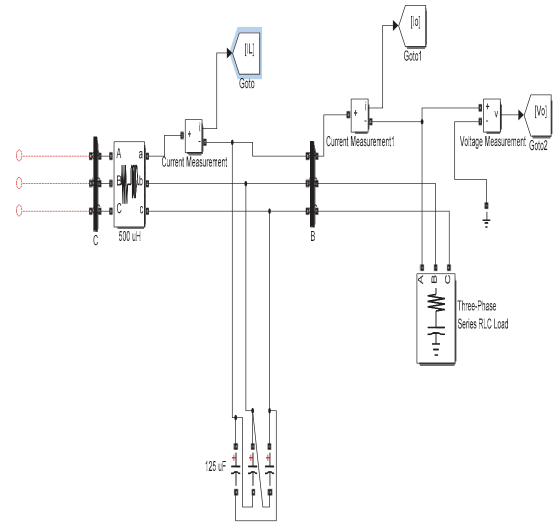

Fig. 6 Inductive filter and reduction of harmonic contents

IV. Results

The effect of variations in input voltage and also load demand is analyzed. Also, the performance of the proposed control loop is also assessed and compared in different situations. A three-phase AC voltage with amplitude of 500V and frequency of 50 Hz is considered as the input source to the AC to AC converter. A single cycle of the sinusoidal input lasts 20 msec providing different AC inputs to the AC-DC converter. The output voltage is generated with an effective amplitude modulation index. The resulted DC voltage is depicted in Fig. 7.

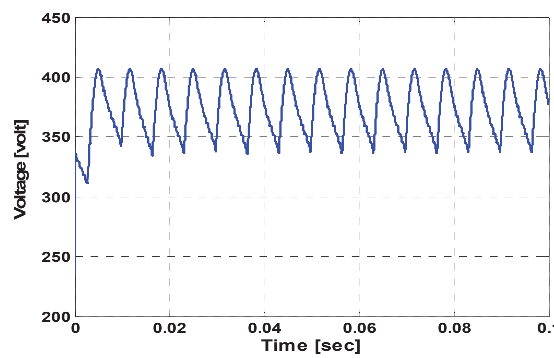

Fig. 7 The output voltage of AC to DC converter

It is observed that the achieved voltage is a DC voltage with significant ripples. The frequency of the ripples is three times the frequency of the input voltage as all three phases of the input are effective in making the ripples.

The second part of the converter is DC to AC converter which transforms the waveform in Fig. 7 into a three phase desired waveform. The output current is used in control loop to adjust the level of generated waveform. The profile of the obtained output current for one of the three phases is illustrated in Fig 8.

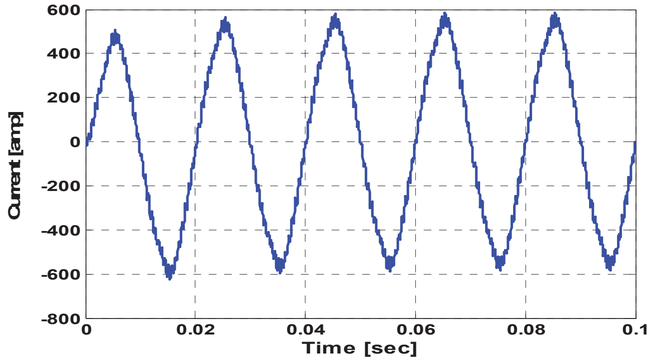

Fig. 8 Output of the AC to AC converter

The output voltage has been filtered and several harmonics has been suppressed. The generated output waveforms for each of the three phases are demonstrated in Fig. 9. The control loop output is multiplied by a sinusoid wave and transformed to a Pulse Width Modulation (PWM) signal for applying to the DC to AC converter circuit. The generated PWM signal is used for two phases of the three-level bridge as demonstrated in Figs. 10 and 11. The set point adjusts the amplitude of the generated output waveform. The amplitude of the input AC voltage is set to 500 volts, and the controller set points adjusted to values 0.95, 0.8 and 0.6. The generated output waveforms are depicted in Fig 12. It is expected that the conversion process remains reasonably uniform over a desired range of the AC source amplitudes. This implies that the proposed converter can be utilized for different applications with different input voltage sources. Results of AC to DC conversion for different values of input voltage amplitudes are presented in Fig. 13.

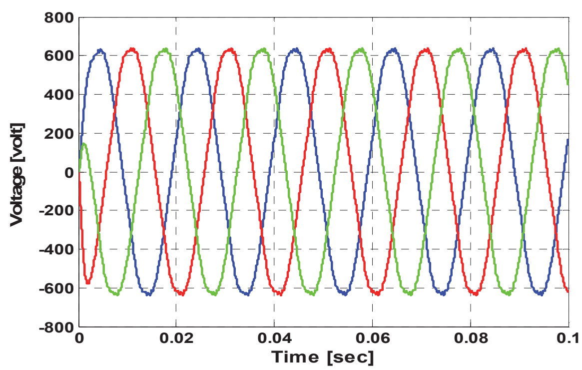

Fig. 9 Output waveforms of the three phases AC to AC converter

Sequentially, the output AC voltage of the converter is compared with the three input voltages of 400, 500, and 600 as demonstrated in Fig. 14.

For further analyzes, the input-output behavior of the converter and input AC sources with different amplitudes are fed to the system and the amplitude of the output waveform is measured in various voltage amplitudes. Figure 15 illustrates the system linearity.

The power converter might be used with different appliances; it may face very diverse range of load variations. Basically the load can have different capacitive, inductive and resistive properties. Based on Simulink, there are few types of loads: Constant Z, Constant PQ and Constant I.

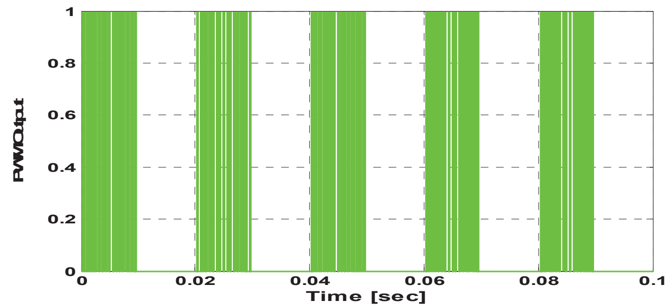

Fig. 10 The PWM control signal

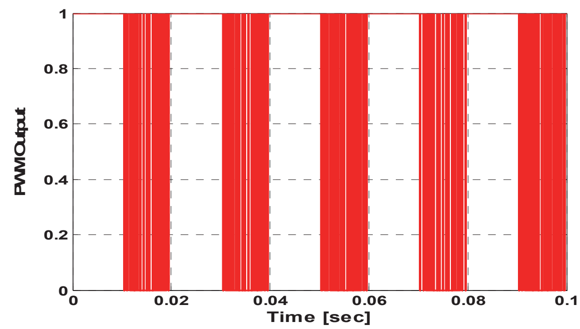

Fig. 11 The PWM control signal for a different phase

If the constant Z model is selected, the load impedance is determined from the nominal phase-to-phase voltage, active power P, and reactive power (QL-QC) specified on the parameters tab of the block dialog box. The output waveform of the AC to AC converter is observed in each scenario. The values of 300, 450 and 600 volts are used to compare its performance as shown in Fig. 16.

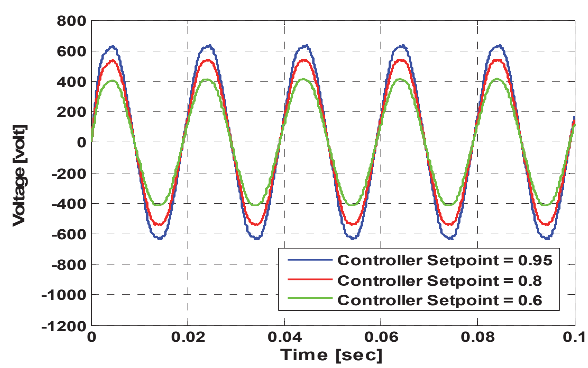

Fig. 12 Effect of controller set point over the output waveform

The power converter might be used with different appliances; it may face load variations. Basically the load can have different capacitive, inductive and resistive properties.

It can be concluded that increasing the phase-to-phase voltage will increase the amplitude of the generated waveform. However, such increase is not uniform. The other point observed during this research is that output waveform has phase shifts as the load changes. The effective value of input voltage was set to 220V at frequency voltage of 50Hz. Figure 17 and 18 show the input and output performance of the proposed controller, respectively.

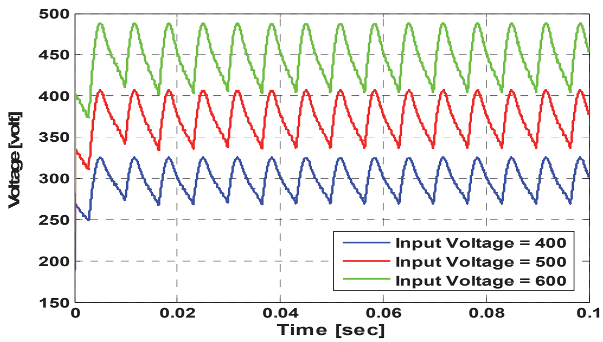

Fig. 13 Effect of input source variation over the DC waveform

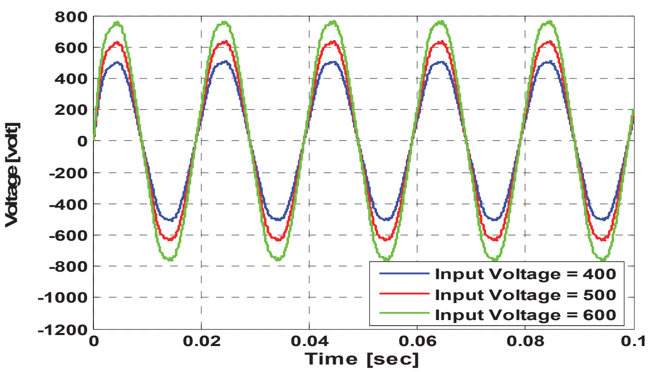

Fig. 14 Effect of input source variation over the generated AC waveform

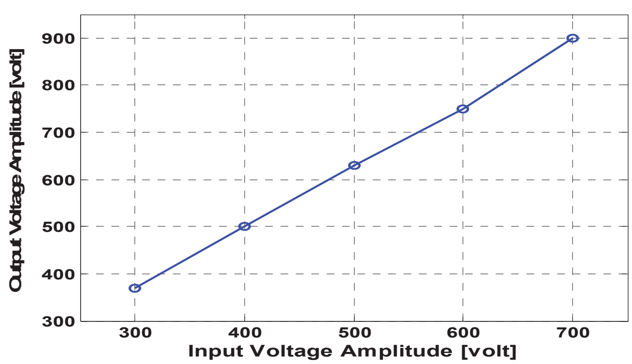

Fig. 15 Empirical input-output mapping of the AC to AC converter

This study generates waveforms with similar phase angles which imply that the converter provides uniform phase performance with different amplitudes of the input AC signal.

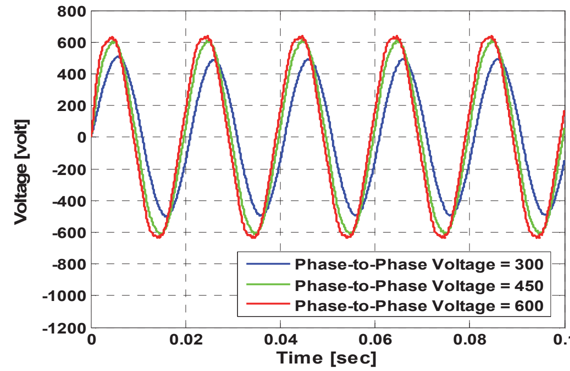

Fig. 16 Effect of load variation over the generated output AC voltage

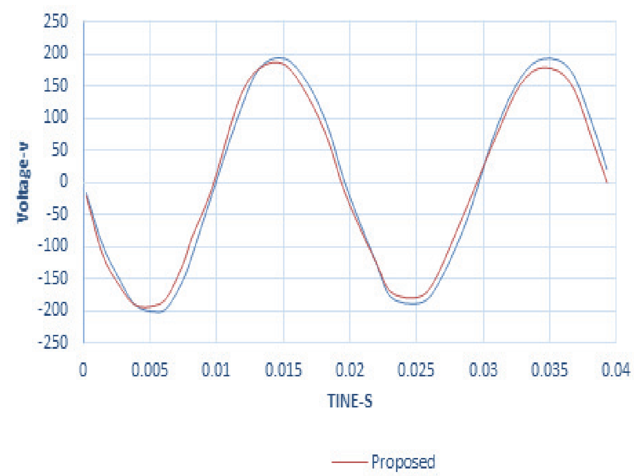

Fig. 17 Input performance result of the proposed design

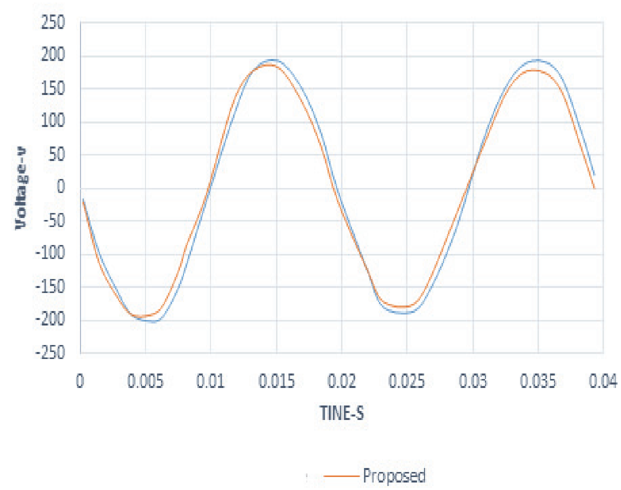

Fig. 18 Output performance of the proposed design

CONCLUSTION

In general, the results have shown a linear and uniform performance of input to output. Additionally, the system was successfully tested under load variations to ensure the system stability. The converter performance to process and transfer signal at the operating power is significantly enhanced.

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