A Doubly-Excited DC- to- 3-Phase AC Buck-Boost Converter Gives Sinusoidal Waveforms: Design, Simulation & Control

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Abstract: - This paper presents a new topology for converting a DC voltage to a 3-phase AC one. The proposed converter is excited from two separate DC supplies so the term "Doubly-Excited". The most important features of the proposed converter are the output voltage (AC Voltage) is lower or higher than the input one (DC Voltage), controllable voltage and frequency, and the output voltage and current are approximately sinusoidal which means low harmonics content. Also, the paper presents the simulation of the proposed converter in different modes of operation under control to show the effectiveness of the proposed control strategy.

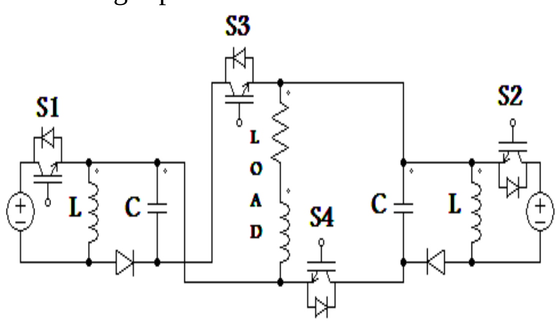
Key-Words: - Boost, Control, DC- to -3-phase AC Converter, Design, Simulation

1 Introduction

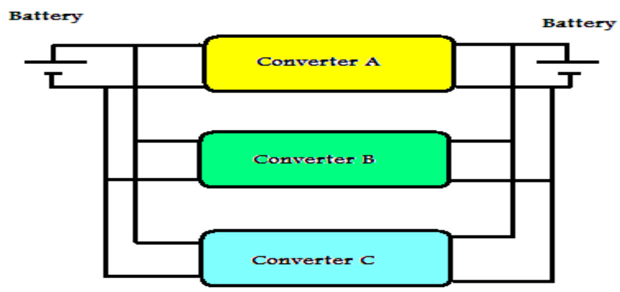
DC-AC converters are extensively used in electrical power applications. They can be used to convert the photovoltaic output voltage (DC voltage) to an AC one. They can be used in uninterruptable power supplies to convert batteries DC voltage to an AC one. They can be also used in electrical drives and other power applications. Different topologies for DC-AC converters are reported in several publications [1-6]. This paper presents a new technique for a DC- to- 3-phase AC buck-boost converter that can be used in several applications. The main important feature of the proposed converter is the output voltage and current are purely sinusoidal without the need for filters at the load terminals in addition to the ability to buck and boost the input voltage.

2 Proposed DC-AC Converter

Fig. 1 shows the circuit diagram of only one phase of the proposed DC- to- 3-phase AC buck-boost converter. As shown from the figure, the proposed converter is supplied from two separate DC supplies and it consists of two simple choppers feeding a half bridge inverter. The chopper switches are controlled so as to make the capacitor voltage vary in a half-wave sinusoidal manner (The control technique will be described in the next sections). As seen from the figure, the converter contains four switches. This number will be increased with the increase of the number of output phases. Fig. 2 shows a block diagram for the proposed DC-to- 3-phase AC converter. As shown from the figure the three phase converter consists of three similar single phase converters which mean that the three- phase converter has a number of switches equal to the triple the single-phase one.



Circuit Diagram of a One-Phase of the Proposed DC-to- 3-Phase AC Buck-Boost Converter
Fig. 1



Block Diagram of the Proposed DC-to- 3-Phase AC Buck-Boost Converter
Fig. 2

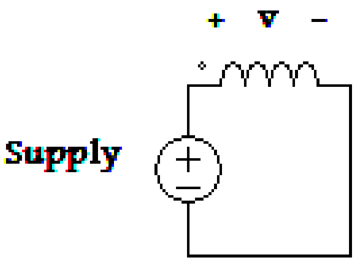
3 Principle of Operation

The principle of operation of the proposed converter can be discussed as follows:

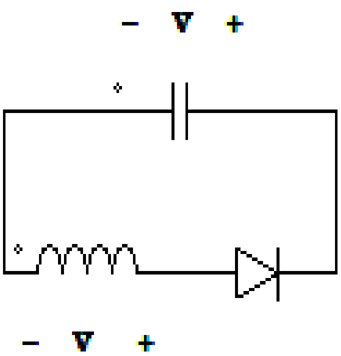
The DC-DC choppers provide DC output voltages lower or higher than the supplies voltage. The principle of operation of each chopper circuit can be discussed as follows:

Figs. 3a & 3b show the modes of operation of the DC-DC chopper. From these figures, the principle of operation of this converter can be discussed as follows:

- When the switch S1 is turned on, the current rises through the inductor and the inductor voltage polarity will be in a direction that opposes the supply polarity.
- When the switch S1 is opened, the inductor reverses its polarity and a current passes through the diode to charge the capacitor C. The capacitor voltage depends on the duty ratio at which the semiconductor switch is switched.

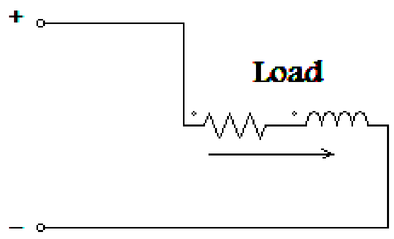


Equivalent Circuit for S1 is Closed
Fig. 3a

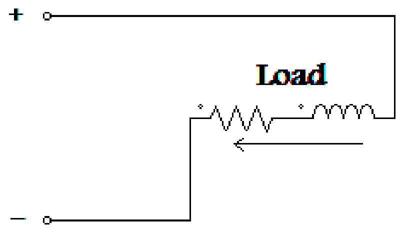


Equivalent Circuit for S1 is Opened
Fig. 3b

The function of the DC-AC converter (Half Bridge Inverter) is to convert the output voltage from the DC-DC converter to AC voltage. Figs. 4a & 4b show the modes of operation of this converter.



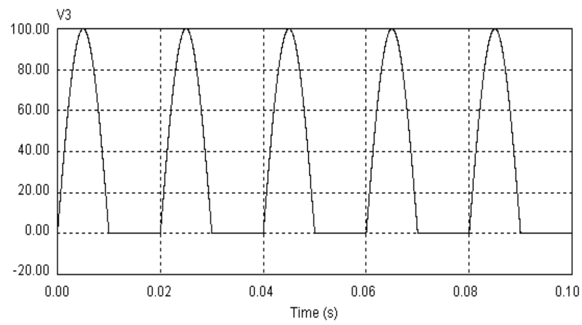
Equivalent Circuit for S3 is Closed & S4 is Opened
Fig. 4a



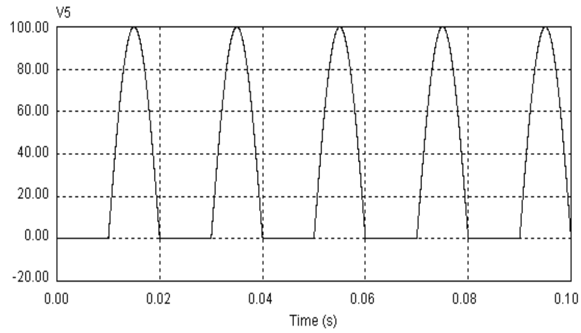
Equivalent Circuit for S3 is Opened & S4 is Closed
Fig. 4b

4 Principle of Converter Control

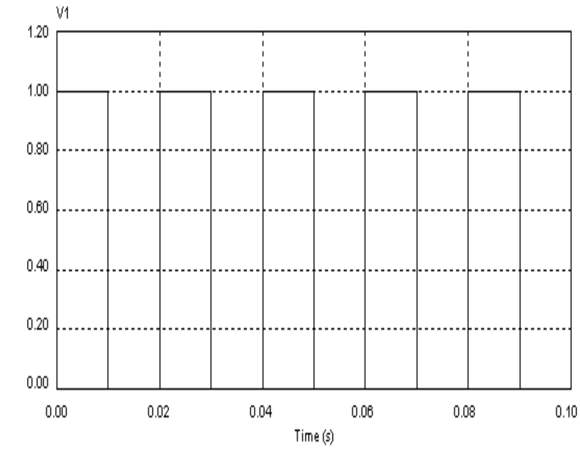
To make the output voltage to be very near to the sinusoidal waveform without the need for filters at the load terminals, the capacitor C voltage shouldn't be a smooth voltage. If the capacitor voltages are controlled to be as in Figs. 5a & 5b, the output voltage will be near to the sinusoidal waveform if the switches of the DC-AC converter are controlled as shown in Figs. 6a & 6b. Fig. 7 shows the predicted output voltage with this control scheme.



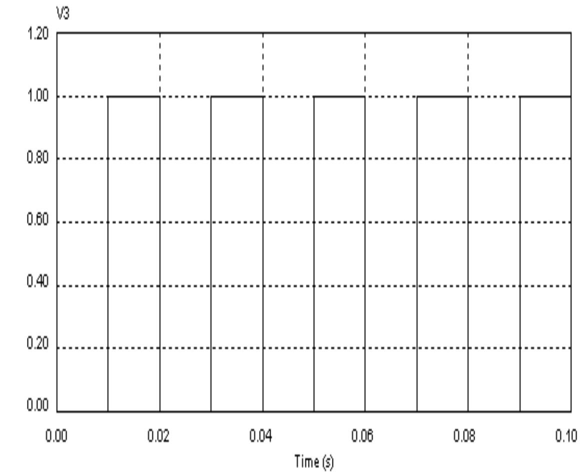
Left Hand Side Capacitor Desired Voltage
Fig. 5a



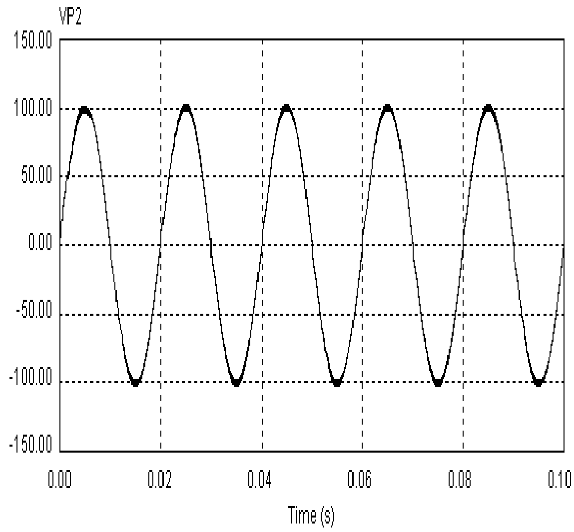
Right Hand Side Capacitor Desired Voltage
Fig. 5b



Control Signal to S3
Fig. 6a



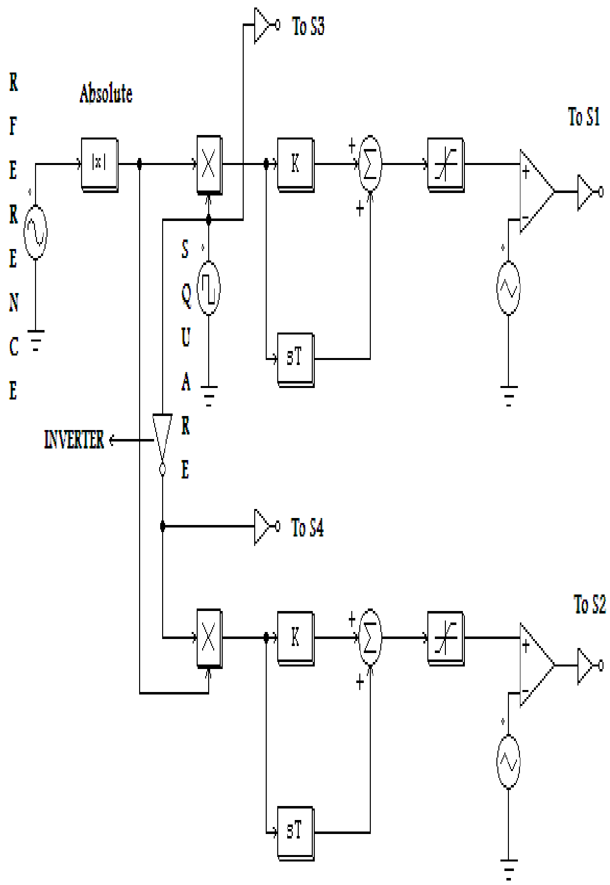
Control Signal to S4
Fig. 6b



Predicted Output Voltage with the Proposed Control Scheme
Fig. 7

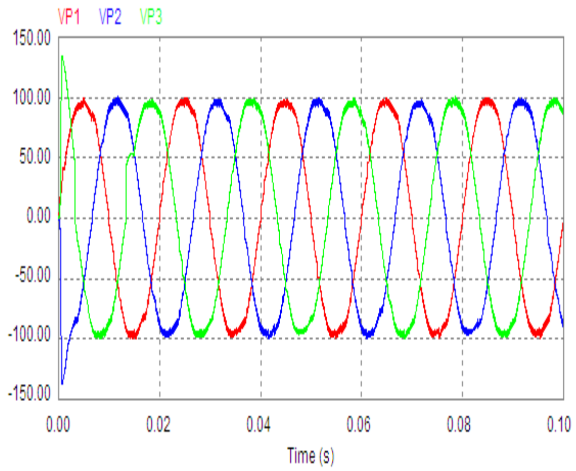
5 Simulation of the Proposed Converter under Closed Loop Control as a Three-Phase Converter

This section presents the performance of the proposed converter under closed loop control condition as a DC to 3-phase AC converter. The control strategy in this paper has been done as described before in section 4. Fig. 8 shows the schematic diagram of the proposed control for only one-phase. The control for the other two phases is the same but with considering the 120 degree phase shift between the phases. In this paper a simple PD (Proportional Differential) controller has been used. Any type of controllers can be used but the PD is chosen here for simplicity and as it gives a satisfactory performance.

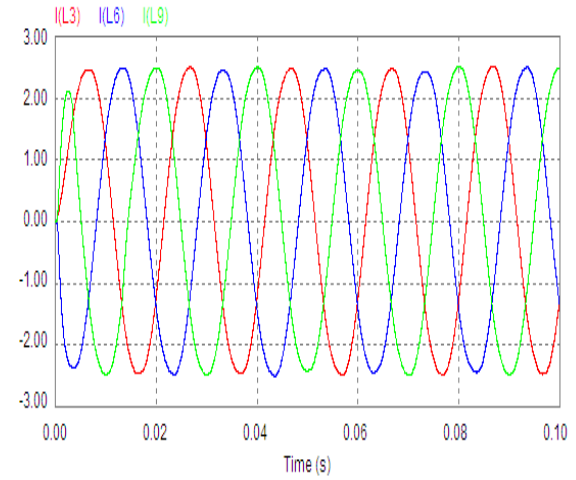


Schematic Diagram of the Proposed Controller
Fig. 8

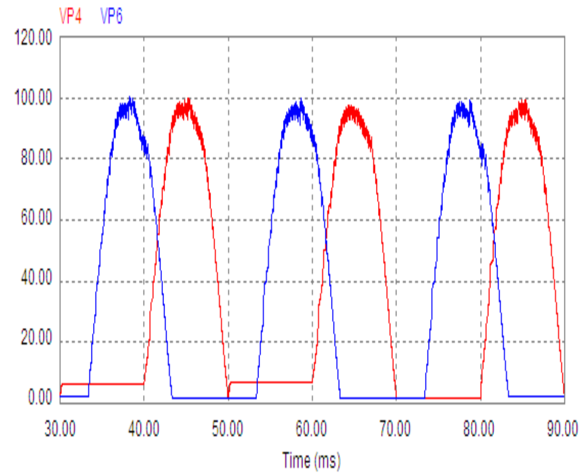
Figs. 9a to 9i show the output voltage, load current, capacitor voltages, supply current and the control signals for a desired output of 50 Hz and 100 volt (Max.).



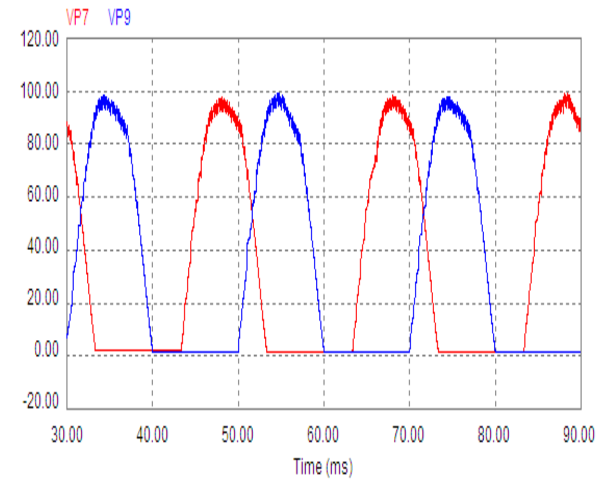
Output Voltage (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 9a



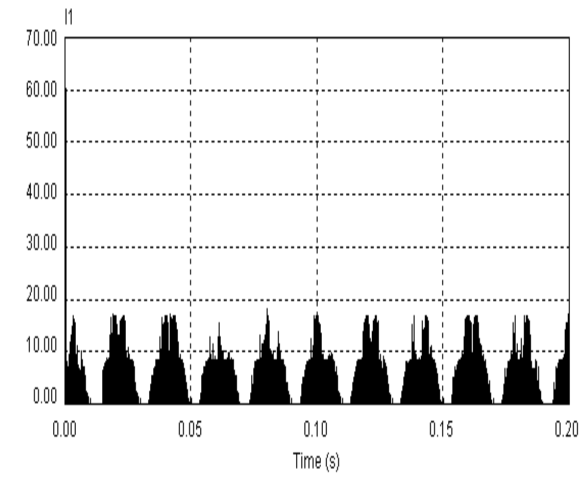
Load Current (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 9b



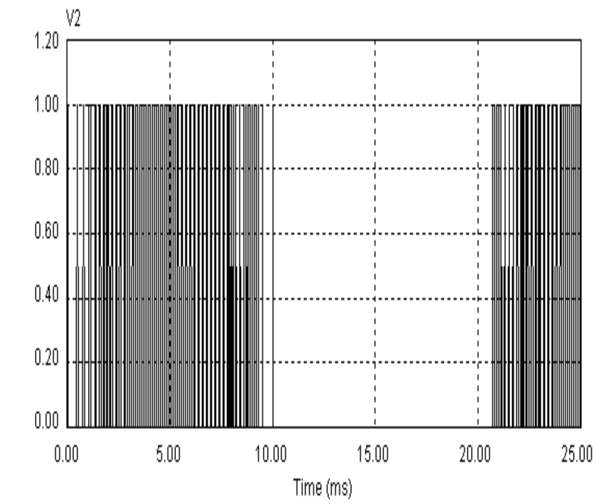
Left Hand Capacitor Voltage for Two Phases (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 9c



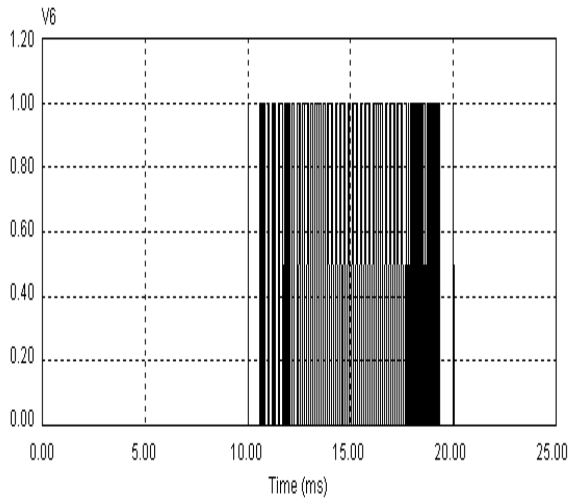
Right Hand Capacitor Voltage for Two Phases (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 9d



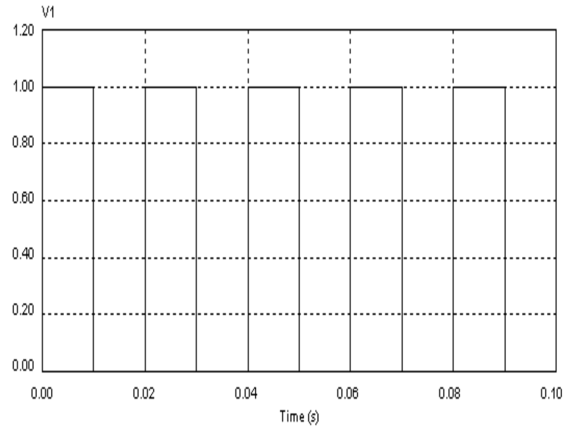
Left Hand Supply Current (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 9e



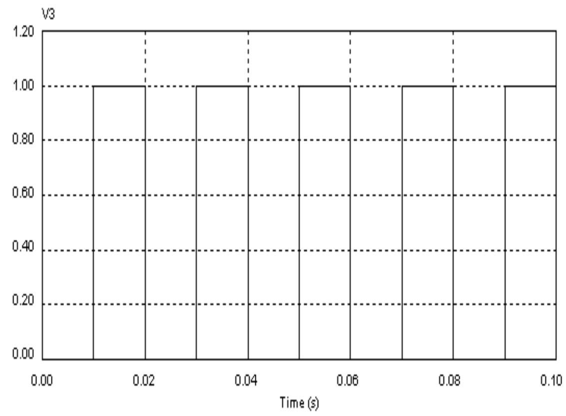
Control Signal to Switch S1
Fig. 9f



Control Signal to Switch S2
Fig. 9g

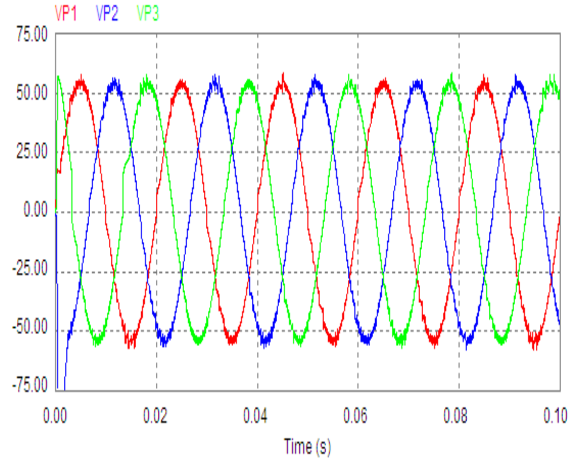


Control Signal to S3
Fig. 9h

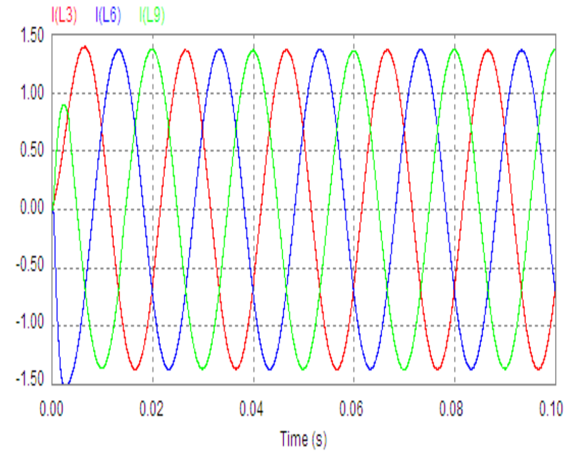


Control Signal to S4
Fig. 9i

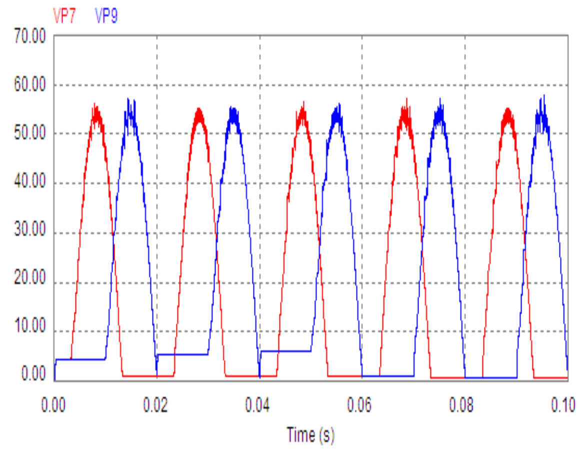
From the above figures, one can see that the load voltage and current waveforms are sinusoidal waveforms which mean low harmonic content. Fig_s. 10a to 10e show the output voltage, load current, capacitor voltages and supply current for a desired output of 50 Hz and 50 volt (Max.).



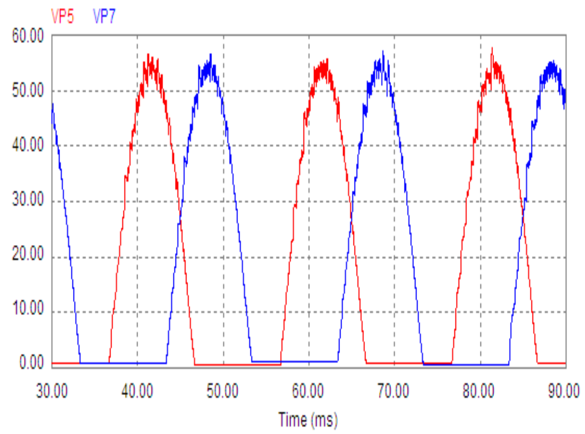
Output Voltage (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 10a



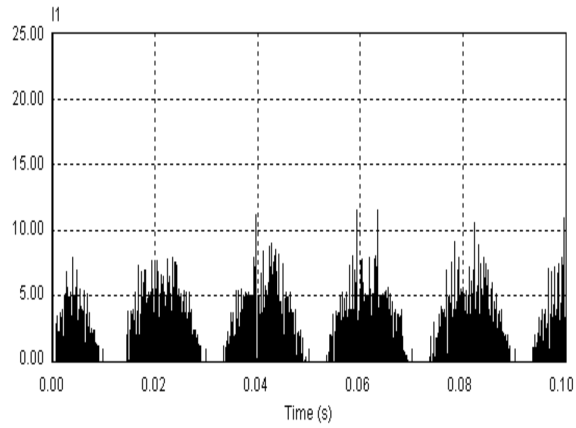
Load Current (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 10b



Right Hand Capacitor Voltage for Two Phases (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 10c

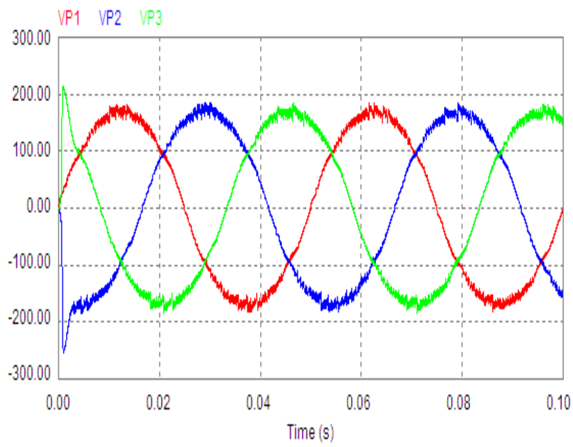


Left Hand Capacitor Voltage for Two Phases (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 10d

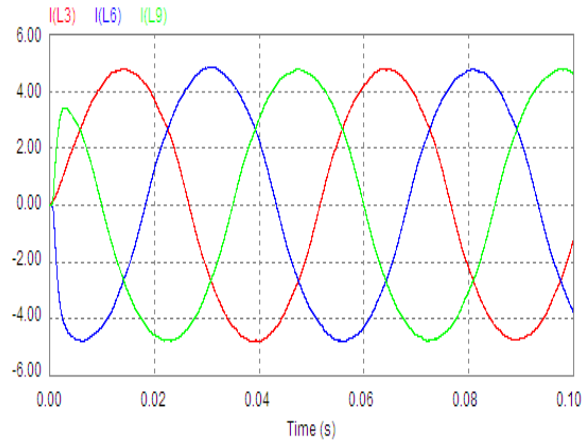


Left Hand Supply Current (50Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 10e

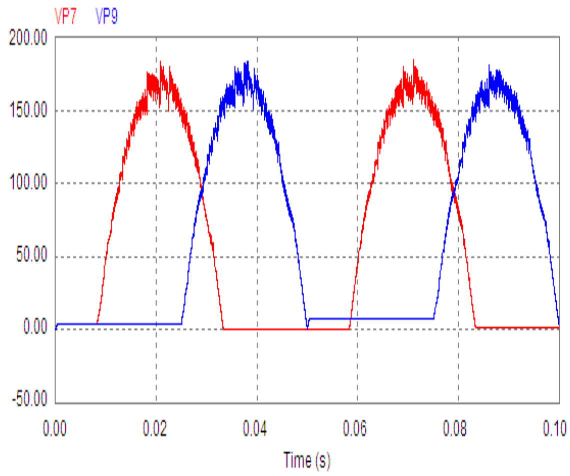
Fig$_s$. 11a to 11e show the output voltage, load current, capacitor voltages and supply current for a desired output of 20 Hz and 200 volt (Max.).



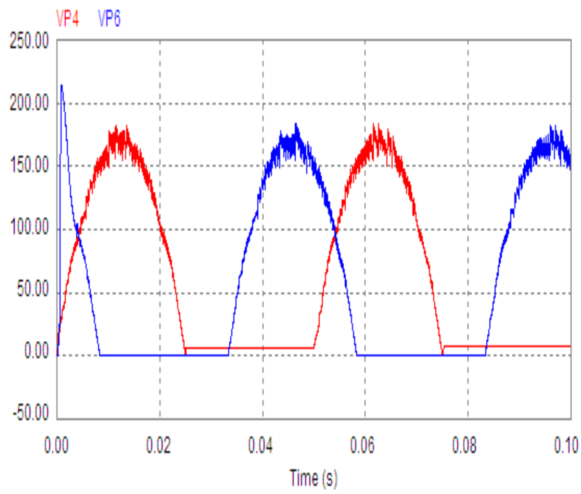
Output Voltage (20Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 11a



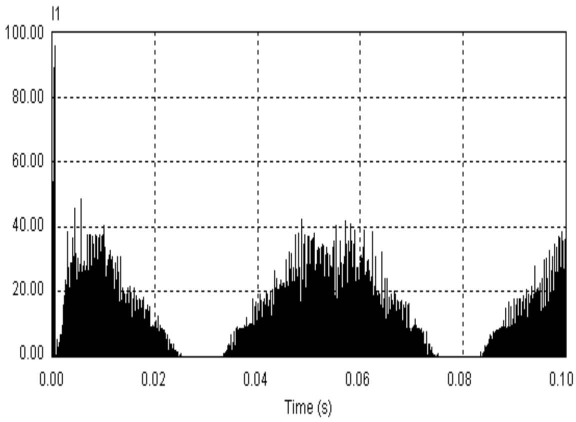
Load Current (20Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 11b



Right Hand Capacitor Voltage for Two Phases (20Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 11c



Left Hand Capacitor Voltage for Two Phases (20Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 11d

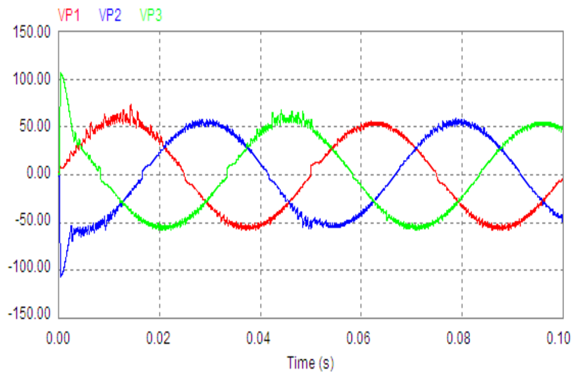


Left Hand Supply Current (20Hz, Supply Voltage=100 Volt (DC), RL-Load, Closed Loop)
Fig. 11e

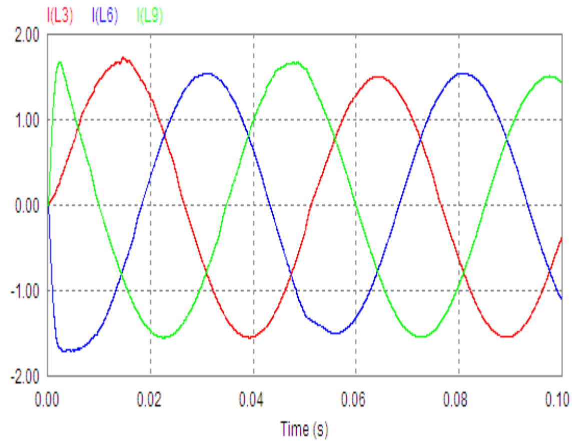
From all the above figures, it can be seen that the output voltage and current are approximately pure sine waves. There is a small error in the voltage magnitude when the desired voltages are greater than the supply voltage (Boosting Mode) but this error can be eliminated or reduced by using an intelligent controller such as the artificial neural network (ANN). The use of ANN can be done in a next paper.

6 Simulation of the Proposed Converter under Closed Loop Control as a Three-Phase Converter at Supply Voltage Variations

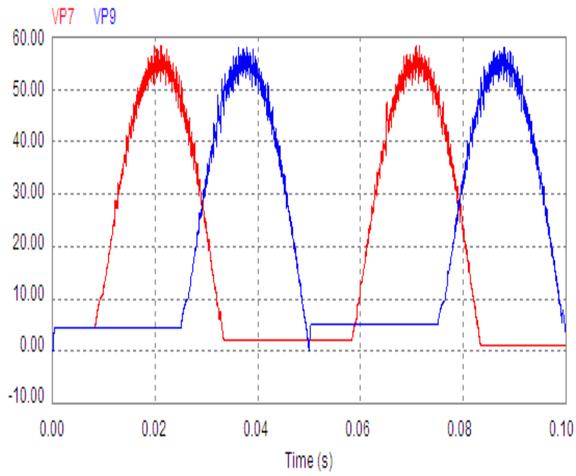
This section presents the performance of the proposed converter under supply voltage variations. Figs. 12a to 12e show the output voltage, load current, capacitor voltages and supply current for a desired output of 20 Hz and 50 volt (Max.) with step change in left hand side supply voltage from 100 volt to 80 volt.



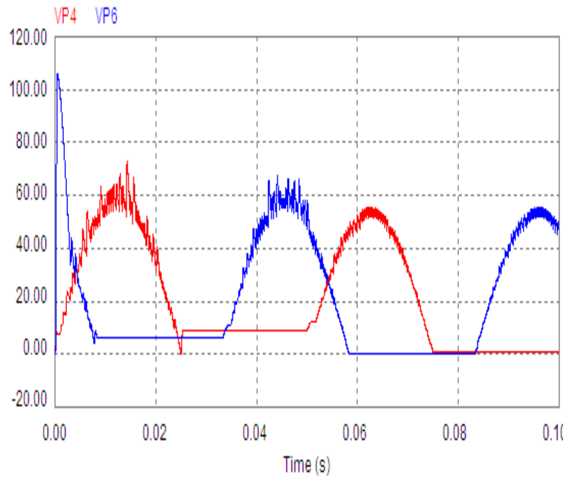
Output Voltage (20Hz, Step Change in supply voltage from 100-80 volt, RL-Load, Closed Loop)
Fig. 12a



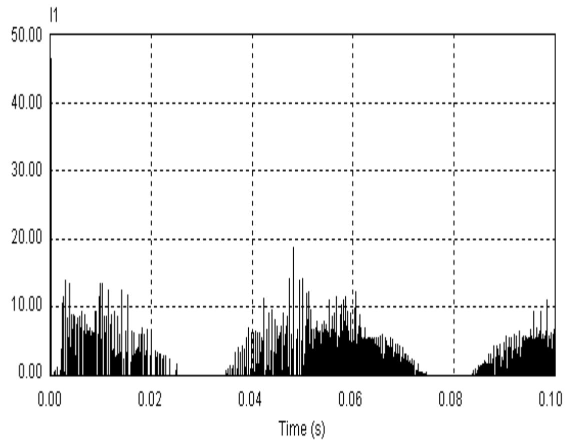
Load Current (20Hz, Step Change in supply voltage from 100-80 volt, RL-Load, Closed Loop)
Fig. 12b



Right Hand Side Capacitor Voltage for Two Phases (20Hz, Step Change in supply voltage from 100-80 volt, RL-Load, Closed Loop)
Fig. 12c

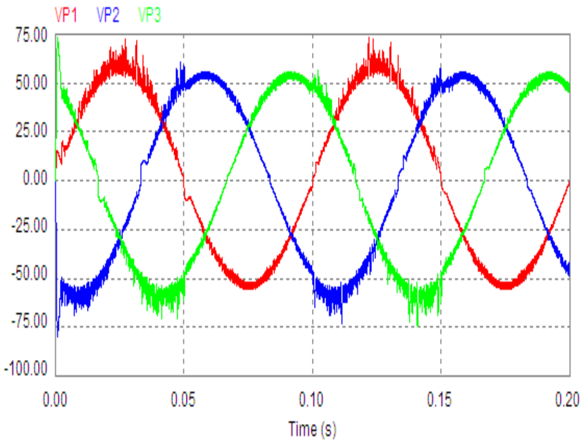


Left Hand Side Capacitor Voltage for Two Phases (20Hz, Step Change in supply voltage from 100-80 volt, RL-Load, Closed Loop)
Fig. 12d

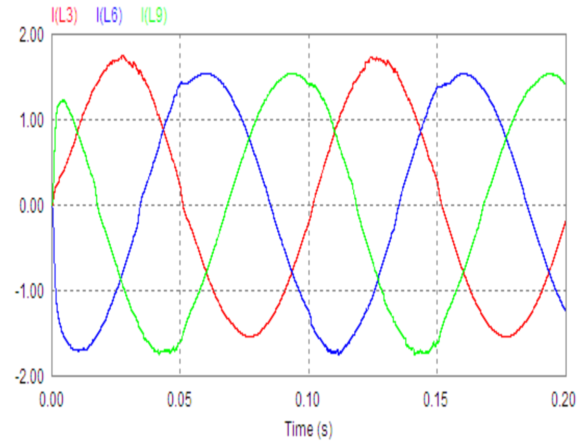


Supply Current (20Hz, Step Change in supply voltage from 100-80 volt, RL-Load, Closed Loop)
Fig. 12e

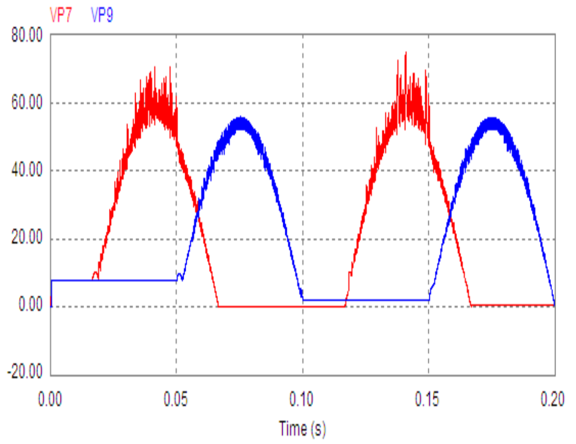
Figs. 13a to 13e show the output voltage, load current, capacitor voltages and supply current for a desired output of 10 Hz and 50 volt (Max.) with step change in both supplies from 100-80 volt.



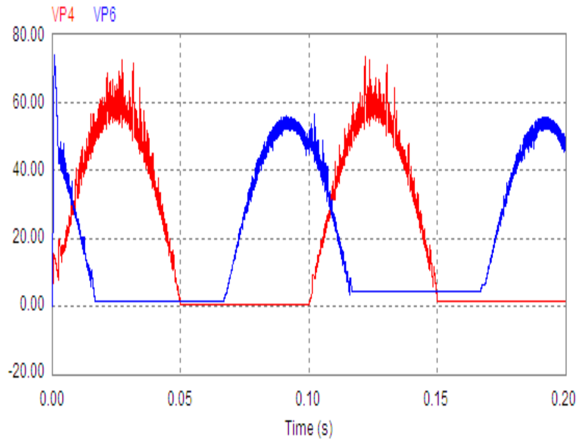
Output Voltage (10Hz, Step Change in both supplies from 100-80 volt, RL-Load, Closed Loop)
Fig. 13a



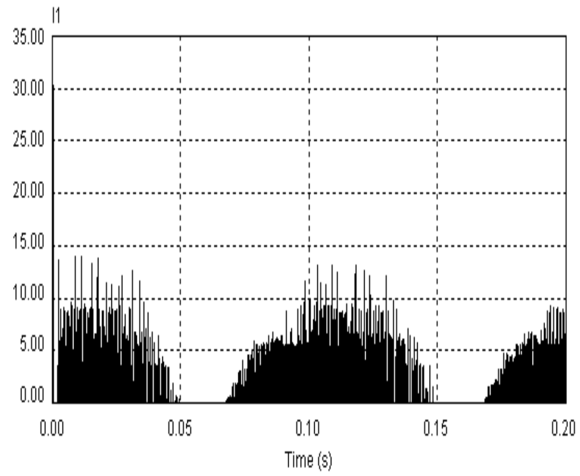
Load Current (10Hz, Step Change in both supplies from 100-80 volt, RL-Load, Closed Loop)
Fig. 13b



Right Hand Side Capacitor Voltage for Two Phases (10Hz, Step Change in both supplies from 100-80 volt, RL-Load, Closed Loop)
Fig. 13c

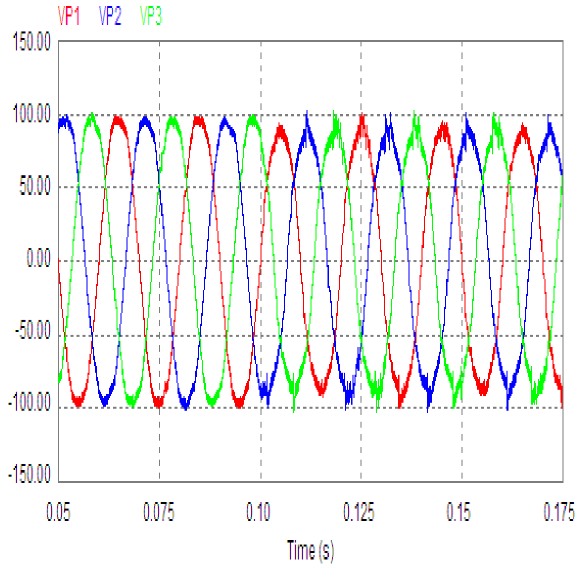


Left Hand Side Capacitor Voltage for Two Phases (10Hz, Step Change in both supplies from 100-80 volt, RL-Load, Closed Loop)
Fig. 13d

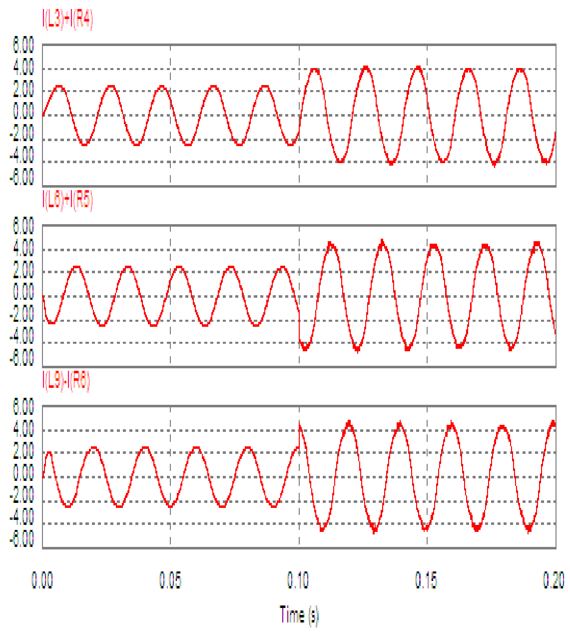


Left Hand Side Supply Current (10Hz, Step Change in both supplies from 100-80 volt, RL-Load, Closed Loop)
Fig. 13e

Figs. 14a & 14b show the output voltage and load current for a desired output of 50 Hz and 100 volt (Max.) with a sudden switching of a resistive load of 50 Ohm.

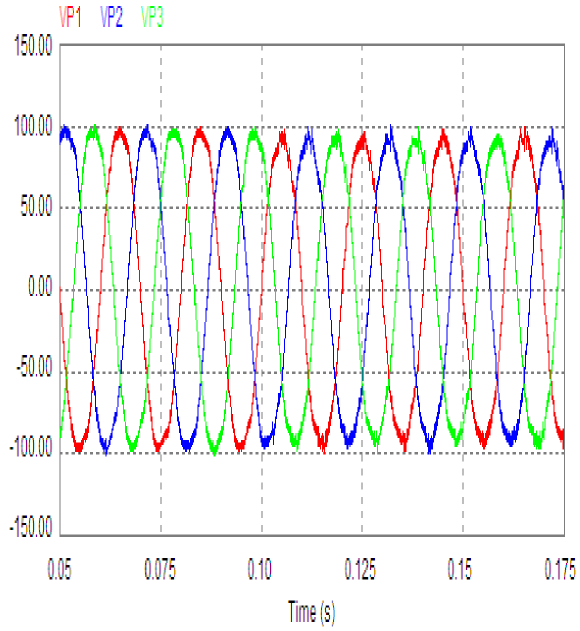


Output Voltage (50Hz, Sudden Switching of R-Load, RL-Load, Closed Loop)
Fig. 14a

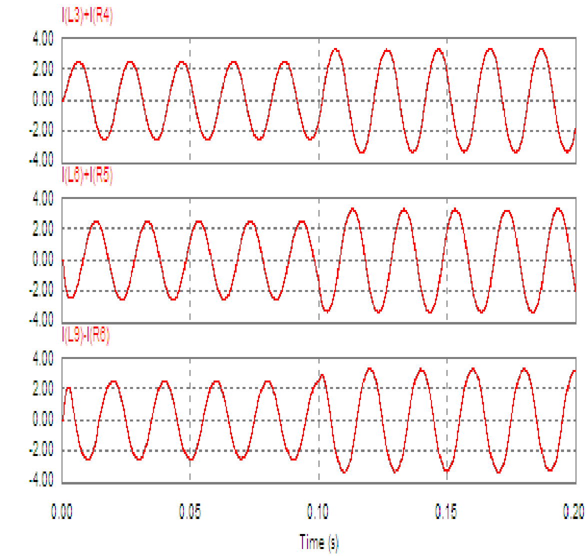


Load Current (50Hz, Sudden Switching of R-Load, RL-Load, Closed Loop)
Fig. 14b

Figs. 15a & 15b show the output voltage and load current for a desired output of 50 Hz and 100 volt (Max.) with a sudden switching of a resistive-inductive load of 100 Ohm resistor and 0.1 H inductor.



Output Voltage (50Hz, Sudden Switching of RL-Load, RL-Load, Closed Loop)
Fig. 15a



Load Current (50Hz, Sudden Switching of RL-Load, RL-Load, Closed Loop)
Fig. 15b

From all the above figures, it can be shown that the control technique gives an effective action against supply voltage and load changes which support the proposed control technique.

7 Conclusion

A new topology for a DC- to- 3-phase AC buck-boost converter has been presented. Control of the proposed converter has been presented in different modes of operation. The proposed control strategy has been found to give a satisfactory performance which supports the use of this converter in several applications.

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Appendix:

<u>Circuit Parameters:</u>
Capacitance C=50 micro Farad.
Inductance =1milli Henery.
Resistance of the Inductor = 1 Ohm.
P Controller Gain= 15.
Differentiator Time Constant = 0.004 Sec.
Load Resistance= 35 Ohm.
Load Inductance= 0.06 H.