

Web-Oriented Power Electronics Learning Aid

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Abstract

A web-based approach to learning about the features of power electronic converters and other important concepts is discussed. The behavior of various types of available converter topologies is not always easy to grasp from a textbook. Practical converters contain non-ideal characteristics, filters, voltage or current limiters, etc. Often, it becomes difficult to see the differences among converters without the aid of computer simulations. The rationale of producing this website is to give students a more intuitive approach whereby they can learn the material by interacting with a computer. All major types of converters are dealt with as well as specific topics such as electromagnetic interference (EMI), heatsink specifications, snubbers, and magnetics. Performance characteristics such as converter efficiency, ripple, and total harmonic distortion (THD) are also discussed.

1. Introduction

Power electronics deals with the conditioning of electrical power to a form that is more economical, more efficient, and more reliable for driving a load. For example, it would not be possible to get the same level of performance in machine tool and robotic drives, or in pulp and paper mill drives, or various vehicle propulsion systems without the use of a proper power electronic converter. The discipline is now becoming vital to industry and its application is spreading by leaps and bounds with the development of new and more powerful devices. Widespread applications of Power electronic devices can be seen in industrial, commercial, residential, utility, military and aerospace environments. Power electronics will play a critical role in energy savings and global industrial automation in the next century.

The power electronics discipline is challenging since we need knowledge in such diverse fields as circuits, control, magnetics, and integration. It also involves signal and power processing using electronic circuits. Traditionally, power processing circuits have been based on linear circuit technology. Therefore, they were low in efficiency and bulky in size. For example an audio power amplifier has efficiency less than 50%. Therefore, bulky heatsinks are required to dissipate the power. In recent years, high frequency switching technology has gained rapid development. Switching circuits use pulse width modulation (PWM) to carry signals and deliver power. The efficiency of a switching circuit can be near 100%. Therefore, power processing with switching circuits is much smaller in size, and lower in weight.

This paper describes a web-based approach to learning some of the important concepts of power electronics. By this webpage, we are not proposing to eliminate the need for a textbook. Rather, the webpage is meant to supplement the material a student learns from a conventional textbook. There are a number of excellent power electronics textbooks [1-4] in the market and

each of them is equally useful for a typical first course in the area. After having taught this course for many years from a textbook, we decided that an alternative approach, such as an animated, interactive graphical scheme could enhance a student's curiosity in learning converter working principles, because of the simplicity in the approach. The World Wide Web and the Java language provides the essential ingredients for creating a user-friendly environment for such a task. We have thus constructed some Java applets and they are placed at the following location: http://www.ece.umn.edu/courses/power_electronics/

The use of Java and the world wide web is now gaining widespread acceptance as a convenient education tool [5-8]. While we agree with the approach as being superior to conventional approaches, however, it remains to be seen whether it is more effective in imparting education to students. We are therefore planning to survey students after the web site has been used in the class.

2. Contents

The following is the list of specific topics that have been (or will be eventually) addressed on the web site.

- ◆ Converters:
 - Ac-dc rectifiers (both single-phase three-phase)
 - Dc-dc switch mode power supplies
 - Buck, boost, buck-boost, and Cuk types
 - Dc-ac inverters (both single-phase three-phase)
 - Resonant Converters
- ◆ Concepts:
 - Device Characteristics
 - Thyristors
 - Bipolar junction transistor (BJT)
 - Gate Turn-off transistor (GTO)
 - Insulated Gate Bipolar Transistor (IGBT)
 - Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
 - MOS-controlled Thyristor (MCT)
 - Magnetics
 - Transformers
 - PWM
 - Snubbers
 - Thermal management (heat Sinks)

3. Applet Specifications

Each applet developed has a number of common characteristics. These are:

- (1) Help window: The help window is an independent frame, which contains brief description about the application. An example is shown in Figure 1a. The window loads up initially whenever an application is launched.

- (2) Mouse-over Characteristics: This characteristic is helpful in explaining certain components in a converter circuit. Where this characteristic is present, a new window containing some information on the component appears when the mouse is placed over the component. This is done by capturing the mouse movements.
- (3) User defined fields: For all the applets, the inputs from the user are taken in plotting the outputs. This is considered as a vital feature as these are used to compare different values. These values are taken by placing labels and textfields in the applet. There are default values placed in these fields which will be helpful for a quick demonstration. The user should follow certain restrictions regarding applet features as well certain input parameters. The restrictions are found in the help window. If the user enters any value beyond the range specified, the applet will not start and flashes warning messages.
- (4) Working Model: In general, the application will have a circuit diagram and for some inputs the application will have some definite output.
- (5) PSpice Analysis: PSpice is a popular simulation software used to analyze power electronics circuits. In the Java applets one can only view the ideal characteristics of a converter. In order to show more realistic plots, PSpice software is used.

3. Description

3.1 DC-DC converters

In this module the student will learn about general properties of DC-DC converters. This module will help the student in understanding the basic topology, special features, operating principles, and the role of each component. The DC-DC converter maintains the integrity of the output power in the presence of non-ideal source characteristics. The module emphasizes this aspect by using animated graphics.

There are a number of sub-modules. After a brief introduction, the various topologies used in DC to DC converters are presented and discussed. For each DC to DC converter topology presented, we plan to make available the corresponding circuit data files for PSpice simulations.

3.2 Buck Converter

$$\text{The input-output relationship is: } V_o = \frac{T_{on}}{T} V_d \quad (1)$$

where V_o is the input voltage and V_d is the input dc voltage.

The output voltage of the converter may be controlled to the desired level by controlling the duty ratio.

Working model: The applet for the Buck Converter is shown in Figure 1a. The duty ratio, frequency in kilohertz and the input voltage are taken as inputs. The help window is also shown. The plots of output voltage, inductor voltage and inductor current are animated. The basic function of the bulk converter is explained in the help window. When the user enters the appropriate values and clicks the "click here" button, the converter animation starts. When the switch closes, the current flows through the input voltage source, inductor and the resistor. This is shown using a red line. After the T_{on} period when the switch opens, the capacitor discharges and this is also shown using a red line. The switch is shown as either closed or open accordingly.

The graphs of the output voltage, the inductor voltage and current across the inductor are shown. These graphs are displayed slowly so that the user can understand how the output voltage or the inductor voltage or the current across the inductor is changing with the opening and closing of the switch. The average values are also shown along with the actual sketch and the corresponding values are marked. The user can experiment with a different set of values.

Figure 1b shows the plot generated by Pspice for the buck converter.

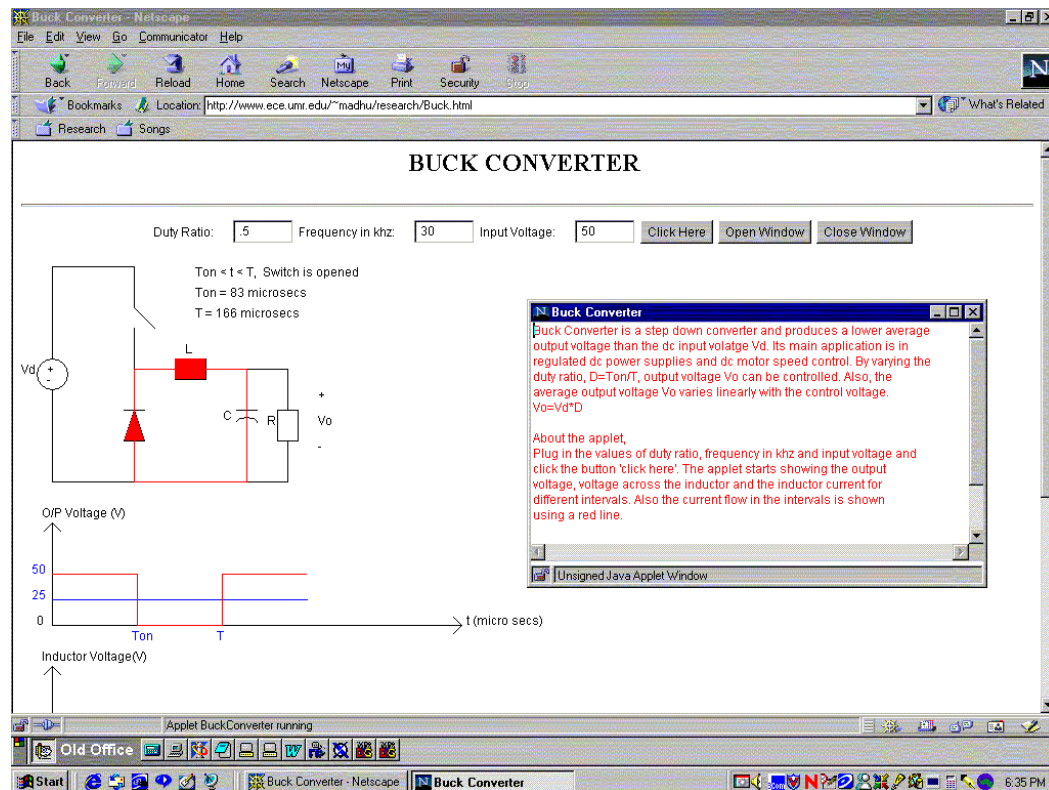


Fig. 1a. The buck Converter

3.3 Boost Converter

The output voltage will be constant and larger than the input voltage. The voltage and the current across the inductor are shown as animated plots. The status of the switch and the values of T_{on} and T are displayed on the applet. Again, the user can interactively choose input parameters to see the converter performance under varying conditions.

3.4 Buck-boost Converter

Some of the characteristics of a buck-boost converter are:

- the output voltage can be less than, or greater than the input voltage
- the output polarity is opposite to the input polarity
- the output voltage ripple percentage is dependant on the load on the converter
- efficiency is better at lower duty ratio

- the input current is discontinuous and pulsating, therefore an input filter might be needed if the source cannot supply such a current

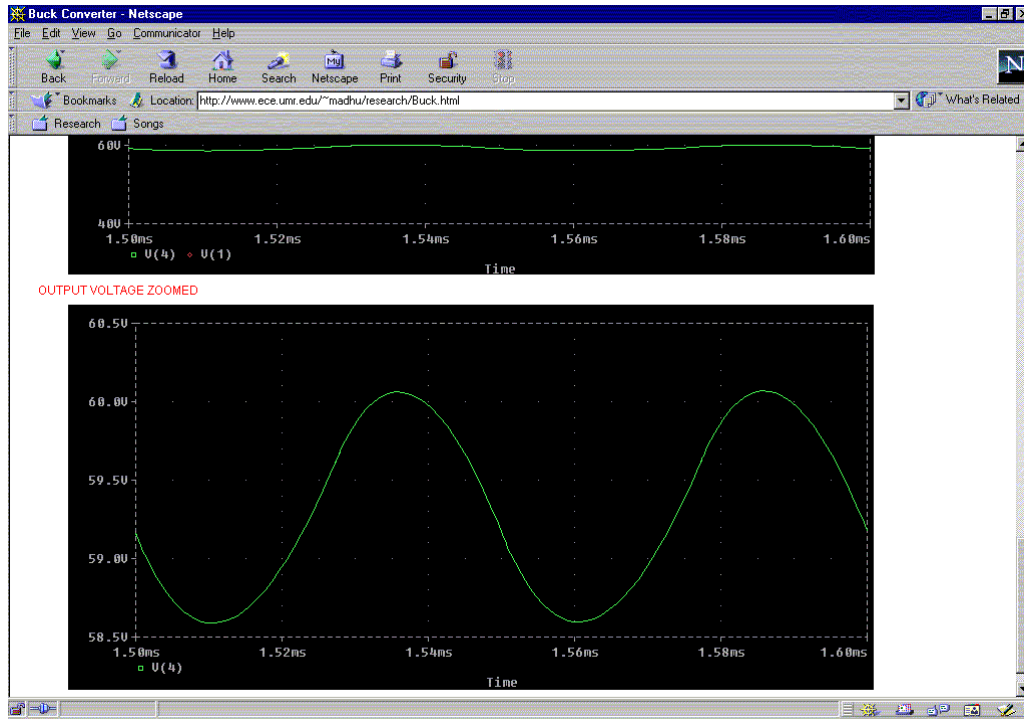


Fig. 1b. Pspice plots for the buck Converter

Working model for the Buck-Boost converter

When the switch is closed, the energy is drawn from input supply and transferred to the load and inductor, as the current builds up. When the switch is open the energy stored in the inductor during the previous part of the cycle gets released to the load.

The output voltage in steady state can be calculated as:

$$V_o = \frac{d}{1-d} V_d \quad (2)$$

$$\text{where } d = \text{duty ratio} = \frac{T_{on}}{T}$$

3.5 Cuk Converter

The Cuk converter is similar to the Buck-Boost converter in terms of its output relationship. However, this converter is superior to the Buck-Boost in that both input current and output current are almost ripple-free and there is a lower external filtering requirement.

Working model: The Cuk converter operating characteristics are shown in Figures 2a and 2b. In the previous dc-dc converters there was one inductor in the circuit. In the Cuk converter, there are two inductors that play important roles. The voltages and currents at these inductors are plotted. The values are also marked at the appropriate places.

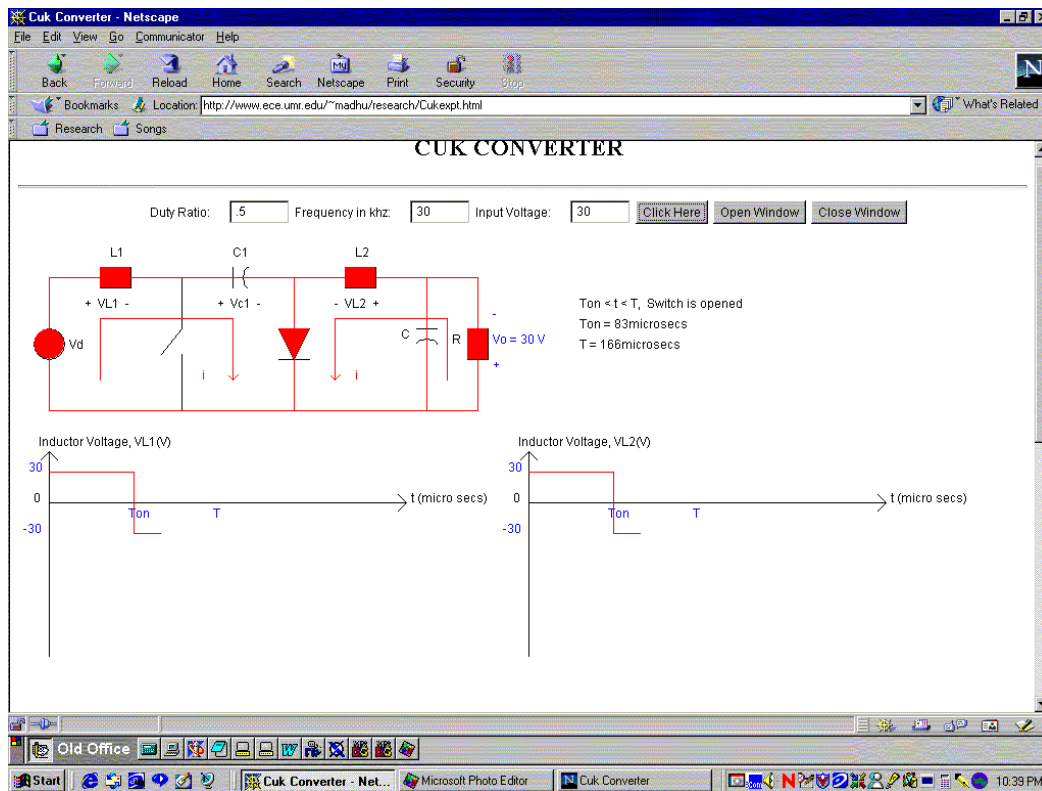


Fig. 2a. The Cuk Converter

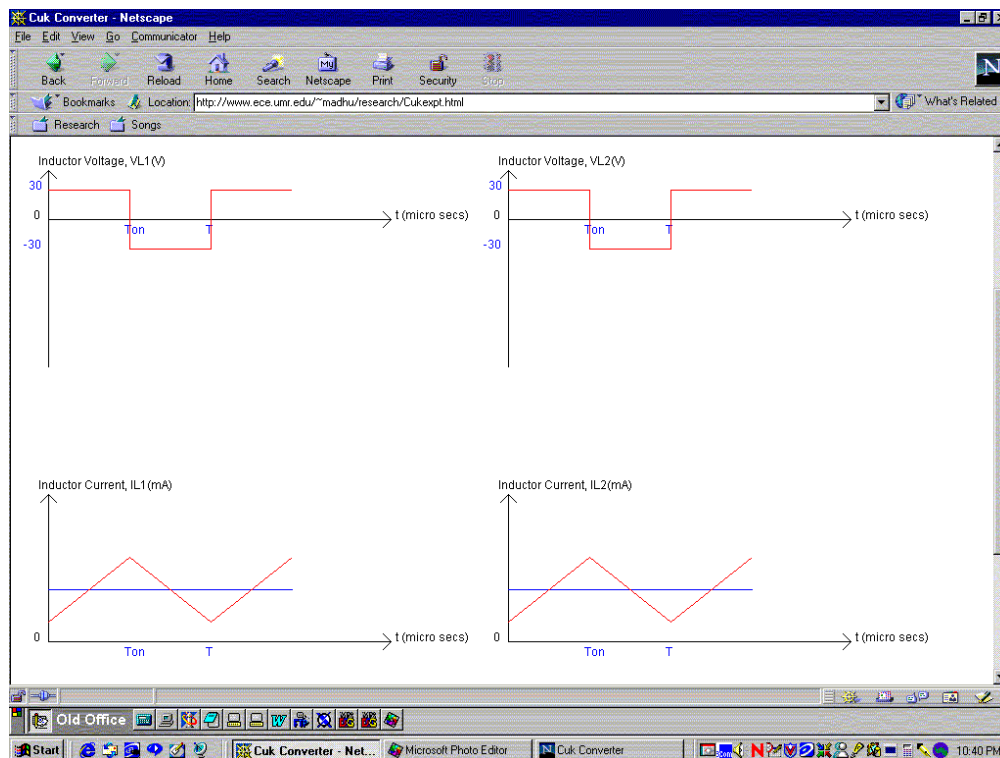


Fig. 2b. The Cuk Converter plots

3.6 DC-AC Inverters

Two classes of inverters are considered. They are

- Single Phase Inverters
- Three Phase Inverters

In the inverters PWM switching is used. There are 2 types of PWM switching. They are

- Square wave PWM
- Sinusoidal PWM

Square Wave PWM

The user can move a horizontal line anywhere on top of a triangular wave to generate a square wave.

Sinusoidal PWM

This PWM switching scheme is generally used in single phase and three phase inverters. This is explained in conjunction with the inverters below.

3.7 Single Phase Inverters

The applet for single-phase inverters is shown in Figures 3a and 3b. There are three text fields, which are to be input by the user. They are (a) the number of triangular pulses in one sine wave, (b) amplitude of the triangular wave and (c) the amplitude of the sine wave. This applet is designed for 1 sine wave only with a variable number of triangular wave cycles. So the frequency of the sine wave is fixed and the frequency of the triangular wave is variable. When the applet is started, the PWM switching scheme with sinusoidal signal on the triangular wave is displayed. Then a red dot moves along the sinusoidal wave and depending on the position of this dot, the switches in the circuit opens and closes and the corresponding output voltage is plotted. The user can change the values at any time and can restart the process. The user can also check the harmonics at any time by clicking the button 'click for harmonics'. Harmonics are displayed at the bottom as shown in Figure 3b.

3.8 Three Phase Inverters

The applet for three-phase inverters is shown in Figures 4a, 4b and 4c. The same inputs that are used for the single-phase inverter are taken here. Initially only the circuit diagram for the conversion process is displayed. After the applet is started the PWM plot with the triangular wave and the three sinusoidal waves for the three phases with different colors on it are displayed. Though all the three phases are shown in the PWM plot, only the line-line voltage between phases A and B is shown. After the PWM plot is displayed, the plots of phase A voltage to neutral, and phase B voltage to neutral are displayed. Then the line-line voltage between phases A and B is displayed. These values will change according to the inputs. Here again, the harmonics, can be displayed.

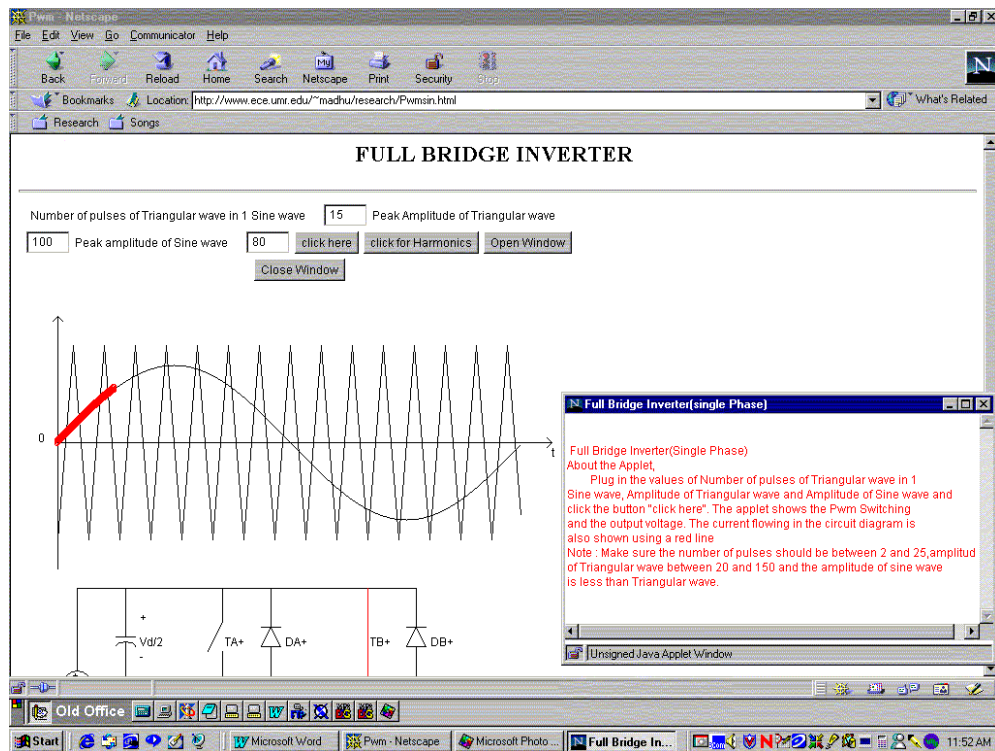


Fig. 3a. The PWM scheme for the single-phase full-bridge inverter

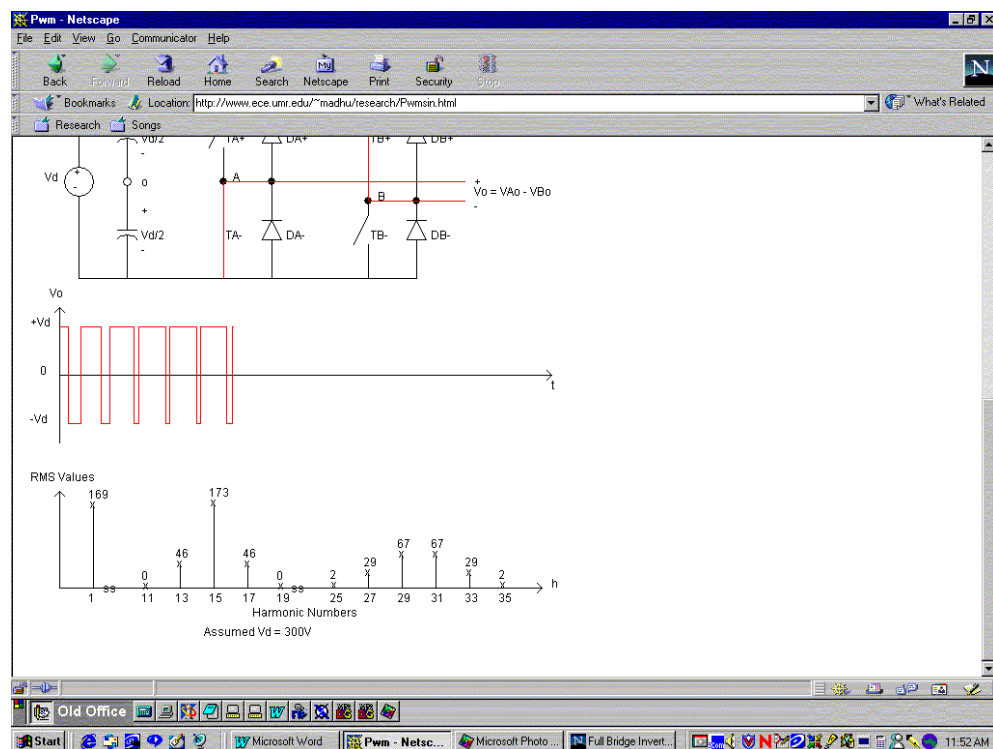


Fig. 3b. The single-phase full-bridge inverter and associated harmonics

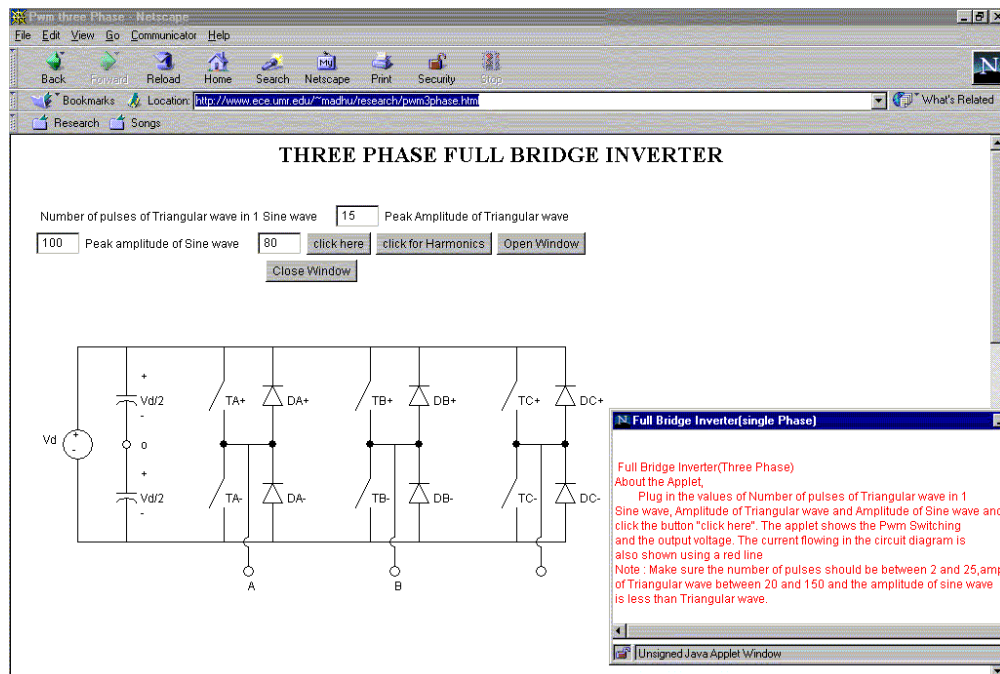


Fig. 4a. The three-phase full-bridge inverter

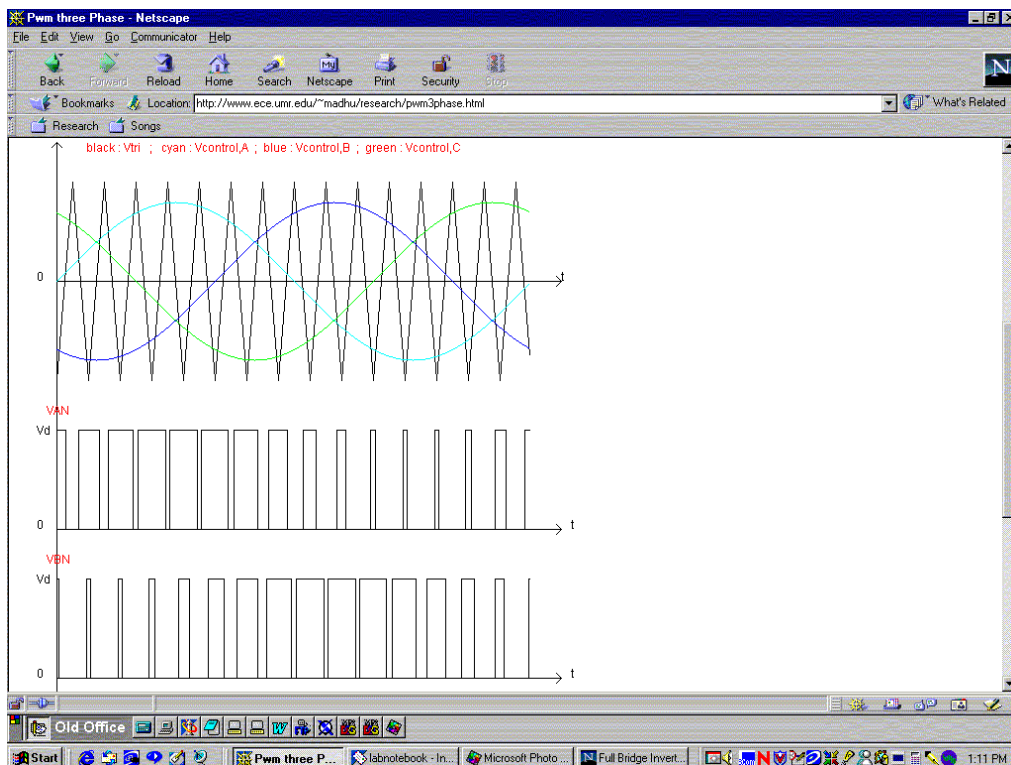


Fig. 4b. The single-phase full-bridge inverter line to neutral voltages

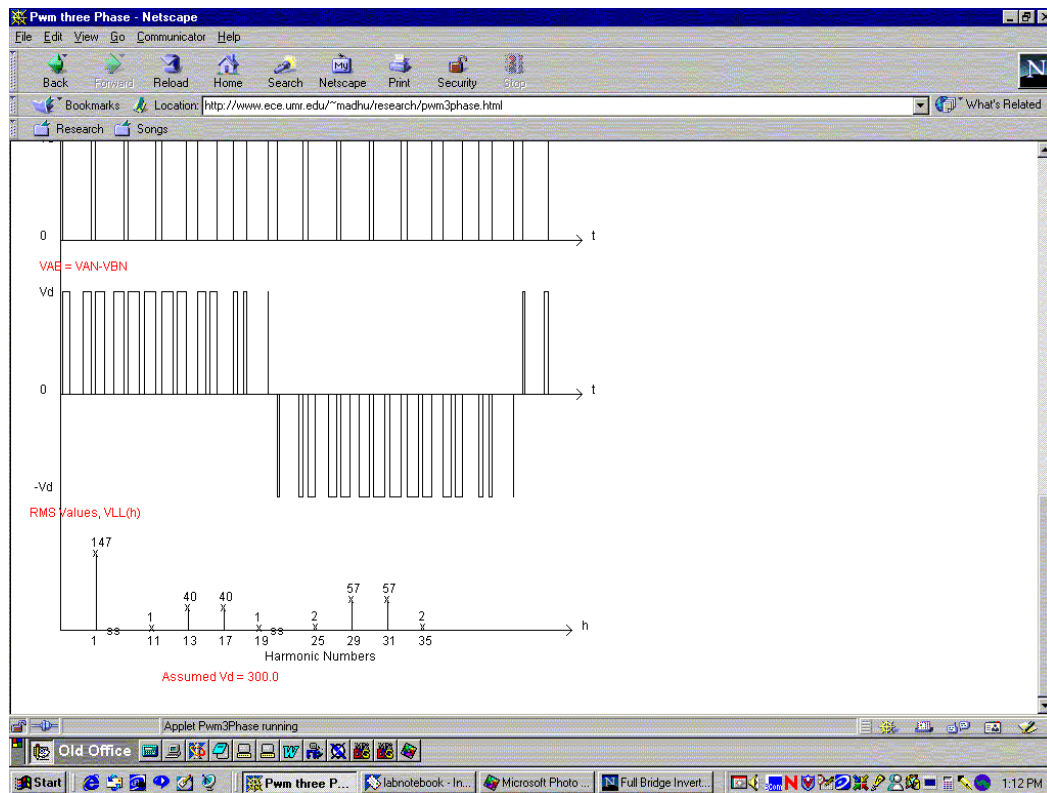


Fig. 4c. The line to line voltage for the three-phase full-bridge inverter

4. Conclusions

This website is not meant to be an alternative to a textbook. Rather, it is meant to enhance a student's learning by a self-paced tutorial sort of an environment. It is only with a combination of the web-based approach, a textbook, lab exercises, and computer simulations can a student realistically learn the material thoroughly.

Java has extensive built-in classes and therefore the need for other programming languages hardly arises. The Java applets that were developed are stand-alone programs. They provide useful information of the operating characteristics of specific power electronic components, circuit elements, and converters. Some background material is provided through pop-up help windows. The applets provide some flexibility in experimenting with different input values. There were some problems encountered during the construction. Most of them would be related to using an older version of the Web browser. One of the potential problems that can become a nuisance is flickering. A flickering in the Java applets was sometimes observed when a graphics was being animated on the screen. This problem was minimized to a large extent by drawing images in the background and then drawing in the foreground.

5. Bibliography

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