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A GUI-SIMULINK BASED EDUCATION TOOLBOX FOR POWER ELECTRONIC DC/DC CONVERTERS

ABSTRACT

Dc/dc converters are widely used today to provide power processing for applications ranging from computing and communications to medical electronics, appliance control, transportation, and high-power transmission. Therefore, dc/dc converters are one of the most important topics for power electronics engineering. This paper presents an educational graphical user interface (GUI) for simulation of various topologies of power electronic dc/dc converters. The educational GUI is developed by using the GUIDE tool of MATLAB, which acts as a front-end interface that can be used for teaching as well as learning. This package can be considered as a virtual laboratory or a useful learning tool for the power community.
Keywords: DC/DC Converter, Power Electronics, GUI, Simulink, Educational Toolbox

DC/DC GÜÇ ELEKTRONİĞİ KONVERTERLERİ İÇİN GUI-SIMULINK TABANLI BİR EĞİTİM SETİ

ÖZET

Dc/dc konverterler günümüzde, bilgisayar ve haberleşme sistemlerinden tıp elektroniğine, kontrol cihazlarına, ulaştırma araçları ve yüksek güç enerji iletimine kadar birçok alanda enerji sağlamak için yaygın biçimde kullanılmaktadır. Bu yüzden dc/dc konverterler, güç elektroniği mühendisliğindeki en önemli konulardan biridir. Bu çalışma, birçok farklı topolojiye ait dc/dc konverterlerin simülasyonu için eğitim amaçlı bir arayüz sunmaktadır. Bu arayüz programı, MATLAB GUIDE kullanılarak geliştirilmiştir; GUIDE, öğrenme ve öğretme için de kullanılabilecek en son tür bir arayüz geliştirme MATLAB eklentisidir. Bu çalışmada geliştirilen arayüz programı, güç sistemleri ile ilgilenen topluluk için sanal bir laboratuar olarak düşünülebilir.
Anahtar Kelimeler: DC/DC Konverter, Güç Elektroniği, Arayüz, Simulink, Eğitim seti

1. INTRODUCTION (GİRİŞ)

Dc/dc converters (switched-mode power supplies) efficiently convert a dc voltage level to another dc voltage level at power levels below a few kilowatts. Originally distributed regulated converters were used in mission-critical space applications, where reliable operation was of prime concern. Nowadays, even the on-board power systems are distributed, where regulated converters are used both as supply converters as well as loads. These converters are nonlinear dynamical systems that contain too stiff mathematical expressions. The nonlinearities arise primarily due to switching, power devices, and passive components, such as inductors, and parasitic [1 and 2].

In the sense of teaching pedagogy, the traditional treatment of all fields of engineering tends to be highly theoretical and mathematical with heavy emphasis on equation derivation and algorithmic development. Such an approach is convenient from the instructor’s point of view but may not be beneficial to the students. Simulations often enrich modern education in all areas [3, 4, 5 and 6]. Various simulation packages are being widely used to design and simulate electrical and electronic circuits’ behavior. However, each of these simulators has their own merits and demerits, limitations either from the analysis point of view or from economical considerations. These simulators also require the user to be proficient in designing the circuits and need deep training to be familiar with. Important demands for education are visualization of the simulation results and the interactivity of the simulation. The student should have the ability to influence parameters and/or conditions during the simulation and thereby see the effects of these variations immediately in his simulation. GUI based interactive simulations are an effective way to go deeper inside a problem [7, 8, 9, 10 and 11].

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Due to increasing demand, the power conversion systems are becoming more and more complex in their structure. As a result of this, it is essential to make computer aided simulations before setting up the power electronic system. In this paper an educational GUI for simulation of various topologies of power electronic dc/dc converters has been presented. An attractive and flexible GUI is built benefiting from the facilities offered by the Matlab programming language. Matlab implements GUIs through GUIDE (Graphical User Interface Development Environment). The developed GUI, no need for any circuitry design, is a user-friendly tool and gives the basic understanding of most commonly used dc/dc converter topologies, so it can be considered as a learning aid system for students to get a comprehensive understanding of power electronic converter operations. Various parameters are made available for the user to change and see their impacts on the converter performance through its waveforms.

3. MATERIAL AND METHOD (MATERYAL VE METOD)

Matlab is a matrix-based software for scientific and engineering numeric computation and visualization. In this paper, Matlab package is chosen as the programming tool primarily because of simple GUIs, simulink libraries, immediate graphics facilities, built-in functions, the possibility of adding user-written functions, interactive mode of work, simple programming and its wide availability on computing platforms. Simulink, a toolbox of Matlab, is dynamic system simulation software that provides a convenient graphical user interface for building system models based on their equations. These factors make

Matlab an excellent language for teaching and a powerful tool for research and practical problem solving [12].

A GUI is a user interface program built with graphical objects such as buttons, text fields, sliders and menus. In fact, these definitions are well known for almost all computer users. Applications that provide GUIs are generally easier to learn and use since the person using the application does not need to know what commands are available or how to use them. GUIs assure the communication process between the user and the system's inference engine. Matlab implements GUI through GUIDE which allows the user to create figure windows containing graphical objects [13]. Matlab also provides the user some built-in templates on which the user can develop further. The user can place graphical objects by drag-and-dropping them on the figure window and modify the default properties of these objects such as foreground and background colors, font types and sizes by invoking the Property Editor.

4. DEMONSTRATIVE EXAMPLES (AÇIKLAMALI ÖRNEKLER)

Basically, the developed GUI consists of two sets of programs. One set is responsible for the main GUI window; and the other is responsible for the selected dc/dc converter window. In the main GUI window a total of eight dc/dc converters are investigated. Therefore, each of converters has its own window. The main GUI window gives a list of dc/dc converters, displays the power circuitry and basic information of selected converter and allows the user to choose any of them to be examined. The power circuitry and basic information, positioned on the right-side of the main window, is activated with push-button labeled with its own converter name. The main GUI window, displaying the power circuitry and basic information on buck converter, is given in Fig.1. All of the power circuitries are formed with the Visio-Technical-Drawing software, and imported and stored into Matlab program as a .gif image; the graphs of conversion ratio are created with the functions in the axes component; the basic information is built with the static-text string property. All of the converters in question can be examined by using the push-buttons labeled with the symbol '>>' positioned on the right-side of the converter type. At any time the user can run all of the converter types independently and compare with each other.

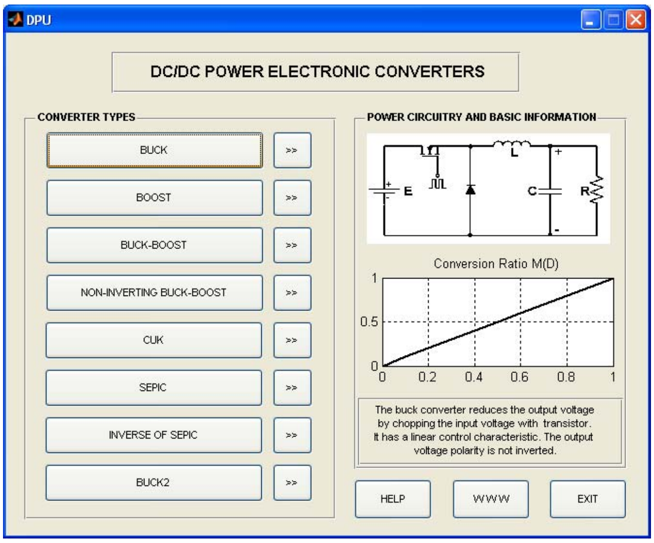


Figure 1. The main window of the GUI
(Şekil 1. GUI ana penceresi)

When the user selects the converter type to simulate by pressing '>>', an individual window showing the circuit specifications will pop-up. Depending upon the nature of the selected converter type, the user needs to enter the required data. Naturally, the required data will be slightly different from each other. The 'HELP' button gives relevant information on dc/dc converter and its usage.

In dc/dc converters the basic topologies are buck and boost topologies. Depending upon the application requirement any one of the topology or combination of both can be used. The buck-boost topology is examined in this section. A buck-boost regulator provides an output voltage which may be less than or greater than the input voltage. The output voltage polarity is opposite to that of the input voltage. This converter is also known as polarity inverting converter.

Depending on the whether the converter switch is ON or OFF, the converter operation can be divided into two modes of operation. During mode-1 the switch is conducting; and energy is transferred from the dc supply to L. During mode-2 the switch is open; and stored energy in L is transferred via diode to both C and R. The load current is provided by the energy stored in C during mode-1, and in L during mode-2. Whenever a converter is designed for a specific purpose, the mode of operation i.e., Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM) of the inductor current has to be decided. If all the stored energy in L is transferred to C before the switch is turned on, operation is termed 'Discontinuous', since the inductor current has reached zero. If the switch is turned on before the current in L reached zero, that is, if continuous current flows in L, operation is termed 'Continuous'. For a given frequency and load, the critical value of inductance can be easily computed with Eq.1.

$$L_{critical} = \frac{R(1-D)^2}{2F_s} \tag{1}$$

where $L_{critical}$ is the critical value of inductance, R is the load resistance, and F_s is the switching frequency. If the selected inductance is greater than $L_{critical}$ then the current is continuous otherwise it is discontinuous.

The next important parameter to be designed is the capacitor. The capacitor can be designed by fixing the output ripple to desired value. Assuming that the ripple-current component of the diode current flows through the capacitor, and its average value flows through the load resistor; the peak to peak voltage ripple is related to circuit parameters given in Eq.2.

$$\frac{\Delta V_0}{V_0} = \frac{D}{RCF_s} \tag{2}$$

where D is duty ratio and V_0 is the output voltage. From Eq.2 the capacitor value can be determined easily. Similar analysis can be also used for rest of the converters by choosing proper modes of operation.

When the user selects 'Buck-Boost Converter' in order to analyze from the main GUI window in Fig.1, an individual window of the buck-boost converter shown in Fig.2 will appear. This individual window mainly consists of five-frame. The first frame entitled 'CONVERTER PARAMETERS' is the part for inputting converter parameters such as input-output voltages, switching frequency, load power and etc. The second frame entitled 'CALCULATIONS' is the part for calculating critical values of the L-C, duty ratio and etc. Calculations are performed by push-button named with 'CALCULATE'. If the user wants to use calculated values of L-C in the converter circuitry, the button labeled with 'SET L-C' must be pressed. Pressing the button 'SET L-C' also changes the contents of two edit-boxes with the calculated values of L-C. If the user prefers different values to the calculated critical values, the button named with 'ENTER L-C' should be pressed. The new values of L-C will appear in the two edit-boxes after editing. In this demonstrative example the values of L-C are set at the calculated critical values for testing the converter.

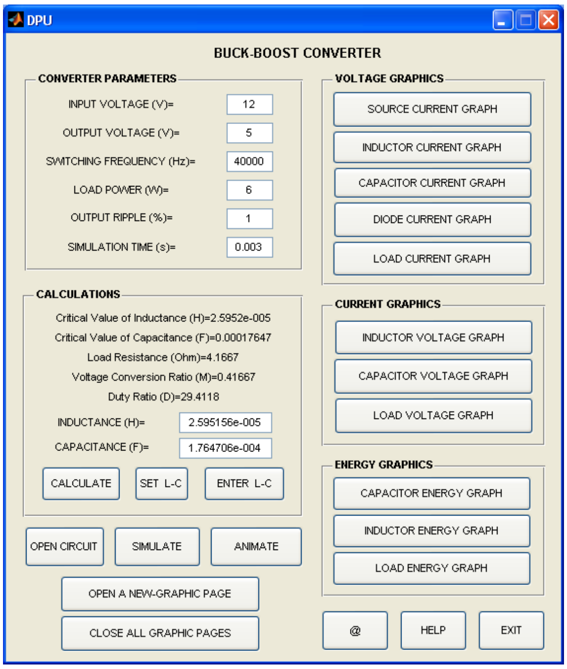


Figure 2. Individual GUI window of the buck-boost converter
(Şekil 2. Buck-boost konverter GUI penceresi)

After inputting the converter parameters and determining the values of L-C component, the buck-boost converter is now ready to simulate and animate. In order to see the simulation circuit the user should press the button named with 'OPEN CIRCUIT'. This button, at the same time, transfers the converter parameters to the simulink file. The circuitry related to the buck-boost converter, designed in simulink power system toolbox of matlab, is given in Fig.3. The diode and mosfet elements in circuitry are assumed to have ideal characteristics. As seen from the fig.3, the circuit also displays properties of the circuit components, which is very helpful for checking variables immediately. When the user clicks the button named with 'SIMULATE', the simulation of circuitry is performed within the time specified in the first frame, and the data obtained from measurement are stored in the file 'buck-boost.mat'.

After simulation of the simulink circuitry the user is able to animate the converter circuitry and draw the all graphs offered on the left side of the GUI. The dynamic animations of the converters are realized with the two-dimensional linear transformation matrixes in non-homogeneous coordinate system. The animation using the data containing currents and voltages is very realistic and helpful for better understanding. A well-regulated output voltage in dc/dc converter is actually obtained by transferring optimum energy from a source to the load. Therefore, energy flow is the most important subject in this topic. Ideally the inductor, capacitor and switch do not dissipate power. The animation circuit has been realized using lossless elements. It is only the resistive element that consumes energy.

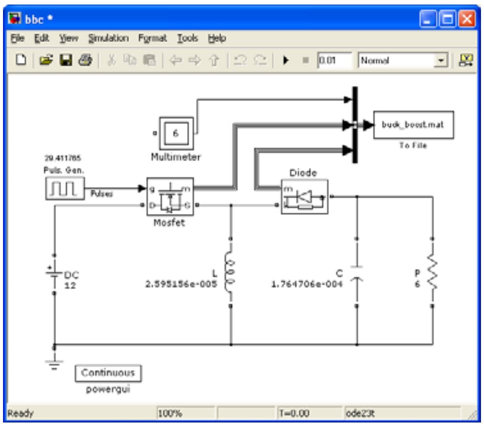


Figure 3. Simulink circuitry of the buck-boost converter
(Şekil 3. Buck-Boost konverter Simulink devresi)

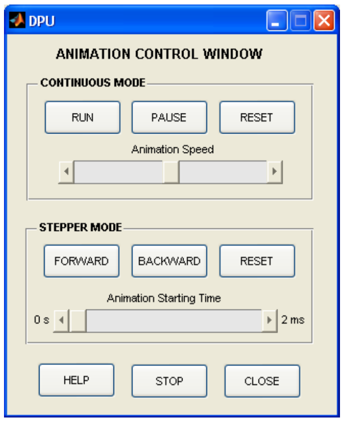
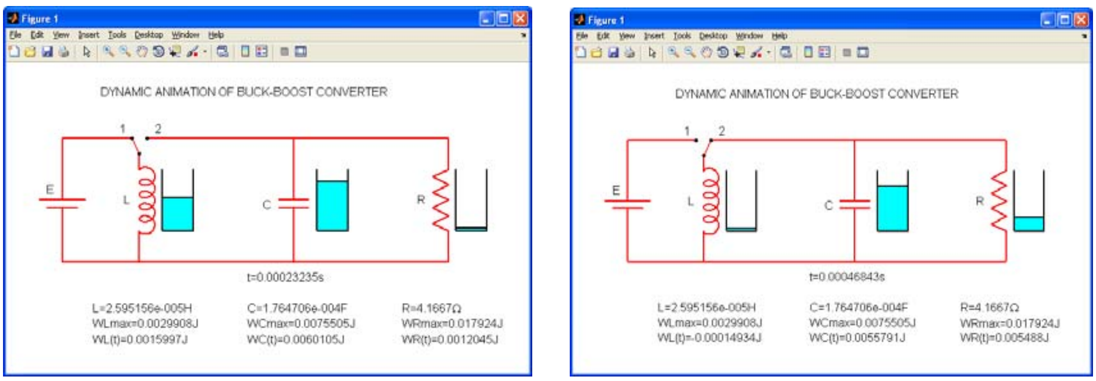


Figure 4. The GUI window of animation control
(Şekil 4. Animasyon kontrol GUI penceresi)

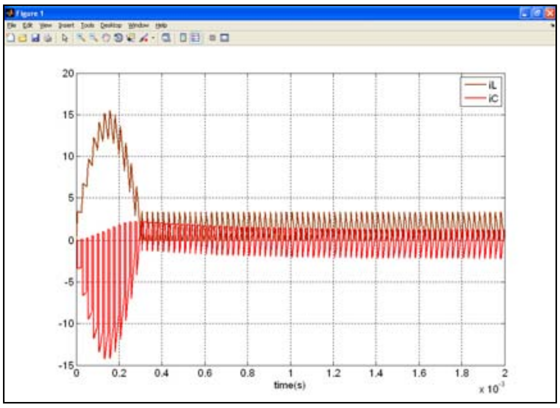
By using the button named with 'ANIMATE' the user can open the 'Animation Control Window' shown in Fig.4. With this individual window the user can animate the converter circuitry in time domain, and see the energy transfer between the components in continuous or stepper mode. In continuous mode, the animation is shown to the user at a specified speed defined by a slider; in stepper mode, it is shown step-by-step as from a specified starting-time defined by a slider. This method is likely the best way to figure the converters out. Instantaneous windows of the dynamic animation are given in Fig.5. The cups near the components represent energy level in related elements. Sizes of the cups are irrelevant each other and proportional to the maximum energy level of related elements in simulation time. Energy level of L-C will be maximum at the beginning of the animation, and then they will decrease slowly until reaching equilibrium. Energy level of R will increase continuously and reach maximum level at the end of the animation. The menus and toolbar located to top of the window can be used for classical window operations such as saving, copying, printing, zooming and etc.



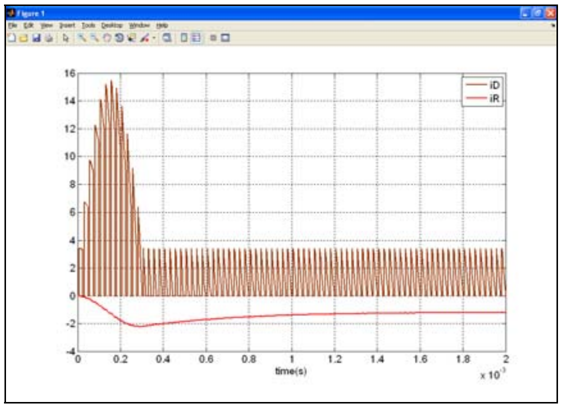
(a) (b)

Figure 5. Instantaneous dynamic-animation windows of the buck-boost converter at the time, a) t=0.00023235s, b) t=0.00046843s
(Şekil 5. Buck-boost konverter bazı anlık dinamik animasyon pencereleri, a) t=0.00023235s, b) t=0.00046843s)

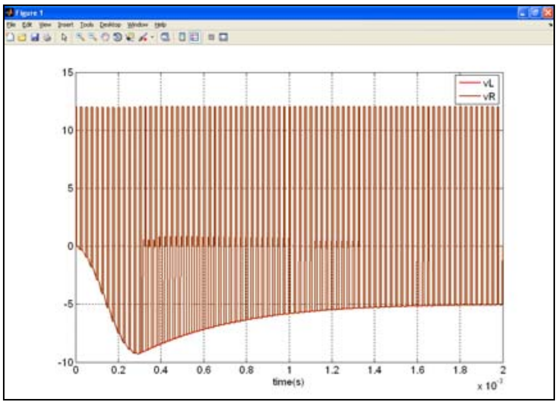
The third, fourth and fifth frames entitled 'VOLTAGE GRAPHICS', 'CURRENT GRAPHICS' and 'ENERGY GRAPHICS' respectively are the parts for displaying related graphics. The names of the graphics are assigned to the related push-buttons. After pressing the button named with 'OPEN A NEW GRAPHIC PAGE' the user can display multiple graphics in the same graphic page; the user can open many graphic pages, also. As an example, the inductance and capacitance currents of the converter are given in Fig.6.a; the diode and load currents are given in Fig.6.b; the inductance and load voltages are given in Fig.6.c; and the energy alterations in R, L and C elements are given in Fig.6.d.



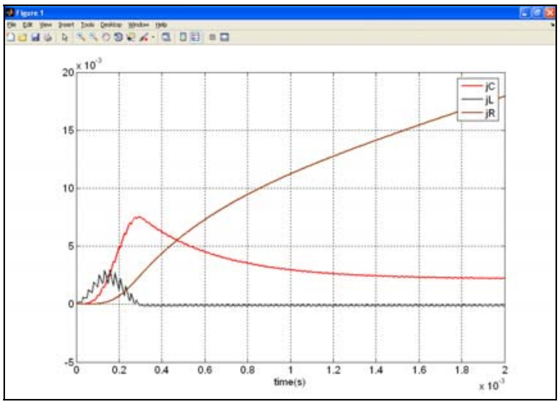
(a)



(b)



(c)



(d)

Figure 6.a) The graphs of inductance and capacitance currents, b) The graphs of diode and load currents, c) The graphs of inductance and load voltages, d) The graphs of energy alterations in R,L,C
(Şekil 6.a) Bobin ve kondansatör akım grafikleri, b) Diyot ve yük akım grafikleri, c) Bobin yük gerilim grafikleri, d) R,L,C elemanlarının sahip olduğu enerji değişim grafikleri)

5. CONCLUSIONS (SONUÇLAR)

This paper presents an educational GUI toolbox for simulation of various topologies of power electronic dc/dc converters. The educational GUI package, a different approach to power electronic education on a personal computer, provides a convenient tool so that many scenarios can be tried with ease. It also provides 'a virtual laboratory', in which the user can choose the dc/dc converter type, enter the related converter parameters and view circuit parameters’s graphs in time domain. In addition, the GUI toolbox is supported with dynamic animations constituted from computer graphics and simulink outputs. This is very helpful for better understanding. The user needs only an elementary knowledge of power electronic circuitry in order to use this educational GUI.

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