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Development of a Material Selection Software for DC-DC Converters Using Python

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ABSTRACT

DC-DC converters are one of the crucial tools of power electronics. Choosing the right materials while designing converters is essential to obtaining the right results. When selecting these components, the requirements of the intended application and the type of DC-DC converter that is to be used should be considered, and appropriate calculations should be carried out accordingly. Components should then be selected based on these calculations. These calculations differ with the requirements of the application and the type of the converter. These calculation tools are rare in market except for commercial material manufacturers. In this study, a Python-based software has been developed to fulfill this task. This software is designed to be used by individuals of all levels of knowledge. It is thought that it will provide great convenience in material selection for undergraduate and graduate students and engineers who design electronic cards.

Python Kullanılarak DC-DC Dönüştürücüler İçin Malzeme Seçim Yazılımının Geliştirilmesi

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ÖZ

DC-DC dönüştürücüler güç elektroniğinin vazgeçilmez araçlarındandır. Dönüştürücü tasarımında doğru malzemelerin seçimi, doğru sonuçların elde edilmesi açısından önemlidir. Malzemeleri seçerken, kullanılacağı uygulamanın gereksinimlerine ve hangi DC-DC dönüştürücü kullanılacağına bakılarak ona uygun olan hesaplamalar yapılmalıdır. Yapılan bu hesaplamalara göre seçim yapılmalıdır. Hesaplamalar uygulamanın gereksinimine ve dönüştürücünün çeşidine göre farklılıklar gösterir. Piyasada bu hesaplamaları yapmak için geliştirilen, ticari yazılımlar dışında çok az sayıda yazılım bulunmaktadır. Bu çalışmada bu görevi gerçekleştirmek üzere Python tabanlı bir yazılım geliştirilmiştir. Geliştirilen yazılım her bilgi düzeyinden kişiler tarafından kullanılabilecek şekilde tasarlanmıştır. Elektronik kart tasarımı yapan lisans, lisansüstü öğrenciler ve mühendisler için malzeme seçiminde büyük kolaylık sağlayacağı düşünülmektedir.

1. INTRODUCTION

Power supply technology provides the opportunity to us to build and operate electronic circuits and systems. Every electronic circuit needs a dc power supply to run. These circuits require different voltage levels. The dc voltage is usually derived from batteries or ac power supplies by using transformers, rectifiers and filters. This raw dc voltage has high ac ripple that is not appropriate to feed electronic circuits. In some cases, this voltage carries the harmonics from unfiltered ac power supply. These unwanted effects can significantly affect the performance of electronic systems, causing malfunctions and inefficiencies. To ensure the quality of dc voltage, DC-DC converters are obligated to use. DC-DC converters do not provide just more stable voltage, they also provide flexibility to change voltage level according to requirements of the electronic systems. By regulating and converting DC voltage efficiently, DC-DC converters help optimize power usage and improve the overall efficiency of electronic devices [1].

For different kind of applications, a vast variety of DC-DC converters have been developed. This article has been written with the intention of it to become a hand guide and a useful application to the ones that work with or will work with DC-DC converters. This article presents a detailed study for seven widely used DC-DC converters: buck, boost, buck-boost, cùk, flyback, forward and push-pull have been selected for this research. These converters have been selected due to their prevalence in various industrial and consumer electronics applications. This work stands out by combining theoretical analysis with a Python-based application. Both theoretical analysis and application show how components of DC-DC converters should have been selected. The parameters of components that should be taken note of are inductance and capacitance values, and voltage and current ratings of switches and diodes [2-4].

DC-DC converters operate in three distinct modes depending on inductor current: Continuous Conduction Mode (CCM), Boundary Conduction Mode (BCM) and Discontinuous Conduction Mode (DCM). In this article, analysis and derivation of the dc voltage transfer functions of DC-DC converters have been done in BCM. Additionally, the derivation of the theoretical equations in the article was also carried out in BCM. However, the developed software is able to calculate the required values for three different modes of DC-DC converters. [1,5-6].

In order to complete the theoretical framework, a computer application has been developed for this article. When the developed software is compared with its commercial equivalents, it is seen that it is designed for the materials that commercial brands produce themselves. Developed application is designed to be brand independent. It is developed to assist engineers, researchers, and students in calculating key parameters, such as inductance, capacitance, voltage and current values of the components of the seven DC-DC converters that have been dwelled upon in this article. The software is designed for universal accessibility, featuring a simple and user-friendly interface. At the top of the interface, users can select their desired DC-DC converter type from the tabs. Then, they input the required parameters for their specific application, such as input voltage, output voltage, switching frequency, and transformer turn ratio. Next, they choose the operating mode for their DC-DC converter. Once all parameters are set, clicking the "Calculate" button generates the necessary component values. Users also have the option to print the calculated values or save them as a TXT file directly through the software.

Developed using Python in this software, Tkinter library has been used to develop user interface. The application uses a tabbed interface structure where each DC-DC converter topology has its dedicated tab. The main components are a notebook widget for tab management, circuit diagram display using canvas, input fields, mode selection using radio buttons, and calculation results display. The application is packaged into a standalone executable using PyInstaller, making it easily distributable to end users. The distribution package includes the main executable file and images of circuit diagrams [7-10].

This article aims to bridge the gap between theoretical analysis and practical application by providing a comprehensive guide to DC-DC converters and an accompanying software tool for convenient calculations. With the continuous evolution of electronic systems and the increasing demand for efficient power conversion solutions, the insights and resources presented in this research will be a crucial data for the ones that related to power electronics. Calculations have been made in detail for all converters given in the tabs in all modes separately. However, instead of sampling all the forms made in the developed application, examples that are different from each other are given.

2. MATERIALS AND METHODS

2.1. Buck Converter

A DC-DC buck converter, as shown in Figure 1 below, is used to produce lower value output voltage from higher value input voltage. There are various applications that buck converter used in, for example, battery operated portable devices, power supplies to laptops, smart phones, power supply network in data centers and electric vehicles. In some applications where the polarity of output voltage needed to be negative, thus the polarity of the input voltage should be negative. Regardless of the comparison between the polarity of input and output voltages, the output voltage polarity will always be same as input voltage [6,11,12].

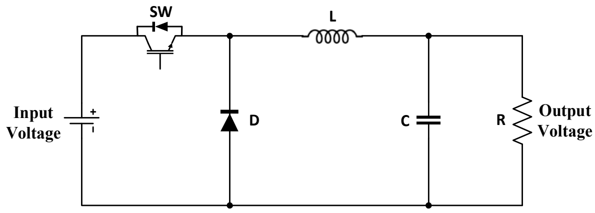

Figure 1. Buck converter circuit

Buck converter can be observed in two states as switch on and switch off as shown in Figure 2. When the switch is on it acts as a short circuit and diode is reverse biased and acts as an open circuit. In this state, input directly supplies energy to the output and inductor. When the switch is off it acts as an open circuit and diode is forward biased and acts as a short circuit. In this state, input has no connection to the output nor inductor and the inductor supplies energy to the output. According to switch on and off states, inductor current is obtained as shown in Figure 3. By using this graph, all desired equations can be calculated [1], [13-14]. The derivations and calculations of buck converter are shown in Equations (1-23).

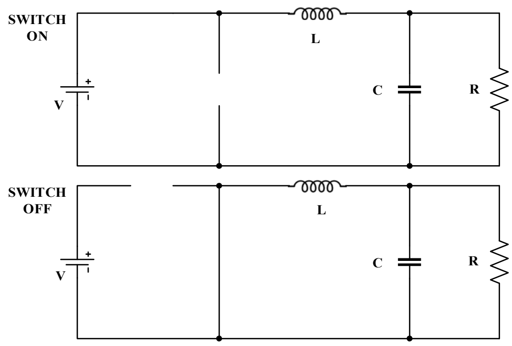

Figure 2. Buck converter ON/OFF states

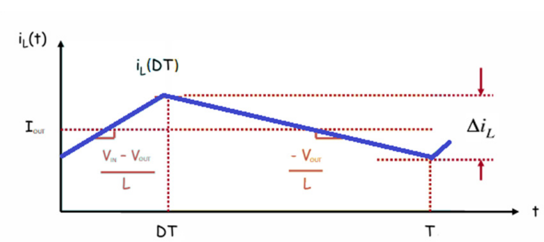

Figure 3. Inductor current graph of buck converter in CCM

Switch is **ON STATE**:

$$V_L = V_{in} - V_{out} \quad (1)$$

$$V_L(t) = L\frac{di_L(t)}{dt} \quad (2)$$

$$\frac{(V_{in} - V_{out})}{L} DT = \Delta i_L \quad (3)$$

Switch is **OFF STATE**:

$$V_L = V_{out} \tag{4}$$

$$\frac{V_{out}}{L}(1-D)T = \Delta i_L \tag{5}$$

$$\frac{V_{out}}{L}(1-D)T = \frac{(V_{in} - V_{out})}{L}DT \tag{6}$$

$$D = \frac{V_{out}}{V_{in}} \tag{7}$$

If buck converter works in BCM, inductor value should be like this:

$$I_{out} = \frac{\Delta i_L}{2} \tag{8}$$

$$L = \frac{(V_{in} - V_{out})DT}{2I_{out}} = \frac{(1-D)R}{2f} \tag{9}$$

Capacitor should be selected according to output voltage ripple sensitivity:

$$C = \frac{V_{in}D(1-D)T^2}{8L\Delta V_{out}} = \frac{1-D}{8Lf^2(\Delta V_{out}/V_{out})} \tag{10}$$

Switch and diode parameters are:

$$I_{L(max)} = I_{out} + \frac{\Delta i_L}{2} \text{ and } V_{SW} = V_{in}, I_{SW} = I_{L(max)}, V_D = V_{in}, I_D = I_{L(max)} \tag{11}$$

Since buck converter has a wide range of applications, its control is extremely important. The output voltage must remain constant even if the input voltage increases or decreases. There are two control types as open loop control and closed loop control. Closed-loop control is preferred to obtain more accuracy and precision. Generally, one of the P, PI, PID control methods is used in power electronics applications. When setting up control circuits, the transfer function of the relevant circuits must be calculated firstly. Calculation steps of a transfer function are given below between Equation 12 and 16.

$$\frac{di_L(t)}{dt} = \frac{V_{in}(t) - V_{out}(t)}{L} \tag{12}$$

$$\frac{di_L(t)}{dt} = \frac{di_C(t)}{dt} + \frac{di_R(t)}{dt} \tag{13}$$

$$\frac{\mathbf{V_{in}(s) - V_{out}(s)}}{\mathbf{L}} = \boldsymbol{s^2CV_{out}(t) + sCV_{out}(0) + CV'_{out}(0) + \frac{sV_{out}(s)}{R}} \tag{14}$$

$$\frac{\boldsymbol{V_{out}(s)}}{\boldsymbol{V_{in}(s)}} = \frac{\mathbf{1}}{\boldsymbol{s^2LC + \frac{L}{R}s + 1}} \tag{15}$$

$$T(s) = \frac{L(s)}{1+L(s)} = \frac{\left(\frac{K_d s^2 + K_p s + K_i}{s}\right)\cdot\left(\frac{V_{in}}{LCs^2 + \frac{L}{R}s + 1}\right)}{1+\left(\frac{K_d s^2 + K_p s + K_i}{s}\right)\cdot\left(\frac{V_{in}}{LCs^2 + \frac{L}{R}s + 1}\right)} = \frac{\frac{V_{in}}{LC}K_d s^2 + \frac{V_{in}}{LC}K_p s + \frac{V_{in}}{LC}K_i}{s^3 + \left(\frac{1}{RC} + \frac{V_{in}}{LC}K_d\right)s^2 + \left(\frac{1}{LC} + \frac{V_{in}}{LC}K_p\right)s + \frac{V_{in}}{LC}K_i} \tag{16}$$

After the calculation of transfer function, K_p, K_i and K_d parameters should be determined. Calculation steps are given between Equation 17 and Equation 23.

$$\boldsymbol{s^3 + 2\zeta\omega_n s^2 + \omega_n^2 s + \omega_n^3 = 0} \tag{17}$$

$$\frac{1}{RC} + \frac{V_{in}}{LC}K_d = 2\zeta\omega_n \tag{18}$$

$$\frac{1}{LC}+\frac{V_{in}}{LC}K_p=\omega_n^2 \quad (19)$$

$$\frac{V_{in}}{LC}K_i=\omega_n^3 \quad (20)$$

$$K_d=\frac{LC}{V_{in}}\left(2\zeta\omega_n-\frac{1}{RC}\right) \quad (21)$$

$$K_p=\frac{LC}{V_{in}}\left(\omega_n^2-\frac{1}{LC}\right) \quad (22)$$

$$K_i=\frac{LC}{V_{in}}\omega_n^3 \quad (23)$$

According to PID parameters and duty cycle, the gate terminal of Buck converter's switch can be triggered. The block diagram of the closed loop control for Buck converter is shown in Figure 4.

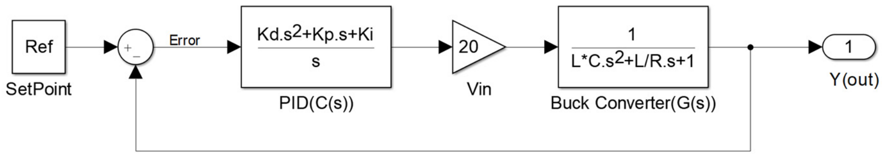

Figure 4. Block diagram of closed loop control

2.2. Boost Converter

DC-DC boost converter, as shown in Figure 5 below, is a step-up converter that means output voltage is always greater than input voltage, and the polarity of input and output voltages are always the same. It is generally used in regulated dc power supplies and regenerative braking systems [4-5], [13].

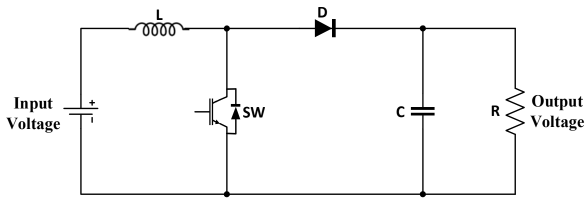

Figure 5. Boost converter circuit

A DC-DC Boost converter can be reviewed in two states as switch on and switch off states as shown in Figure 6 such as a Buck converter.

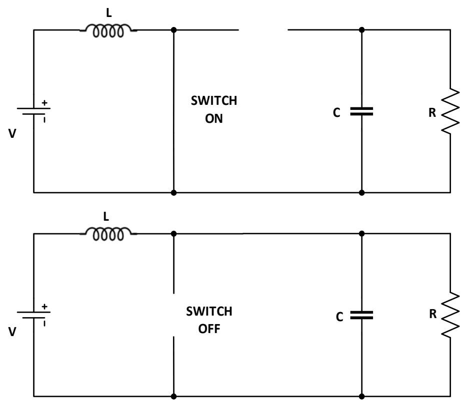

Figure 6. Boost converter states

When the switch is on state that makes it short circuit and diode is reverse biased that makes it open circuit. In this state output is isolated and input supplies energy to the inductor. The current supplied to output is discontinuous and the filter capacitor must supply dc current to output when diode is off state. When the switch is on state that makes it open circuit and the diode is forward biased that makes it short circuit. In this state output is fed from inductor as well as from input. In the meantime, the filter capacitor is charging [13,14]. The derivations and calculations of boost converter are shown in Equations (24-34).

Switch is **ON STATE**

$$V_L = V_{in} \quad (24)$$

$$V_L(t) = L\frac{di_L(t)}{dt} \quad (25)$$

$$\frac{V_{in}}{L}DT = \Delta i_L \quad (26)$$

Switch is **OFF STATE**

$$V_L = V_{in} - V_{out} \quad (27)$$

$$\frac{(V_{in} - V_{out})}{L}(1 - DT) = \Delta i_L \quad (28)$$

$$\frac{(V_{in} - V_{out})}{L}(1 - DT) = \frac{V_{in}}{L}DT \quad (29)$$

$$D = 1 - \frac{V_{in}}{V_{out}} \quad (30)$$

If boost converter works in BCM, inductor value should be like this:

$$I_L = \frac{V_{in}}{(1-D)^2R} = \frac{\Delta i_L}{2} \quad (31)$$

$$L = \frac{V_{in}DT}{2I_L} = \frac{D(1-D)^2R}{2f} \quad (32)$$

Capacitor should be selected according to output voltage ripple sensitivity:

$$C = \frac{V_{out}DT}{R\Delta V_{out}} = \frac{D}{Rf(\Delta V_{out}/V_{out})} \quad (33)$$

Switch and diode parameters are:

$$I_{L(max)} = I_L + \frac{\Delta i_L}{2} \text{ and } V_{SW} = V_{out}\,,\, I_{SW} = I_{L(max)}\,,\, V_D = V_{out}\,,\, I_D = I_{L(max)} \quad (34)$$

2.3. Buck-Boost Converter

Buck-boost converter, in another words step-down/step-up converter can give an output voltage that can be either higher or lower than input voltage. Its main applications are regulated power supplies where a negative-polarity output voltage may be desired. The buck-boost converter can be obtained by cascade connection of step-down (buck) converter and step-up (boost) converter, in a condition that the switches of both converters have same duty ratio. The cascade connection can be obtained into a single buck-boost converter that is shown in Figure 7 [13].

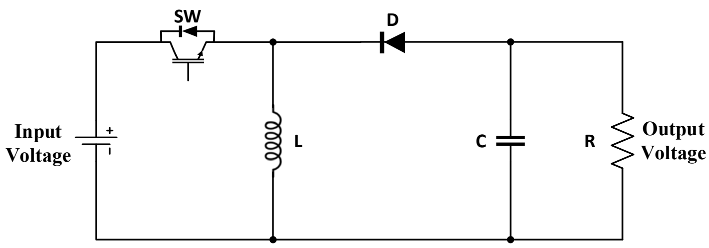

Figure 7. Buck-Boost converter circuit

Buck-boost converter can be analyzed in two states: switch on and switch off that is shown in Figure 8. In switch on state switch acts as short circuit and diode is reversed biased and acts as open circuit. In this state, input provides energy to the inductor. In switch off state switch acts as an open circuit and diode is forward biased and acts as short circuit. In this state, the inductor provides energy to the output and the output voltage will be negative when the ground is reference point [13-14]. The derivations and calculations of buck-boost converter is shown in Equations (35-45).

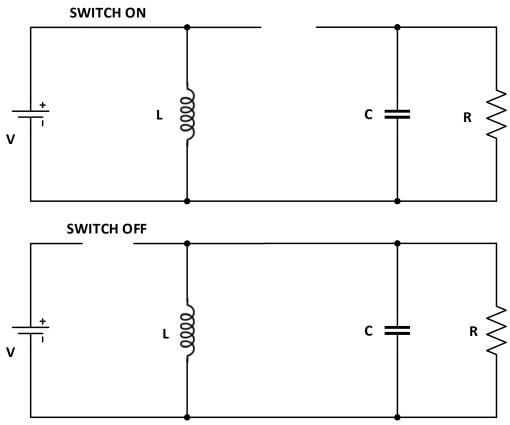

Figure 8. Buck-Boost converter states

Switch is **ON STATE**

$$V_L = V_{in} \tag{35}$$

$$V_L(t) = L\frac{di_L(t)}{dt} \tag{36}$$

$$\frac{V_{in}}{L}DT = \Delta i_L \tag{37}$$

Switch is **OFF STATE**

$$V_L = -V_{out} \tag{38}$$

$$\frac{-V_{out}}{L}(1-D)T = \Delta i_L \tag{39}$$

$$\frac{V_{in}}{L}DT = \frac{-V_{out}}{L}(1-D)T \tag{40}$$

$$D = \frac{V_{out}}{V_{out}-V_{in}} \tag{41}$$

If buck-boost converter works in BCM, inductor value should be like this:

$$I_L = \frac{V_{in}D}{(1-D)^2R} = \frac{\Delta i_L}{2} \tag{42}$$

$$L = \frac{V_{in}DT}{2I_L} = \frac{(1-D)^2R}{2f} \tag{43}$$

Capacitor should be selected according to output voltage ripple sensitivity:

$$C = \frac{V_{out}DT}{R\Delta V_{out}} = \frac{D}{Rf(\Delta V_{out}/V_{out})} \tag{44}$$

Switch and diode parameters are:

$$I_{L(max)} = I_L + \frac{\Delta i_L}{2} \text{ and } V_{SW} = V_{in} - V_{out}\text{ , } I_{SW} = I_{L(max)}\text{ , } V_D = V_{in} - V_{out}\text{ , } I_D = I_{L(max)} \tag{45}$$

2.4. Cùk Converter

Cùk converter is a derivation of boost-buck converter. The output voltage of cùk converter is either smaller or larger than the input voltage. The polarity of the output voltage is opposite of the input voltage. The inductor on the input side acts as a filter for power supply to prevent large harmonic content. Unlike the other converters, capacitor C_1 stores and transfers energy. The circuit of cùk converter given in Figure 9 [1,13,15].

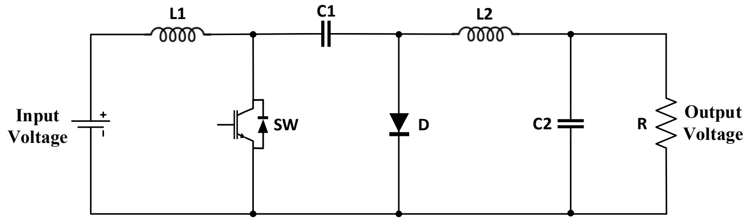

Figure 9. Cùk converter circuit

Cùk Converter can be analyzed in two states: switch on and switch off. When the switch is on, it acts as a short circuit and diode is reverse biased and acts as an open circuit. In this state, inductor currents I_{L1} and I_{L2} flow through the switch, C_1 discharges through the switch and transferring energy to output and L_2, meanwhile, input feeds energy to L_1. When the switch is off, it acts as an open circuit and diode is reverse biased and acts as a short circuit. In this state, inductor currents I_{L1} and I_{L2} flow through the diode, C_1 charges through the diode from both input and L_1, energy stored in L_2 feeds the output. The derivations and calculations of Cùk converter is shown in Equations (47-63). The states of Cùk Converter are represented in Figure 10 [13-15].

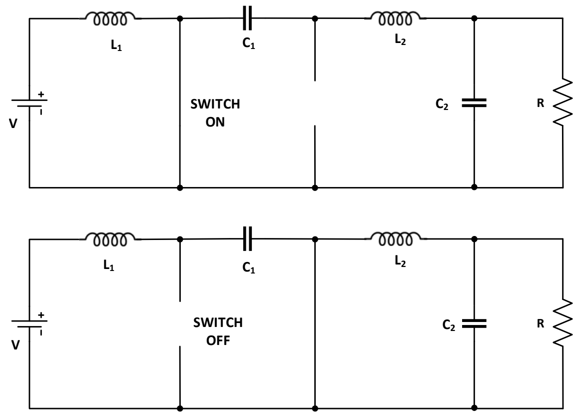

Figure 10. Cùk converter states

Switch is **ON STATE**

$$i_{C1} = -I_{L2} \tag{46}$$

Switch is **OFF STATE**

$$i_{C1} = I_{L1} \quad 47)$$

$$-V_{out}I_{L2} = V_{in}I_{L1} \quad 48)$$

$$[(i_{C1})_{closed}]DT + [(i_{C1})_{open}](1-D)T = 0 \tag{49}$$

$$-I_{L2}DT + I_{L1}(1-D)T = 0 \tag{50}$$

$$\frac{I_{L1}}{I_{L2}} = \frac{V_{out}}{V_{in}} \tag{51}$$

$$D = \frac{V_{out}}{V_{out} - V_{in}} \tag{52}$$

If Cùk Converter works in BCM, inductor value should be like this:

$$L_1 = \frac{(1-D)^2 R}{2Df} \tag{53}$$

$$L_2 = \frac{(1-D)R}{2f} \tag{54}$$

Output capacitor should be selected according to output voltage ripple sensitivity:

$$C_2 = \frac{1-D}{8L_2 f^2 (\Delta V_{out}/V_{out})} \tag{55}$$

Input capacitor should be selected according to capacitor voltage ripple sensitivity:

$$C_1 = \frac{DV_{out}}{Rf\Delta V_{C1}} \tag{56}$$

Switch and diode parameters are:

$$I_{L2} = \frac{V_{out}}{R} \tag{57}$$

$$I_{L1} = I_{L2} \frac{V_{out}}{V_{in}} \tag{58}$$

$$\Delta i_{L1} = \frac{V_{in} D}{L_1 f} \tag{59}$$

$$\Delta i_{L2} = \frac{V_{in} D}{L_2 f} \tag{60}$$

$$I_{L1(max)} = I_{L1} + \frac{\Delta i_{L1}}{2} \tag{61}$$

$$I_{L2(max)} = I_{L2} + \frac{\Delta i_{L2}}{2} \tag{62}$$

$$V_{SW} = V_{in} \,,\, I_{SW} = I_{L1(max)} + I_{L2(max)} \,,\, V_D = V_{out} \,,\, I_D = I_{L1(max)} + I_{L2(max)} \tag{63}$$

2.5. Flyback Converter

Flyback converter is an isolated or transformer version of buck-boost converter. In flyback converter, inductance of buck-boost converter is replaced by a transformer and a magnetizing inductance added to it. Flyback converter generally used in applications that demand below 50W power. On the contrary to buck-boost converter, according to replacement of transformer windings, the polarity of output voltage can be either positive or negative in flyback converter. The circuit of flyback converter represented in Figure 11 [1,14,16].

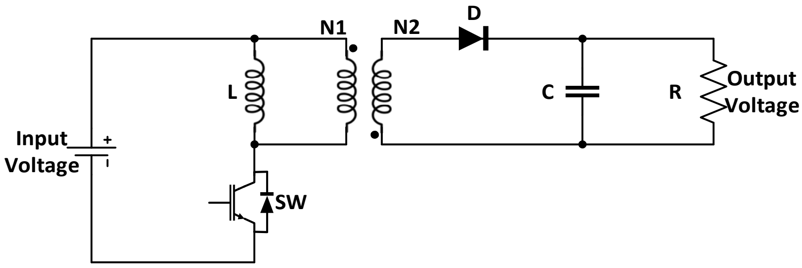

Figure 11. Flyback converter circuit

Flyback converter can be analyzed in two states: switch on and switch off. When the switch is on it acts as a short circuit and diode is reverse biased and acts as an open circuit. In this state, the current in the magnetizing inductance increases linearly and there is no current in the ideal transformer windings. When the switch is off it acts as an open circuit and diode is forward biased and acts as a short circuit. In this state magnetizing inductance supplies current to the ideal transformer windings therefore to the output. The derivations and calculations of flyback converter is shown in Equations (64-74) The states of flyback transformer are represented in Figure 12 [1,13,15].

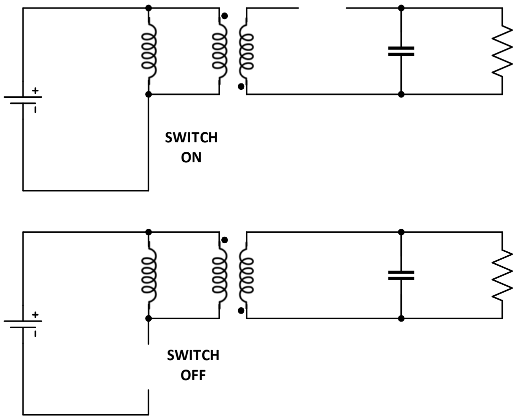

Figure 12. Flyback converter states

Switch is **ON STATE**

$$V_L = V_{in} \tag{64}$$

$$V_L(t) = L\frac{di_L(t)}{dt} \tag{65}$$

$$\frac{V_{in}}{L}DT = \Delta i_L \tag{66}$$

Switch is **OFF STATE**

$$V_L = V_{out}\frac{N_1}{N_2} \tag{67}$$

$$\frac{V_{out}}{L}\frac{N_1}{N_2}(1-D)T = \Delta i_L \tag{68}$$

$$\frac{V_{in}}{L}DT = \frac{V_{out}}{L}\frac{N_1}{N_2}(1-D)T \tag{69}$$

$$D = \frac{1}{\frac{V_{in}N_2}{V_{out}N_1}+1} \tag{70}$$

If flyback converter works in BCM, inductor value should be like this:

$$I_L = \frac{V_{in}D}{(1-D)^2R}\left(\frac{N_2}{N_1}\right)^2 = \frac{\Delta i_L}{2} \tag{71}$$

$$L = \frac{V_{in}DT}{2I_L} = \frac{(1-D)^2R}{2f}\left(\frac{N_1}{N_2}\right)^2 \tag{72}$$

Capacitor should be selected according to output voltage ripple sensitivity:

$$C = \frac{V_{out}DT}{R\Delta V_{out}} = \frac{D}{Rf(\Delta V_{out}/V_{out})} \tag{73}$$

Switch and diode parameters are:

$$I_{L(max)} = I_L + \frac{\Delta i_L}{2} \quad (74)$$

$$V_{SW} = V_{in} + V_{out}\frac{N_1}{N_2} \;,\; I_{SW} = I_{L(max)}\frac{N_2}{N_1}, V_D = V_{in}\frac{N_2}{N_1} - V_{out} \;,\; I_D = I_{L(max)} \quad (75)$$

2.6. Forward Converter

Forward converter is one of the converters that derived from buck converter. It is made by adding a transformer and diode D_1 between switch and diode D_2. It has three transformer windings. Windings 1 and 2 are used for voltage transmission from source to load, winding 3 used to allow a path to magnetizing current that it can go down to zero before a new switching cycle. Forward converter used in applications up to power level of a kW that needs isolation. The circuit of forward converter given in Figure 13 [1,15], [16].

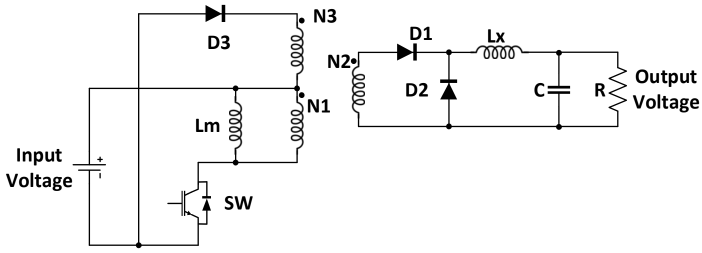

Figure 13. Forward converter circuit

Forward converter can be analyzed in two states: switch on and switch off. When the switch is on, it acts as a short circuit, D_3 is reverse biased and acts as an open circuit, D_2 is reverse biased and acts as an open circuit and D_1 is forward biased and acts as a short circuit. In this state, energy is transferred from input to output and stored in magnetizing inductance L_m and inductive element L_x.

When switch is off, it acts as an open circuit, and D_1 is reverse biased and acts as an open circuit, D_2 is forward biased and acts as a short circuit and D_3 is forward biased and acts as a short circuit. In this state, inductive element L_x supplies energy to output. The magnetizing current that stored in the core of the transformer dissipated through the winding 3 and diode D_3. The derivations and calculations of forward converter are shown in Equations (76-89). The states of forward transformer represented in Figure 14 [14-16].

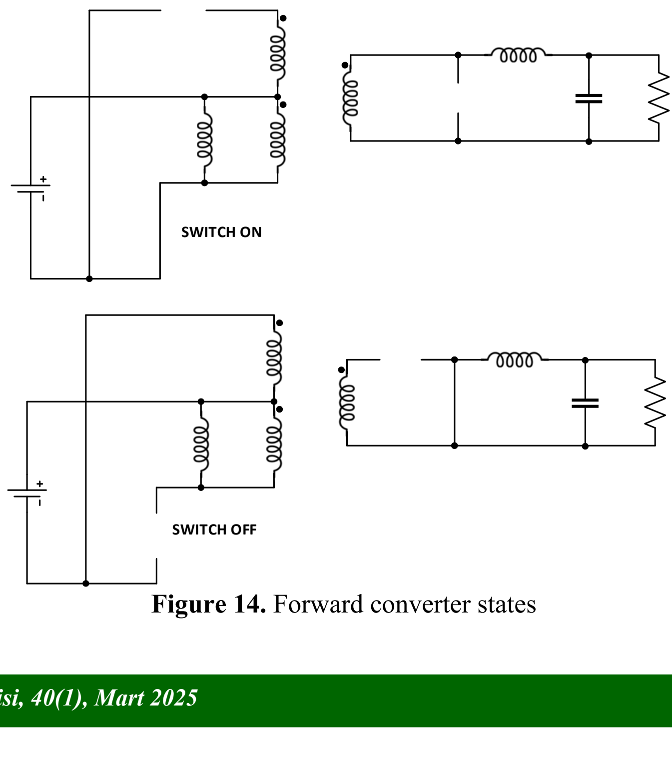

Figure 14. Forward converter states

Switch is **ON STATE**

$$V_{Lx} = V_{in}\frac{N_2}{N_1} - V_{out} \tag{76}$$

$$V_{Lx}(t) = Lx\frac{di_{Lx}(t)}{dt} \tag{77}$$

$$\left(V_{in}\frac{N_2}{N_1} - V_{out}\right)\frac{DT}{Lx} = \Delta i_{Lx} \tag{78}$$

Switch is **OFF STATE**

$$V_{Lx} = V_{out} \tag{79}$$

$$\frac{V_{out}}{Lx}(1-D)T = \Delta i_{Lx} \tag{80}$$

$$\left(V_{in}\frac{N_2}{N_1} - V_{out}\right)\frac{DT}{Lx} = \frac{V_{out}}{Lx}(1-D)T \tag{81}$$

$$D = \frac{V_{out}}{V_{in}\frac{N_2}{N_1}} \tag{82}$$

If forward converter works in BCM, inductor value should be like this:

$$I_{Lx} = \frac{V_{out}}{R} = \frac{\Delta i_{Lx}}{2} \tag{83}$$

$$Lx = \frac{V_{out}(1-D)T}{2I_{Lx}} = \frac{(1-D)R}{2f} \tag{84}$$

$$Lm = \frac{V_{in}D}{\Delta i_{Lm}f} \tag{85}$$

Capacitor should be selected according to output voltage ripple sensitivity:

$$C = \frac{V_{in}D(1-D)T^2}{8Lx\Delta V_{out}} = \frac{1-D}{8Lxf^2(\Delta V_{out}/V_{out})} \tag{86}$$

Switch and diodes parameters are:

$$I_{Lx(max)} = I_{Lx} + \frac{\Delta i_L}{2} \tag{87}$$

$$V_{SW} = V_{in}\left(1 + \frac{N_1}{N_3}\right), I_{SW} = I_{L(max)}\frac{N_2}{N_1}, \tag{88}$$

$$V_{D1} = V_{in}\frac{N_2}{N_3} - V_{out}, I_{D1} = I_{Lx(max)}, V_{D2} = V_{out}, I_{D2} = I_{Lx(max)}, V_{D3} = V_{in} \tag{89}$$

2.7. Push-Pull Converter

Push-pull converter is another example derived from buck converters. Its main advantage is that its switches are driven with respect to the ground. The disadvantages of the converter are that the voltage stress of its switches is high equal to the $2V_{in}$ and during the power transfer, only one half of the primary and secondary windings of the transformer used. The switches of push-pull converter operate shifted in phase by T/2 with the same duty ratio, so, the duty ratio of switches must be smaller than 0.5. The power level of its applications differs from 150W to 500W. The circuit of push-pull converter is represented in Figure 15 [1,14,16].

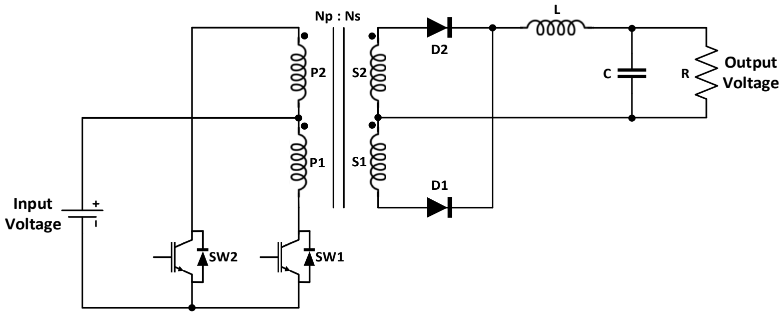

Figure 15. Push-Pull converter circuit

Push-pull converter works in two intervals that follow one another, that one interval can be analyzed in two states as shown in Figure 16.

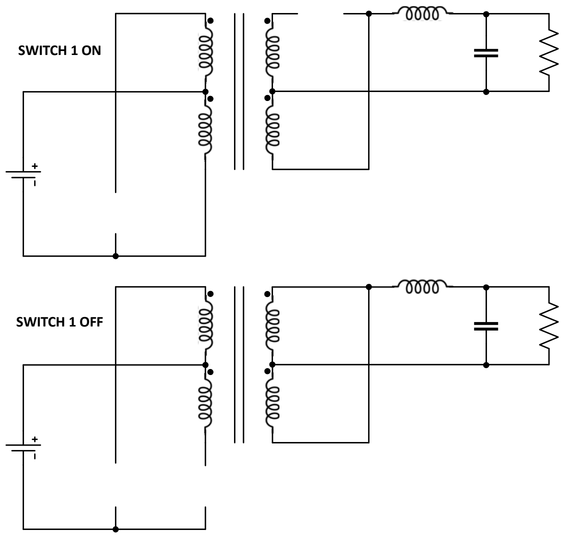

Figure 16. Push-Pull converter states in T/2

When switch 1 is on, it acts as a short circuit, D_1 is forward biased and acts as a short circuit and D_2 is reverse biased and acts as an open circuit. In this state, input directly supplies energy to output and charges inductor. When switch 1 is off, it acts as an open circuit, D_1 is forward biased and acts as a short circuit and D_2 is forward biased and acts as a short circuit. In this state, inductor supplies energy to output, D_1 and D_2 equally share the current of the inductor. Same things are going to happen for the other interval [1,14]. The derivations and calculations of Push-Pull converter are shown in Equations (90-102).

Switch is **ON STATE**

$$V_L = V_{in}\frac{N_s}{N_p} - V_{out} \quad (90)$$

$$V_L(t) = L\frac{di_L(t)}{dt} \quad (91)$$

$$\left(V_{in}\frac{N_s}{N_p} - V_{out}\right)\frac{DT}{L} = \Delta i_L \quad (92)$$

Switch is **OFF STATE**

$$V_L = V_{out} \quad (93)$$

$$\frac{V_{out}}{L}(1-D)T = \Delta i_L \quad (94)$$

$$\left(V_{in}\frac{N_s}{N_p} - V_{out}\right)\frac{DT}{L}DT = \frac{V_{out}}{L}(1-D)T \tag{95}$$

$$D = \frac{V_{out}N_p}{2V_{in}N_s} \tag{96}$$

If push-pull converter works in BCM, inductor value should be like this:

$$I_L = \frac{V_{out}}{R} = \frac{\Delta i_L}{2} \tag{97}$$

$$L = \frac{V_{out}DT}{2I_L} = \frac{R}{2f}\left(\frac{1}{2} - D\right) \tag{98}$$

Capacitor should be selected according to output voltage ripple sensitivity:

$$C = \frac{V_{out}DT}{R\Delta V_{out}} = \frac{1-2D}{32Lf^2(\Delta V_{out}/V_{out})} \tag{99}$$

Switches and diodes parameters are shown in Equations (100,102):

$$I_{L(max)} = I_L + \frac{\Delta i_L}{2} \tag{100}$$

$$V_{SW} = 2V_{in}\ ,\ I_{SW} = I_{L(max)}\frac{N_2}{N_1}\ , \tag{101}$$

$$V_D = V_{in}\frac{N_2}{N_1} - V_{out}\ ,\ I_D = I_{L(max)} \tag{102}$$

3. DEVELOPMENT OF SOFTWARE

DC-DC Converter Calculator is a comprehensive software tool that was developed using python. This application serves as a practical and educational tool for power electronics engineers and students. The application lets the users calculate and visualize key parameters of various DC-DC converter topologies.

The steps of the software running algorithm as under:

1. Start the program
2. Select the converter tab and conduction mode
3. Enter the input values
4. Press the "Calculate" button to write the calculated values on the screen
5. If you want to print the calculated values, press "Print…" button
6. If you want to save the calculated values into a TXT file, press "Save as…" button
7. Exit the program

For the user interface design, Tkinter graphical user interface library has been used. The application uses a tabbed interface structure where each DC-DC converter topology has its dedicated tab. The main components are a notebook widget for tab management, circuit diagram display using canvas, input fields for voltage, power, frequency, ripple percentage, and transformer turn ratio parameters, mode selection using radio buttons (CCM, BCM, DCM), calculation results display for inductance, capacitance, and voltage and current values of switches and diodes [7,8].

The application covers seven fundamental DC-DC converter types: Buck, Boost, Buck-Boost, Cùk, Flyback, Forward, and Push-Pull converters. Interface of the application can be seen in Figure 17.

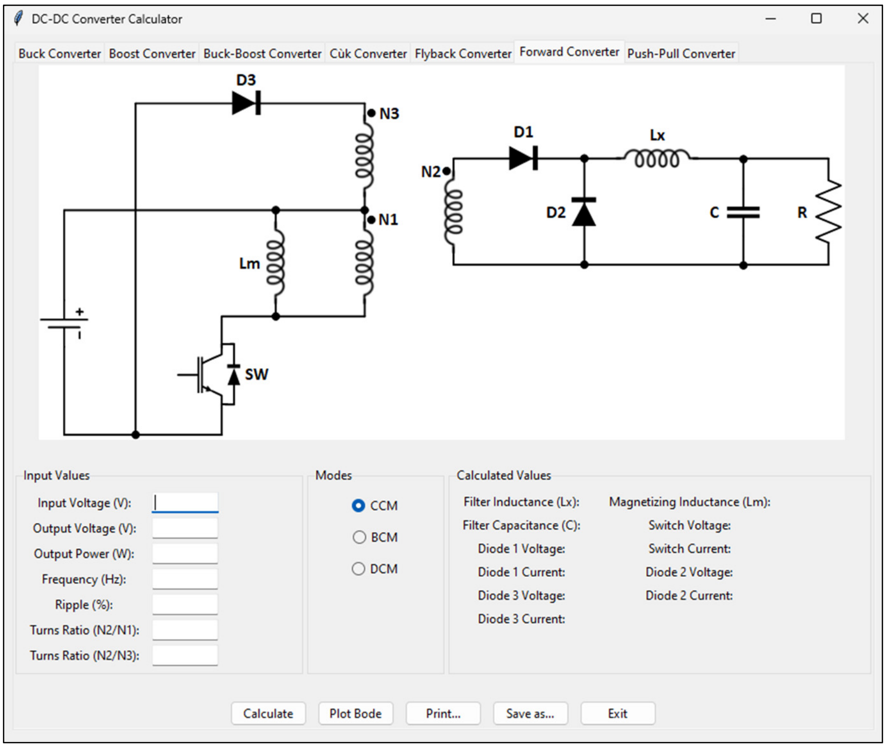

Figure 17. Software user interface

In the application interface, each converter tab displays a circuit diagram with dynamic parameter overlays. The application does instant computation of inductance, capacitance, and component stresses for three modes that DC-DC converters work in: Continuous Conduction Mode (CCM), Boundary Conduction Mode (BCM), and Discontinuous Conduction Mode (DCM). For CCM calculations, as a reference, inductor values are calculated 30% higher than BCM in the application. For DCM calculations, duty ratio value selected as %80 of the original value. The interface of calculations in DCM are shown in Figure 18.

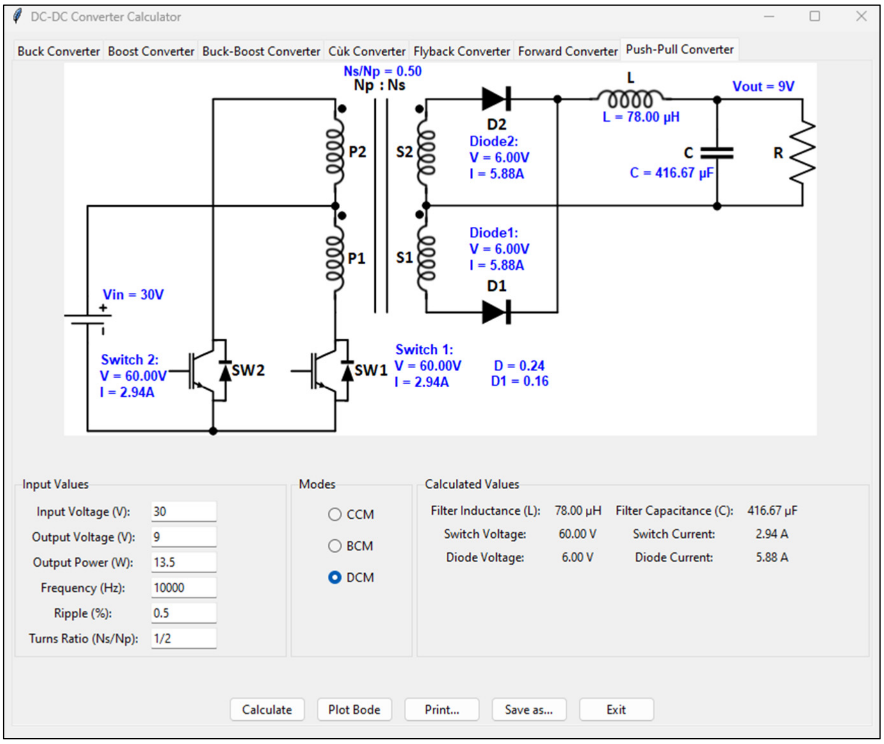

Figure 18. Push-Pull converter calculations in DCM

After pressing the Calculate button, if desired, the calculated values can be sent to the printer by using Print button, saved to a txt file by using Save as button, drawn to the bode plot of DC-DC converter by using Plot Bode button, or can be quitted from the application by using Exit. Print, Save As and Bode Plot Screens are shown in Figure 14 respectively.

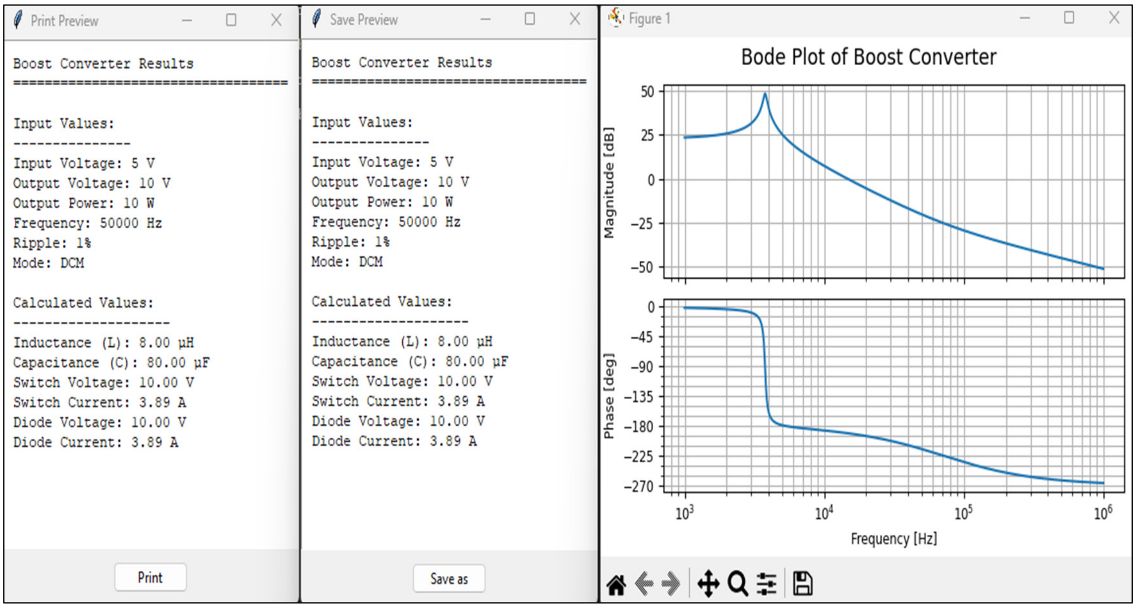

Figure 19. Print, save as and bode plot screens

The application is packaged into a standalone executable using PyInstaller, making it easily distributable to end users. The distribution package includes the main executable file and circuit diagrams of images. This tool serves as a practical learning aid for power electronics students, quick reference tool for engineers and visualization platform for understanding converter behavior under different operating conditions. Potential improvements can be the addition of more converter topologies, waveform visualization, component selection recommendations, showing functions of calculations and letting users to modify the formulas [9,10].

The DC-DC Converter Calculator is a practical engineering tool. Its modular design, user-friendly interface, and comprehensive calculations make it a valuable resource for power electronics education and design. This article section provides an overview of the application's development while remaining accessible to readers with a basic understanding of power electronics and software development.

4. CONCLUSION

In this study, information related to DC-DC converters that were selected for this article has been given. DC-DC converters are power electronics devices that change voltage levels according to user or application needs. There are various kinds of DC-DC converters that are developed for different usage areas. Different formulas have been computed for every DC-DC converter. These formulas are used to select components of DC-DC converters. This article is written with the aim of making these calculations more convenient.

In this article, component selection formulas of DC-DC converters that work in BCM have been given. The software the has been developed for this article covers the formulas for three conduction modes that the selected DC-DC converters work in. The formulas that have been used in this study can be seen in Table 1.

Consequently, in this study, the implementation of DC-DC converter calculator software that calculates inductance, capacitance and stress values of DC-DC converters is carried out. With this article and software, calculations for DC-DC converters will be easier.

Table 1. DC-DC converter formulas in BCM

Components / Converters	Duty Cycle	Inductance	Capacitance	Switch	Diode
Buck Converter	$D = \frac{V_{OUT}}{V_{IN}}$	$L = \frac{(1-D)*R}{2*f}$	$C = \frac{(1-D)}{8*L*f^2*ripple}$	$V_{SW} = V_{IN}$ $I_{SW} = \frac{V_{OUT}}{R} + \frac{(1-D)*V_{OUT}}{2*f*L}$	$V_D = V_{IN}$ $I_D = \frac{V_{OUT}}{R} + \frac{(1-D)*V_{OUT}}{2*f*L}$
Boost Converter	$D = 1 - \frac{V_{IN}}{V_{OUT}}$	$L = \frac{D*(1-D)^2*R}{2*f}$	$C = \frac{D}{R*f*ripple}$	$V_{SW} = V_{OUT}$ $I_{SW} = \frac{V_{IN}}{(1-D)^2*R} + \frac{D*V_{IN}}{2*f*L}$	$V_D = V_{OUT}$ $I_D = \frac{V_{IN}}{(1-D)^2*R} + \frac{D*V_{IN}}{2*f*L}$
Buck-Boost Converter	$D = \frac{V_{OUT}}{V_{OUT} - V_{IN}}$	$L = \frac{(1-D)^2*R}{2*f}$	$C = \frac{D}{R*f*ripple}$	$V_{SW} = V_{IN} - V_{OUT}$ $I_{SW} = \frac{V_{IN}}{(1-D)^2*R} + \frac{D*V_{IN}}{2*f*L}$	$V_D = V_{IN} - V_{OUT}$ $I_D = \frac{V_{IN}}{(1-D)^2*R} + \frac{D*V_{IN}}{2*f*L}$
Ćuk Converter	$D = \frac{V_{OUT}}{V_{OUT} - V_{IN}}$	$L_1 = \frac{(1-D)^2*R}{2*D*f}$ $L_2 = \frac{(1-D)*R}{2*f}$	$C_1 = \frac{D*V_{OUT}}{R*f*\Delta V_{C1}}$ $C_2 = \frac{(1-D)}{8*L_2*f^2*ripple}$	$V_{SW} = V_{IN}$ $I_{SW} = \frac{P}{V_{IN}} + \frac{D*V_{IN}}{2*f*L_1} + \frac{V_{OUT}}{R} + \frac{D*V_{IN}}{2*f*L_2}$	$V_D = V_{OUT}$ $I_D = \frac{V_{OUT}}{R} + \frac{D*V_{IN}}{2*f*L_2} + \frac{P}{V_{IN}} + \frac{D*V_{IN}}{2*f*L_1}$
Flyback Converter	$D = \frac{1}{\frac{V_{IN}}{V_{OUT}} * \frac{N_2}{N_1} + 1}$	$L = \frac{(1-D)^2*R}{2*f}\left(\frac{N_1}{N_2}\right)^2$	$C = \frac{D}{R*f*ripple}$	$V_{SW} = V_{IN} + \frac{V_{OUT}*N_1}{N_2}$ $I_{SW} = \frac{V_{OUT}^2}{V_{IN}*D*R} + \frac{D*V_{IN}}{2*f*L}$	$V_D = \frac{V_{IN}*N_2}{N_1} - V_{OUT}$ $I_D = \frac{I_{SW}*N_1}{N_2}$
Forward Converter	$D = \frac{V_{OUT}}{V_{IN} * \frac{N_2}{N_1}}$	$L_x = \frac{(1-D)*R}{2*f}$ $L_m = \frac{R}{2*f}\left(\frac{N_1}{N_2}\right)^2$	$C = \frac{(1-D)}{8*L_x*f^2*ripple}$	$V_{SW} = V_{IN} * \left(1 + \frac{N_1}{N_3}\right)$ $I_{SW} = \left(\frac{P}{V_{OUT}} + \frac{(1-D)*V_{OUT}}{2*f*L_x}\right)\frac{N_1}{N_2} + \frac{D*V_{IN}}{2*f*L_m}$	$V_{D1} = \frac{V_{IN}*N_2}{N_3}$ $V_{D2} = V_{OUT}$ $V_{D3} = V_{IN}$ $I_{D1} = I_{D2} = \frac{V_{OUT}}{R} + \frac{(1-D)*V_{OUT}}{2*f*L_x}$ $I_{D3} = 0$
Push-Pull Converter	$D = \frac{V_{OUT}*N_p}{2*V_{IN}*N_s}$	$L = \frac{R}{2*f}\left(\frac{1}{2} - D\right)$	$C = \frac{(1-2*D)}{32*L*f^2*ripple}$	$V_{SW} = 2*V_{IN}$ $I_{SW} = \left(\frac{V_{OUT}}{R} + \frac{(1-D)*V_{OUT}}{2*f*L}\right)\frac{N_2}{N_1}$	$V_{D1} = V_{D2} = V_{IN}$ $I_{D1} = I_{D2} = \frac{V_{OUT}}{R} + \frac{(1-D)*V_{OUT}}{2*f*L}$

This article and software will be a practical and educational tool for students, experienced engineers and newly graduated engineers that are associated with power electronics. It is thought that this software will at least be a reference point for users. In order to obtain the program, it is recommended to contact the corresponding author via e-mail.

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