Power Circuit Models of Buck-Boost Basic DC-DC Convertor

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Abstract- In this study, generalized models of the fundamental transformers used in DC-DC converters were built and presented. These models included Buck, Boost, and Buck-Boost components. Using mathematical software and switching functions, models are created via the synthesis process. It is possible to simulate both the continuous conduction mode and the discontinuous conduction mode, which are the two primary modes of operation for converters. The modelling approach that was used is suitable for application in engineering practice as well as in the teaching of power electronics enthusiasts. It is possible to synthesis, realize, and set the regulator in the functioning of devices such as voltage, current, or power stabilizers with the assistance of the models that have been constructed. Furthermore, models are constructed on the basis of a model-based design of the power electronics devices that were investigated. In this manner, the design process is accelerated, and specific optimizations are carried out using target functions that have been allocated. The MATLAB/Simulink software is used to carry out the program implementation of the models.

Key words: Power circuit, Buck-Boost components, Dc-Dc convertor, MATLAB.

1. INTRODUCTION

An example of one of the most common types of converters is the DC-DC converter. From milliwatts to megawatts and from kilohertz to megahertz, they are used in practice over the whole spectrum of power and frequency. One may draw the conclusion, based on the findings of a large number of studies that have been published, that there is almost no system of power electronic converters in which they do not participate. Based on the findings of several studies that have been published, it is possible to draw the conclusion that there is almost no system of power electronic converters in which they do not participate. The use of direct current to direct current converters in fields such as electric cars, various forms of power sources, industries, and decentralized energy production [1, 2, 3]. The purpose of this study is to provide generalized mathematical models of a certain class of fundamental DC-DC converters, which includes Buck, Boost, and Buck-Boost converters. These converters are not only the most often used, but they are also systematically significant for the teaching of power electronics. It is possible to create comparable models and more sophisticated circuit configurations using them as a foundation. Some examples of these configurations include bi-directional converters, soft current and/or voltage switches.

2. MODELS OF MATHEMATICAL DATA

In the majority of instances, single transistor DC-DC converters do not need the use of a transformer. They have a straightforward architecture, strong regulatory capabilities, and a high efficiency that, when using synchronous circuits, surpasses 98%. These are the characteristics that define them. The fact that they possess these characteristics has allowed them to establish themselves as base circuits within this category of conversion devices.

In addition, this is a precondition for the many research that are dedicated to the design, building, and modelling of these things. In this study, the models of the particular schemes are compiled based on the following assumptions, which are considered to be the following: The semiconductor devices that were utilized in the schematics (transistors and diodes) have been replaced with one-way conductors, which are operated in antiphase. All of the components of the circuit are perfect; the current is both interrupted and uninterrupted, and the load is active. This is true for the vast majority of applications that are considered feasible while running at frequencies up to 500Hz. Another assumption that is made in this particular piece of writing is that it is functioning without the need of a regulator and controller.

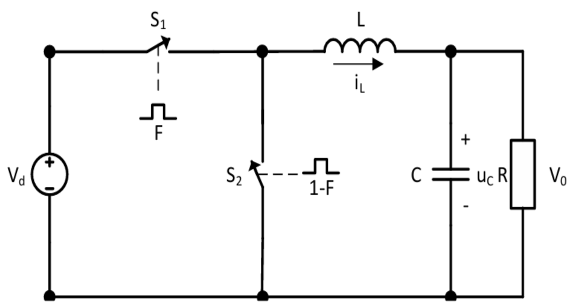


FIG. 1. Power circuit of Buck convertor

Additionally, the power design of the Buck converter is shown in Figure 1. S1 and S2 are the semiconductor keys that make up this structure, together with load R, inductance L, and C. It is possible to manipulate the keys in phase using rectangular impulses that have a set frequency and a variable duty cycle [1, 2, 3]. In the figure, this is shown by the rectangular voltage generator F and its inverse value, which is denoted by 1-F correspondingly. [1, 3, 4] offers an explanation of the fundamental concept behind this converter. When operating in a continuous conduction mode, it is possible to differentiate between two states: the first state happens when the switch S1 is closed and the switch S2 is open, and the second state occurs when the key S1 is open and the key S2 is closed. However, in the discontinuous conduction mode, in addition to the two states that have been described above, there is also a third state that exists. This state is characterized by the fact that neither of the two switches is activated, which is the status of the two key switches S1 closed and S2 closed. In this third condition, the current that flows through the inductance is reset, and the value of iL is equal to zero. In the process of modelling the converters, it is important to keep in mind that the resetting moment takes place inside the operational range of the circuit when the S1 switch is turned off. On the other hand, this instant is uncertain and is dependent on the values of the components of the circuit that are R, L, and C, in addition to the duty cycle D and the switching frequency. During the course of the study, a modelling technique that makes use of a switching function F has been selected. The kind of switching function F is shown in Figure 2. The switching function is responsible for describing the many intervals that make up the functioning of the circuit. In essence, it substitutes the logical equations that are required for modelling electrical circuits with a number of states and the ability to transition between them. The essence of the switching function is that it is a control pulse that is used to switch the semiconductor switches between two discrete values, namely 0 and 1. One indicates that the particular semiconductor device is turned on, whereas zero indicates that it is turned off.

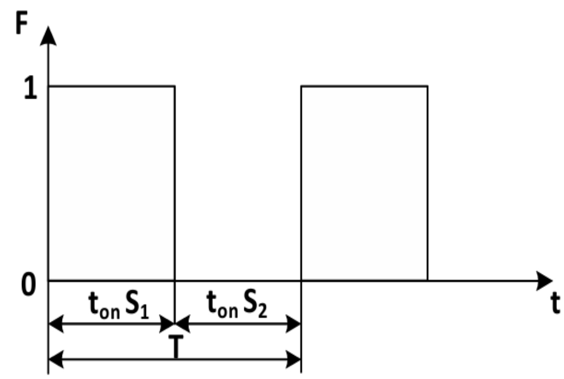


FIG. 2. Type of switching function

With the help of the switching function, the following generalized differential equation system (1) is defined. This system represents the behavior of the circuit shown in Figure 1 for both continuous conduction mode and discontinuous conduction mode operation:

$$\left| \begin{array}{l} L\dfrac{di_L}{dt} = F.V_d - u_C \\ C\dfrac{du_C}{dt} = i_L - \dfrac{u_C}{R} \end{array} \right. \quad if \quad i_L \geq 0 \quad \left| C\dfrac{du_C}{dt} = -\dfrac{u_C}{R} \right. \quad if \quad i_L = 0 \quad , \qquad (1)$$

Where,
V_d represents the voltage of the input supply, i_L represents the current through the inductance, u_C represents the voltage of the capacitor, and R represents the load. The solution to this system provides instantaneous current values by means of the inductance and the voltage across the capacitor, which is representative of the output voltage. Following the application of transformations to the state variables that have been provided, all of the additional dimensions that are required for the design of the device are produced. MATLAB and Simulink are the environments in which the system that is being shown is implemented. Figure 3 depicts the model that is being discussed. A determination is made by using the "Compare to Zero" check of the $i_L \geq 0$ value to ascertain the point at which the structure enters a state of interrupted current. Once the interrupted current mode, also known as the discontinuous conduction mode, has been identified, the only equation that continues to be valid is the condensation voltage equation, which is reset with the exception of the magnitude i_L and its first derivative variables. In order for the scheme to begin with the zero starting conditions of the state variables in the model, it is necessary to specify a non-zero initial condition of the integrator that is referred to as "current."

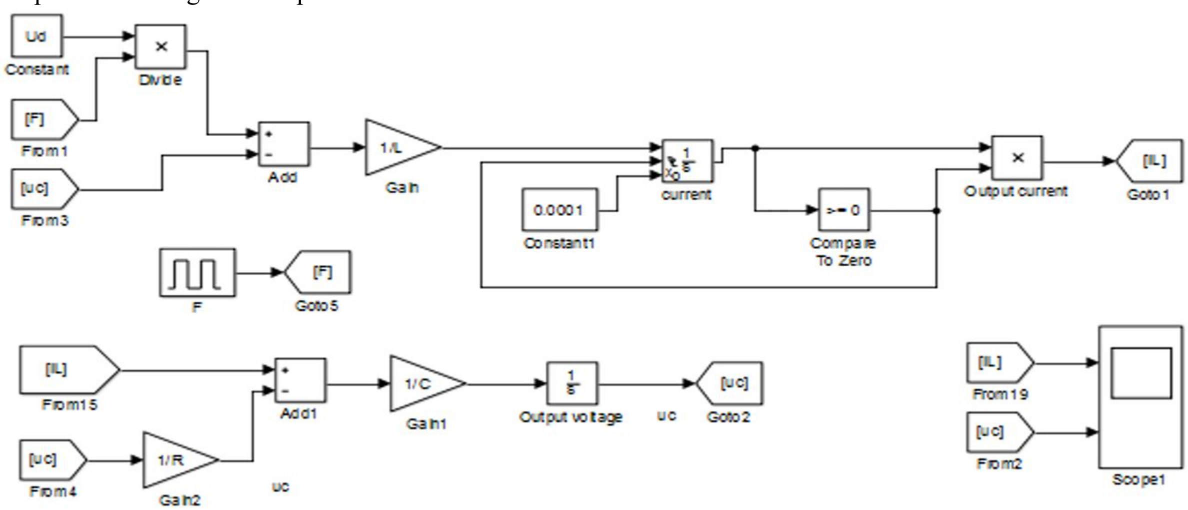


FIG. 3. Generalized model of Buck convertor

Figure 4 depicts the model that was used in the process of modeling the boost converter. In contrast to the buck converter that was previously investigated, it is made up of the same fundamental components, but its topology is distinct from that of the buck converter. During the functioning of this converter, the switch S1 is turned off in order to facilitate the transmission of energy from the intake to the exit. As a result of its characteristics, it is sometimes referred to as the reverse converter [2, 3, 4, 8, 9].

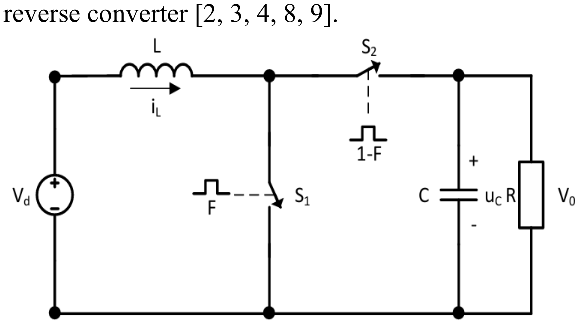


FIG. 4. Power circuit of Boost convertor

Using the inverse switching function $F_{inv}=1-F$ is required in order to maintain the community of the aforementioned concerns in the construction of reverse converters. This is important in order to keep the community. In order to represent the functioning of the converter that is being considered in all of its various modes of operation, the following set of equations is utilized:

$$\begin{cases} L\dfrac{di_L}{dt} = V_d - F_{inv}.u_C \\ C\dfrac{du_C}{dt} = F_{inv}.i_L - \dfrac{u_C}{R} \end{cases} \quad if \quad i_L \geq 0 \quad \left| C\dfrac{du_C}{dt} = -\dfrac{u_C}{R} \quad if \quad i_L = 0 \right. \qquad (2)$$

MATLAB and Simulink are the visual programming environments that are used in the process of implementing the system solution (2). Figure 5 depicts the generalized model in its entirety when it is presented. In the process of constructing it, the identical technique is used, just as it was in the direct converter model. The distinction is in the use of an inverse switching function, which allows for a response to the characteristics of the electromagnetic processes that are taking place inside the converter. By verifying the "Compare to Zero" condition and switching from one configuration to the model in accordance with the results, it is possible to determine the border between interrupted and uninterrupted currents, also known as continuous conduction mode and discontinuous conduction mode.

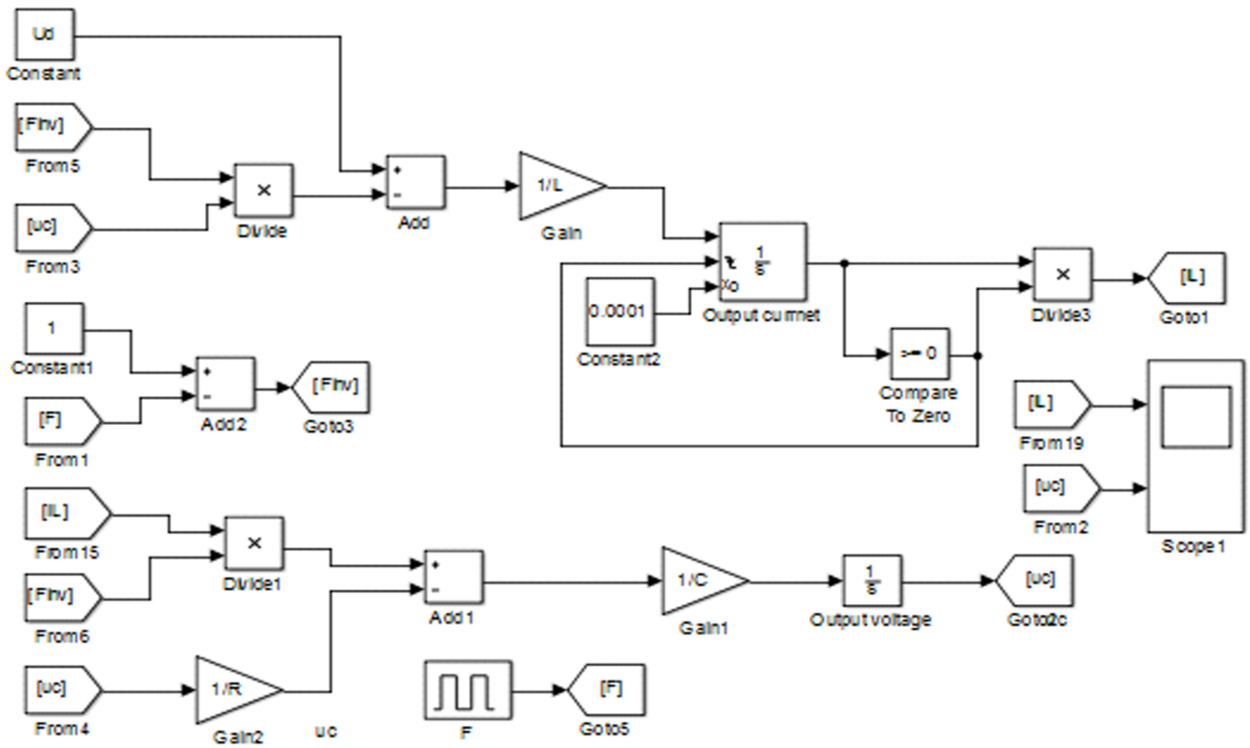


FIG. 5. Generalized model of Boost convertor

Figure 6 depicts the Buck-Boost converter, which is the next schema that is designed after the previous one. When the S1 switch is turned off and the output voltage has a polarity that is opposite to that of the input, the power transfer from the input to the output occurs. This is a typical example of this phenomenon. For this reason, the modeling of the power scheme that is being considered also makes use of a switching function that has values that are of the opposite direction.

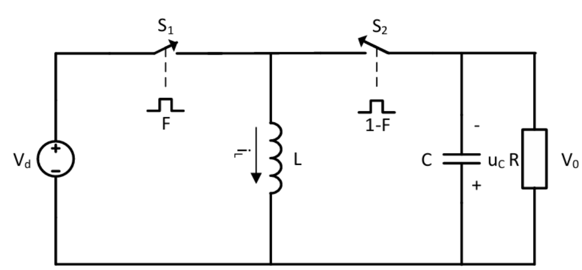


FIG. 6. Power circuit of Buck-Boost convertor

As a consequence of this, the equations that are provided below are those that reflect the operating performance of the converter:

$$\begin{cases} L\dfrac{di_L}{dt} = V_d.F + F_{inv}.u_C \\ C\dfrac{du_C}{dt} = -F_{inv}.i_L - \dfrac{u_C}{R} \end{cases} \quad if \quad i_L \geq 0 \qquad \left| C\dfrac{du_C}{dt} = -\dfrac{u_C}{R} \quad if \quad i_L = 0 \right. \tag{3}$$

In order to solve the system (3), a visual programming environment is used. This allows for the determination of the state variables in the converter along with their associated instantaneous values. Figure 7 depicts the generalized model of the Buck-Boost converter with its components. When using the model, the use of the same strategies that are utilized in the other two are utilized. These techniques include the identification of the interrupted current mode and the transition to the simpler circuit design, in which the output voltage is given by the energy that is stored in the capacitor. The demonstration of the system (3) demonstrates that the modeling of the converter under discussion makes use of both the right switching function and the inverse switching function. Immediately after the compilation of the models, it is necessary to verify them. This is accomplished via the use of lab models that are produced by Texas Instruments and are part of the Power Management Lab Kit series PMLK.

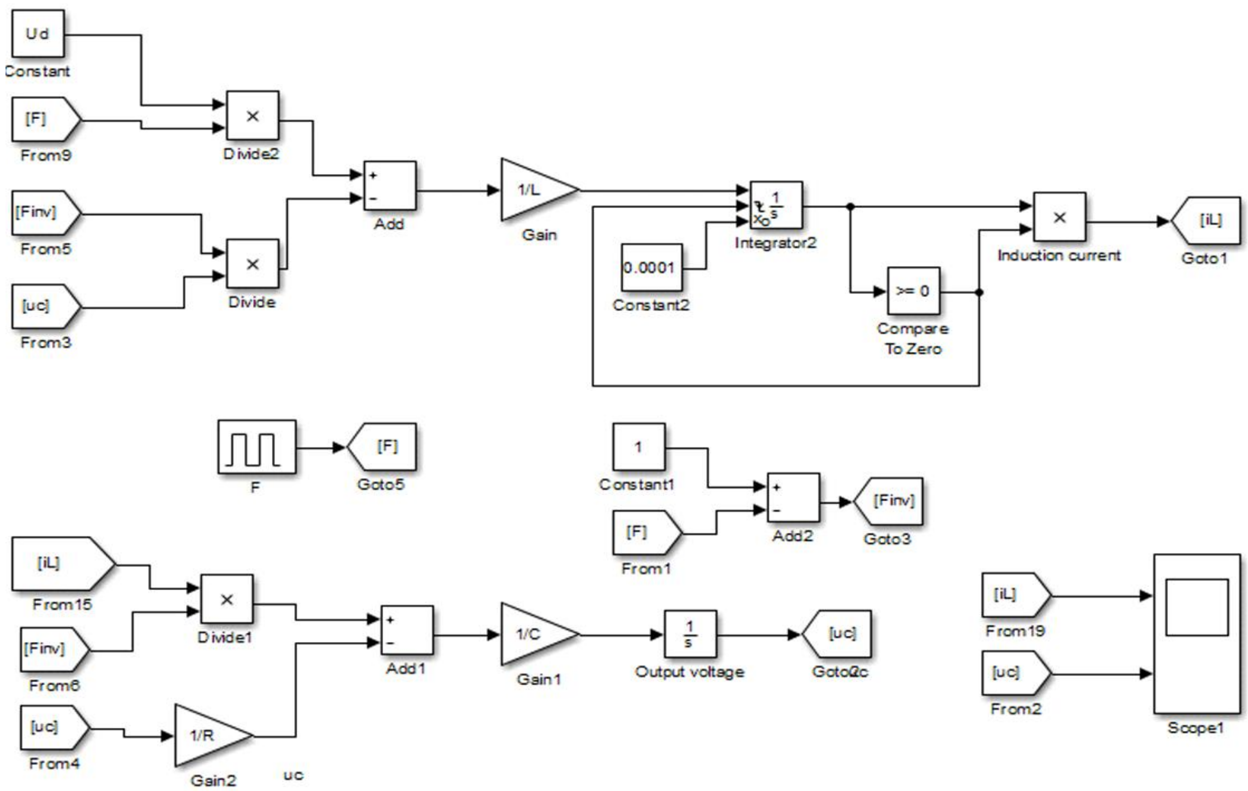
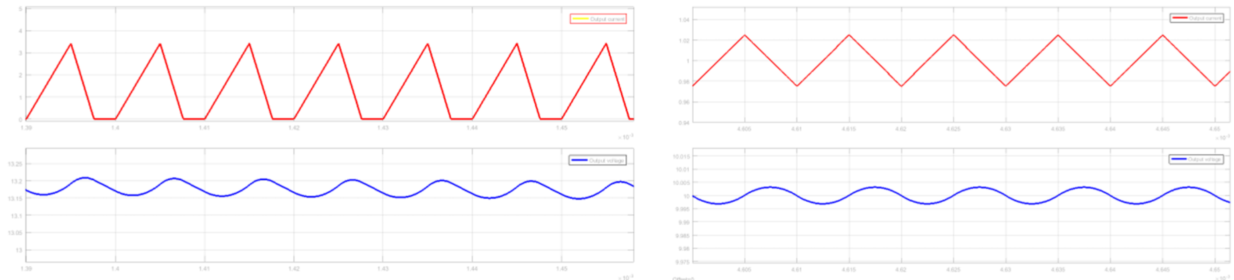


FIG. 7. Generalized model of Buck-Boost convertor

3. OUTCOMES

Numerous tests were carried out with the models that were constructed in order to investigate the behavior of power circuits while they were functioning in the two different modes of operation, which are the continuous conduction mode and the discontinuous conduction mode.

Figure 8 illustrates the outcomes that were achieved by the use of the Buck converter generalized model.



Discontinuous conduction mode with parameters:

Ud=20V; L=0.01e-3H; C=100e-6F; R=10Ω.

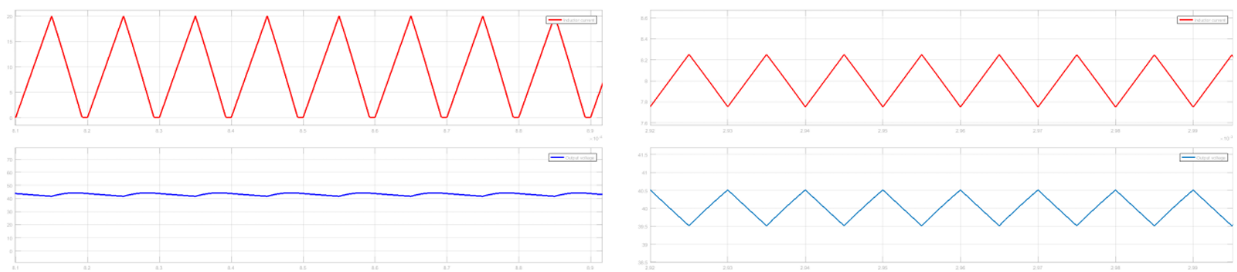
Continuous conduction mode with parameters:

Ud=20V; L=1e-3H; C=10e-6F; R=10 Ω.

FIG. 8. Results of Buck convertor modeling

When the switching frequency was set to 100 kHz and the duty cycle was set to 0.5, the findings that are reported were achieved. Following the completion of the transition procedures, the time diagrams of the operation of the scheme in the established mode are shown in the figures.

Figure 9 illustrates the outcomes that were achieved by the use of the Buck converter generalized model.



Discontinuous conduction mode with parameters:

Ud=20V; L=5e-6H; C=10e-6F; R=10Ω.

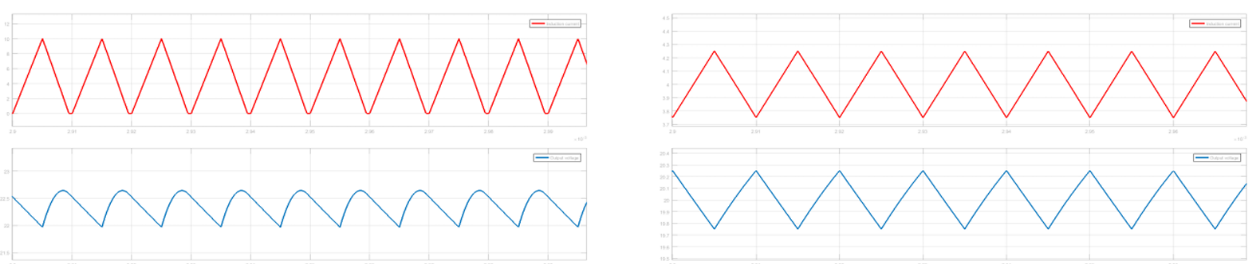
Continuous conduction mode with parameters:

Ud=20V; L=2e-3H; C=20e-6F; R=10 Ω.

FIG. 9. Results of Boost convertor modeling

When the switching frequency is set to 100 kHz and the duty cycle is set to 0.5, the current time ranges via the inductance and voltage of the capacitor are obtained. These illustrations are intended to illustrate how the scheme should be implemented in a predetermined manner.

In Figure 10, the findings that were achieved via the use of the Buck-Boost converter generalized model are shown.



Discontinuous conduction mode with parameters:

Ud=20V; L=10e-6H; C=10e-6F; R=10Ω.

Continuous conduction mode with parameters:

Ud=20V; L=0.2e-3H; C=20e-6F; R=10 Ω.

FIG. 10. Results of Buck-Boost convertor modelling

The figures are presented in the following manner: current diagrams via inductance and voltage representations of capacitors. The switching frequency is set to 100 kHz, and the duty cycle is set to 0.5. These results are achieved simultaneously. The graphical findings that are shown in this article pertain to the functioning of the scheme in a mode that has been developed.

4. CONCLUSION

Generalized models of transformer less DC-DC converters are presented in the paper. They are used in a visual programming environment, which is practical from an instructional and methodical standpoint. Numerous optimization and other issues may be defined, formalized, and resolved with the use of the complex mathematical models. However, the models are combined with other models for the regulation and control of the power equipment. They serve as the foundation for a model-based design of this class of converters, which guarantees the outputs' performance while varying the parameters. The modelling technique makes it possible to develop a practical formalization process that permits their upgrading and complexity. In some situations, and applications, this is quite beneficial. Furthermore, models are readily interchangeable across different programming environments and products. This enables us to operate in accordance with our available resources and possibilities.

The suggested method's applicability to power electronic device training is one of its main advantages. This is crucial because powerful electronic devices are complicated systems that need a broad understanding of many different disciplines and technologies. The modelling process's use of switching functions captures the characteristics of power circuits when semiconductor devices perform in key mode. This enables the development and use of reduced models with similar and reasonably fast computations.

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