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Implementation and Design of Buck Converter by Using MATLAB

Salam Waley Shneen[1] Zainab Ameer AL-DABBAGH[2]
Qusay A. Jawad[3] Salman Hussien Omran[1]

[1] Energy and Renewable Energies Technology Centre, University of Technology- Iraq, Baghdad
[2]Department of Construction and Projects, Ministry of Higher Education and Scientific Research, Baghdad, Iraq.
[3] Electrical Engineering Department, University of Technology- Iraq, Baghdad

Abstract:
Work is underway to develop a model to simulate one of the types of converter using the buck converter design method using matlab. Converting voltage from one value to another is of interest to researchers and companies that manufacture most electronic devices. It requires choosing a type of converter and developing an appropriate design that is tested and verified for its effectiveness through laboratory experiments, which is extremely important. Work is being done to test a step-down converter with an input voltage of 50 volts that provides and converts it to a voltage of 20 volts. A mathematical representation is developed and mathematical calculations are performed to find appropriate values for the converter components for both inductance and capacitance and the frequency of the mug pulses for opening and closing electronic switches in addition to the appropriate resistive load value. After writing the code for the mathematical relationships that connect the system components in an m-File file and obtaining the system parameters, the model was built and tested to verify its effectiveness. The results demonstrated the possibility of obtaining the required output voltage of 20 volts from a 50 volt source carrying two 20 ohm resistors, an inductance of 400 micro-henry, a capacitance of 100 microfarad, and a pulse frequency of 20 kilohertz.

Keywords: buck converter, direct current, duty cycle and Common mode continuous operation.

الملخص

يجري العمل حالياً على تطوير نموذج لمحاكاة أحد أنواع المحولات باستخدام طريقة تصميم محول باك باستخدام برنامج MATLAB. إن تحويل الجهد من قيمة إلى أخرى أمر يهم الباحثين والشركات المصنعة لمعظم الأجهزة الإلكترونية. ويتطلب الأمر اختيار نوع المحول ووضع التصميم المناسب الذي يتم اختباره والتحقق من فعاليته من خلال التجارب المعملية، وهو أمر في غاية الأهمية. يجري العمل على اختبار محول تنحي بجهد دخل 50 فولت يقوم بتزويده وتحويله إلى جهد 20 فولت. تم تطوير تمثيل رياضي وإجراء حسابات رياضية لإيجاد القيم المناسبة لمكونات المحول لكل من الحث والسعة وتردد نبضات القدح لفتح وإغلاق المفاتيح الإلكترونية بالإضافة إلى قيمة حمل المقاومة المناسبة. بعد كتابة كود العلاقات الرياضية التي تربط مكونات النظام في ملف mFile والحصول على معلمات النظام، تم بناء النموذج واختباره للتحقق من فعاليته. أظهرت النتائج إمكانية الحصول على جهد الخرج المطلوب 20 فولت من مصدر 50 فولت يحمل مقاومتين 20 أوم، ومحاثة 400 ميكروهنري، وسعة 100 ميكروفاراد، وتردد نبض 20 كيلو هرتز
.

1. Introduction

Converters, in general, are important in many applications in various fields and for all countries of the world, as they can be included in industrial systems, including generation and distribution systems [1-3]. They need conversion systems as part of an integrated system. Modern systems consider the presence of electronic power devices to be an essential factor in building electronic converters, which enabled designers to overcome many of the disadvantages of traditional converters [4-7]. What increases and raises the efficiency rates of these systems as a result of improving performance also enables them to be desirable and safe. Therefore, it can be said that modern systems enjoy the presence of power devices [8-10]. Electronic power converters are among the electronic power converters in many applications. The widespread use of converters in various applications such as battery charging systems, systems for supplying engines with the specified voltage, and lighting systems, in addition to their primary use in power plants and satellite applications in space [11, 12]. Different power generation systems that may not be suitable for the loads require Power transformers to achieve the desired operation. The transformer can be classified according to the input and output of four types or classifications, including a direct current input or an alternating current, as well as the output, which is a continuous input and a continuous output, another is a continuous input and an alternating output, a third is an alternating input and an alternating output, and finally an alternating input and a continuous output. The converter can also be single or three-phase. It can also be a riser or a reducer, and so it can be said that there is a significant number that covers all the outputs required to feed the loads with appropriate electrical quantities [13,14].

The system includes energy sources, power-electronic systems, PWM technique and controller with load). Energy sources like PV system, wind, dc power supply, ac source…etc. [15, 16]. The power-electronic systems include first, single phase or three phase inverters [17]. Second, single phase or three phase rectifiers [18, 19]. Third, single phase or three phase ac-ac converter [20]. Fourth, dc-dc converter like boost dc-dc converter, buck dc-dc converter, buck-boost dc-dc converter [21, 22]. The controller includes first type Proportional, Integral and Derivative (PID) that called classical controller. Second type, expert system like fuzzy logic controller and artificial neural network (FLC&ANN) [23-25]. Third types, Optimization controller like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Grey Wolf Optimizer (GWO), Biogeography based optimization (BBO) and Flower Pollination Algorithm (FPA) …etc. [26-28]. The final part in the system include resistance load, light, motor (DC motor, induction motor(I.M.) brushless DC (BLDC) motor, permanent magnet synchronous motor (PMSM), servo motor, brushless permanent magnet (BLPM) motor, stepper motor ….etc.[29-31].

In the current study, the researchers presented a simulation model in which a step-down converter was designed for an input voltage higher than the output voltage and fed the load with the required voltage. The system components of the converter were suitable, the required voltage was provided, and verifying the effectiveness of the system requires writing the special code that represents the system and building the model to conduct the proposed simulation, as in the following paragraphs. After building the model, simulation results can be obtained, analyzed, and appropriate recommendations can be made as a result of the behavior obtained according to operating conditions suitable for many similar applications in future work.

2. Topology of buck converter and Essentials for using an electronic converter

The paper presents the basics of topology of buck converter, how it works and how to design it. It is characterized by the fact that it works to convert a voltage value from a fixed value linked by the power source to a variable value at the output terminal linked to the load to be equipped with a specific voltage. It is known that normal converters operate on alternating current, while to convert direct current, electronic converters are used as an alternative to normal transformers, in addition to the presence of electronic converters for alternating current with the possibility of controlling a variable output at the output end of the transformer. Some converters work to reduce the electrical quantity coming out of the converter and are called step-down converters. There is also another type of transformer that works to raise the transformer output value above the input value and is called the step-up converter. Hence, the importance of using electronic transformers is highlighted, and some important applications can be mentioned, such as DC power supplies and solar energy systems when using Maximum Power point Tracking, In addition to converting energy and transmitting it as direct current.... etc. It works according to the principle of using

electronic switches such as thyristors and transistors. Within the opening and closing periods of the switches, the required transformer output can be controlled. A filter can also be added to obtain a pure output free of distortions.

The hypotheses through which the research steps are carried out when the power source is a DC source such as batteries or a solar energy source with a voltage of fifty volts and a load is to be operated at a voltage lower than the source voltage, say twenty volts. The available options are: First, use a normal transformer as show in fig.2. This option cannot be used because the transformer operates by induction, which is not possible with DC current, so this option is excluded. The second option is to connect a resistor in series with the source and perform the necessary calculations to choose its value to be another load that takes the remaining voltage from the source voltage as show in fig.3. Thus, a current will pass and there will be power losses, and this option will also be excluded. High losses mean low efficiency, which is a negative for the second proposal.

From the previous test, i.e. adding a resistance, it is possible to add a variable resistance, a potentiometer as show in fig.4, to control raising or lowering the output voltage, but there will be power losses, so they are compensated for or replaced by an electronic switch such as a transistor that works with a linear regeneration system. This means that the total output current of the transistor depends on the base current multiplied by a gain ratio called beta. The relationship is direct between the current and the output voltage and direct with the base current. Therefore, it is possible to control the transformer output and supply the load with the required voltage by controlling the transformer input current. These circuits are called linear voltage regulators and are widely available in the labor market. Also, this proposal has the disadvantage of having lost power due to the voltage drop between the two ends of the electronic switch.

The best solution is to use a switching converter (DC chopper) as show in fig.5, in it the transistor does not operate in the linear region, but rather in saturation and cutoff, i.e. it is either a switch in the conduction or disconnection state, depending on the condition. When this type is used, the value of the converted output can be controlled through the duty cycle, which depends on the ratio between the period of operation or connection of the electronic switch to the sum of the periods of operation and disconnection. It can now be widely used to control the speed of motors that are used in many applications. This case is also characterized by the absence of losses as a result of the power on the switch being equal to the current times the voltage, and the voltage being zero as a result of connecting the switch, and thus the power loss being equal to zero. When the switch is in the non-conducting state, the current value is equal to zero, and therefore the power loss is also equal to zero.

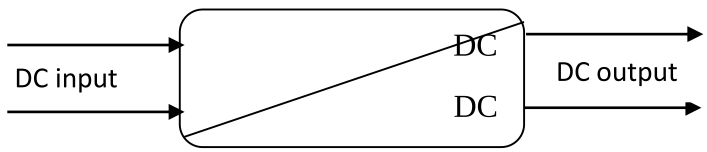

Fig.1. DC-DC Converter (DC chopper) system

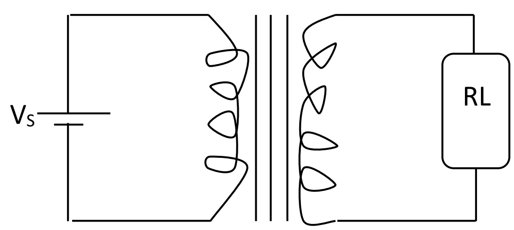

Fig.2. a normal transformer

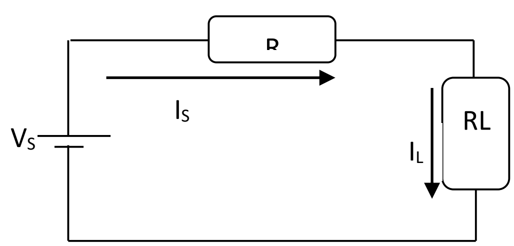

Fig.3. connect a resistor in series with the source

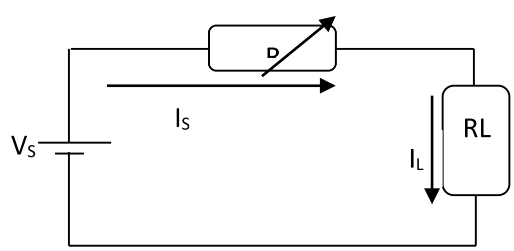

Fig.4. connect a resistor in series with the source (a variable resistance, a potentiometer)

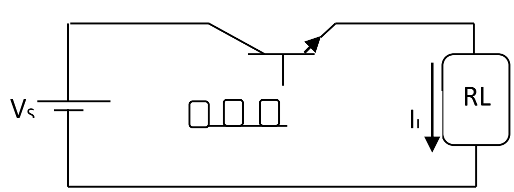

Fig.5. a switching converter (DC chopper)

3. Buck converter design and using simulation by matlab

3.1. Buck converter design

The Buck converter has the following Parameter, Vin=50Volt; D=0.4; C=100microfirad; L=400microhinrey; RL=20ohm; F=20 Kilohertz. At assuming ideal component then calculate the output voltage (Vo); minimum and maximum inductor current (ILmin & ILmax); peak to peak output voltage ripple and voltage ripple content. First step calculates the Vout by using Vin and D that show in equation one below:

$$Vout = Vin * D \quad (1)$$

Vout=Vin*D=50*0.4=20Volt

Second step calculate the Iout, the buck converter works according to the operation of the electronic switches. The mode can be known through the circuit current, the output current, and the sub-currents of the inductor and capacitor. The output current can be calculated mathematically after calculating the output voltage from the following equation No. 2:

$$Iout = \frac{Vout}{R} \quad (2)$$

$$Iout = \frac{Vout}{R} = \frac{20}{20} = 1Amper$$

The boundary value of the output current is calculated and compared with the value of the output current to know the type of operation. Common mode continuous operation when the output current is greater than the boundary value of the output current as in the first case to calculate the output current or the circuit

load current as in the following third equation:

$$ILB = \frac{Vout(1-D)}{2LF} \quad (3)$$

$$ILB = \frac{Vout(1-D)}{2LF} = \frac{20*(1-0.4)}{2*400*10^{-6}*20*10^{3}} = 0.75Amper$$

When Iout>ILB that mean converter operating in CCM. Then the change in current (ΔIL: Peak − peak ripple current) can be calculated when the output current is greater than the boundary current of the output current from the following relationship:

$$\Delta IL = \frac{Vout(1-D)}{2LF} = \frac{20*(1-0.4)}{400*10^{-6}*20*10^{3}} = 1.5Amper$$

The next step is to calculate the highest and lowest output current from the following two relationships:

$$ILmax = Iout + \frac{\Delta IL}{LF} \quad (4)$$

$$ILmax = Iout + \frac{\Delta IL}{LF} = 1 + \frac{1.5}{2} = 1.75Amper$$

$$ILmin = Iout - \frac{\Delta IL}{LF} \qquad (5)$$

$$ILmin = Iout - \frac{\Delta IL}{LF} = 1 - \frac{1.5}{2} = 0.25Amper$$

Then comes the step of calculating the change in the output voltage value, which can be represented by the equation below, and calculating its value from this equation as follows:

$$\Delta\text{Vout}=\frac{Vout(1-D}{8*LCF^2} \qquad (7)$$

$$\Delta\text{Vout}=\frac{Vout(1-D}{8*LCF^2} = \frac{20(1-0.4)}{8*400*10^{-6}*100*10^{-6}*(20*10^3)^2} = \frac{3}{32} = 0.09375Volt$$

Finally, the voltage ripple content can be calculated from the following equation:

$$\text{Voltage ripple content} = \frac{\Delta Vout}{\text{Vout}} \qquad (6)$$

$$\text{Voltage ripple content} = \frac{\Delta Vout}{\text{Vout}} = \frac{0.09375}{20} = 0.47\%$$

3.2. Simulation of Buck converter

To build the model and conduct the proposed tests, it can be presented in steps:

The first step is to build the code and write the system information that represents the data. It included the input voltage, which represents the value of the supply voltage, the resistive load, the amount of inductance and capacitor, the frequency of change to open and close the electronic switch, and the percentage of change between the input and output voltages, as in fig.6. The second step is to write the mathematical relationships between the components of the system to calculate the electrical quantities of the output, including the current and voltage of the resistance, inductor, and capacitor, and the rates of change with those values, as in the fig.7 and third fig.8. The third step is to build a simulation model and look at the behavior of the system, as in the simulation model in Fig. 9, and the simulation results as in the figures (10-13). As a first step, using the same mathematical relationships using the MATLAB program to calculate the mathematical quantities that represent the results of the proposed simulation, the MATLAB program is applied to calculate them as in the following figures:

```
%Parameters of buck dc-dc converter%
Vd=50; %Vd:input dc voltage source
D=0.4;
L=400e-6;
C=100e-6;
F=20e3;
R=20;
```

Fig.6.m-file for Parameters of buck dc-dc converter

```
%Parameters of buck dc-dc converter%
Vd=50; %Vd:input dc voltage source
D=0.4;
L=400e-6;
C=100e-6;
F=20e3;
R=20;
%Calculation of Vo, ILmax,ILmin,Vo-pp_ripple and V_ripple content
Vo=D*Vd;%Vo=0.4*50=20Volt
Vo
Io=Vo/R;%Io=20/20=1Amper
Io
ILB=(Vo*(1-D))/(2*L*F);%ILB=20(1-0.4)/2*400e-6*20e3=0.75Amper
ILB
Io>ILB%Converter operating in CCM
dIL=(Vo*(1-D))/(L*F);%ILB=20(1-0.4)/400e-6*20e3=1.5Amper
dIL
ILmax=Io+dIL/2;%ILmax=1+1.5/2=1.75Amper
ILmax
ILmin=Io-dIL/2;%ILmax=1-1.5/2=0.25Amper
ILmin
dVo=(Vo*(1-D))/(8*L*C*F^2);%20(1-0.4)/8*400e-6*100e-6*(20*e3)^2=3/32=0.09375volt
dVo
VCr=dVo/Vo;%VCr:Ripple voltage content=dVo/Vo=0.09375/20=0.47%
VCr
```

Command Window

Fig.7.m-file of buck dc-dc converter with mathematical relationships between the components of the system

```
New to MATLAB? See resources for Getting Started.

Vo =

    20

Io =

     1

ILB =

    0.7500

ans =

     1

dIL =

    1.5000

ILmax =

    1.7500

ILmin =

    0.2500

dVo =

    0.0938

VCr =

    0.0047

>>
```

Fig.8. Results of mathematical calculations of buck dc-dc converter

After obtaining the data required for the design through applying the mathematical representation of the model, the simulation model is built to verify the effectiveness of the system by adopting the results of the proposed simulation according to the following system tests:Using the simulation model in the figure 9, which represents the system components and determining the operating time of half a second, we notice through the simulation results that the required output is obtained, as in the figures (10-12):

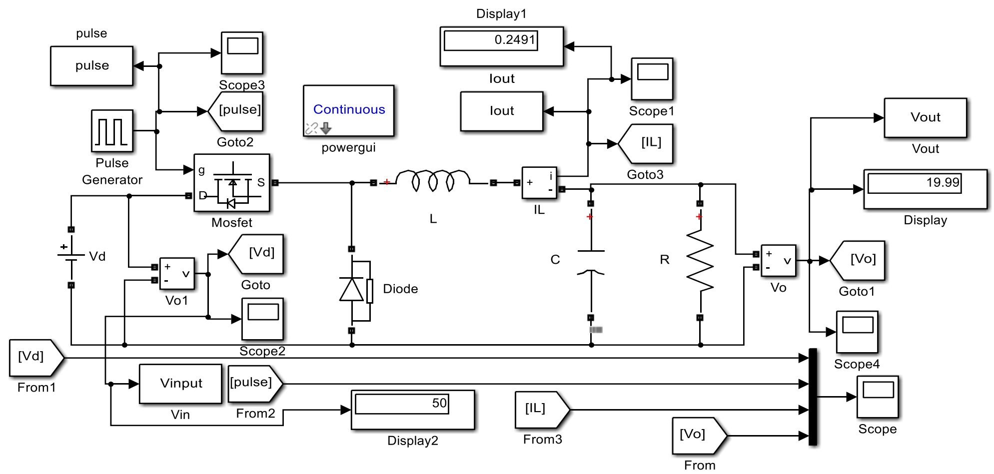

Fig.9.Simulation model of buck dc-dc converter

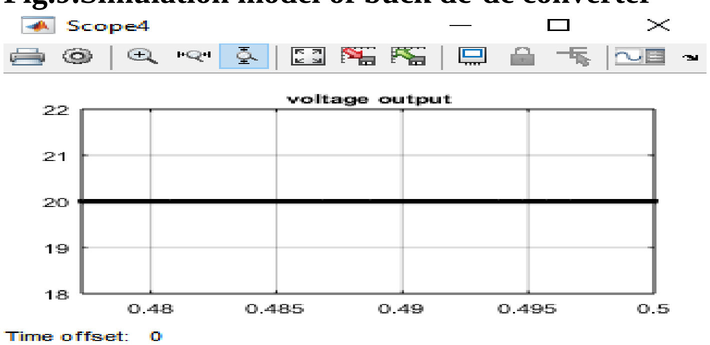

Fig.10. Simulation result for voltage output of buck dc-dc converter

The simulation results can also be observed and analyzed on the other hand for the output current associated with opening and closing the electronic transistor switch. We notice that when the switch is in the on state, there is a gradual increase in the current value until it reaches the highest value (1.75) which is the value that was calculated mathematically. After disconnecting the switch, the current begins to decrease until it reaches the lowest value (0.25) which was calculated theoretically, which confirms the effectiveness of the system and the consistency of the simulated results with the mathematical calculations as in the figure below:

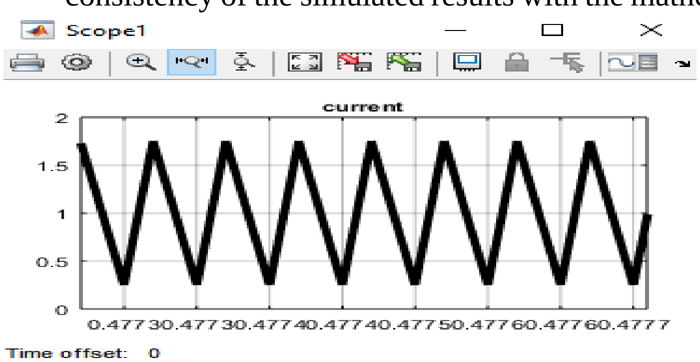

Fig.11. Simulation result for current output of buck dc-dc converter

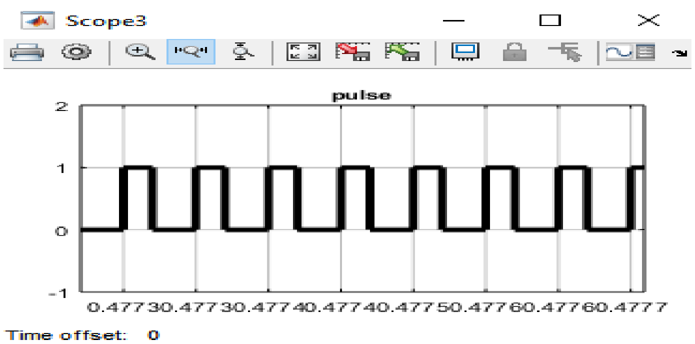

Fig.12. Simulation result for pulse of buck dc-dc converter

It can be observed that the transformer is in a continuous operation state through the current results, which show that the current does not drop to zero and that it operates between the highest and lowest values calculated for this mode.

To analyze the behavior of the system, the relationship between the change in current and the states of the electronic switch can be shown by looking at the fig.13 below. It can be observed that the value of the current increases and decreases with the change in the period of opening and closing the switch between two values, the highest and the lowest value of the current. 1.75 represents the highest value and 0.25 represents the lowest value of the current. In addition to the possibility of observing the change in the value of the output voltage, as in Fig. 14 below:

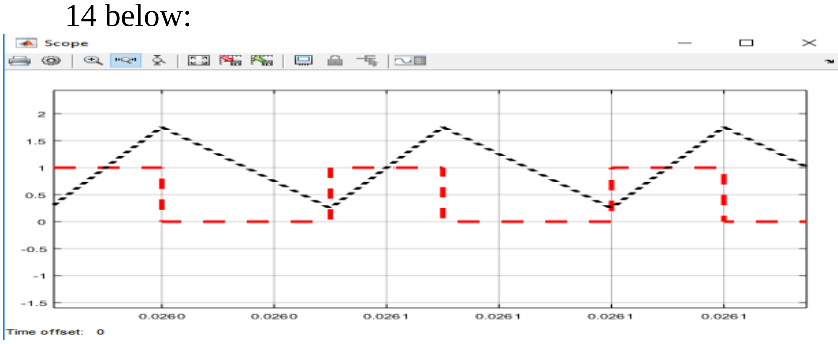

Fig.13. Simulation result for voltage output of buck dc-dc converter

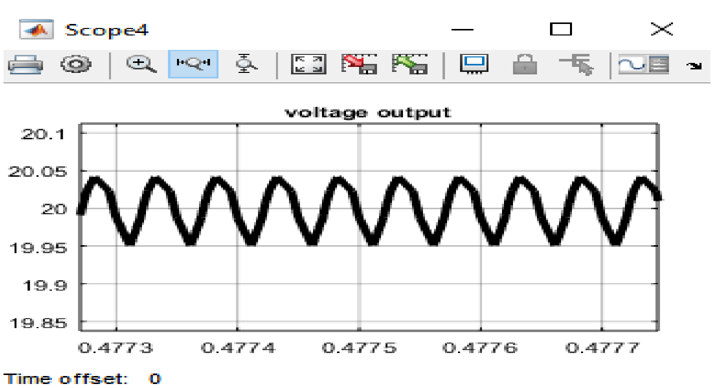

Fig.14. Simulation result with change in the value of the voltage output of buck dc-dc converte

4. Conclusion

Tests were conducted using Matlab to simulate the step-down converters, and the possibility of obtaining the specified voltage to meet the demand was verified. It was achieved to build a model of the step-down converters that can be used in many applications by verifying the effectiveness of the model used in the current simulation to suit operating conditions similar to work in real time. It was possible to represent the system after tests were conducted after representing the model mathematically and mathematically by writing the system specifications code in the C++ programming language through the MATLAB program, representing the model in the form of a block, and conducting tests to represent the system parameters. The two operating states of the linear system with a fixed load were verified as follows: The condition of providing the scheduled voltage with changing load has been verified, which is the case of nonlinear systems, which is compatible with many systems in industrial and other applications. The current model can be adopted to operate loads whose output voltage is proportional to the converters output.

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